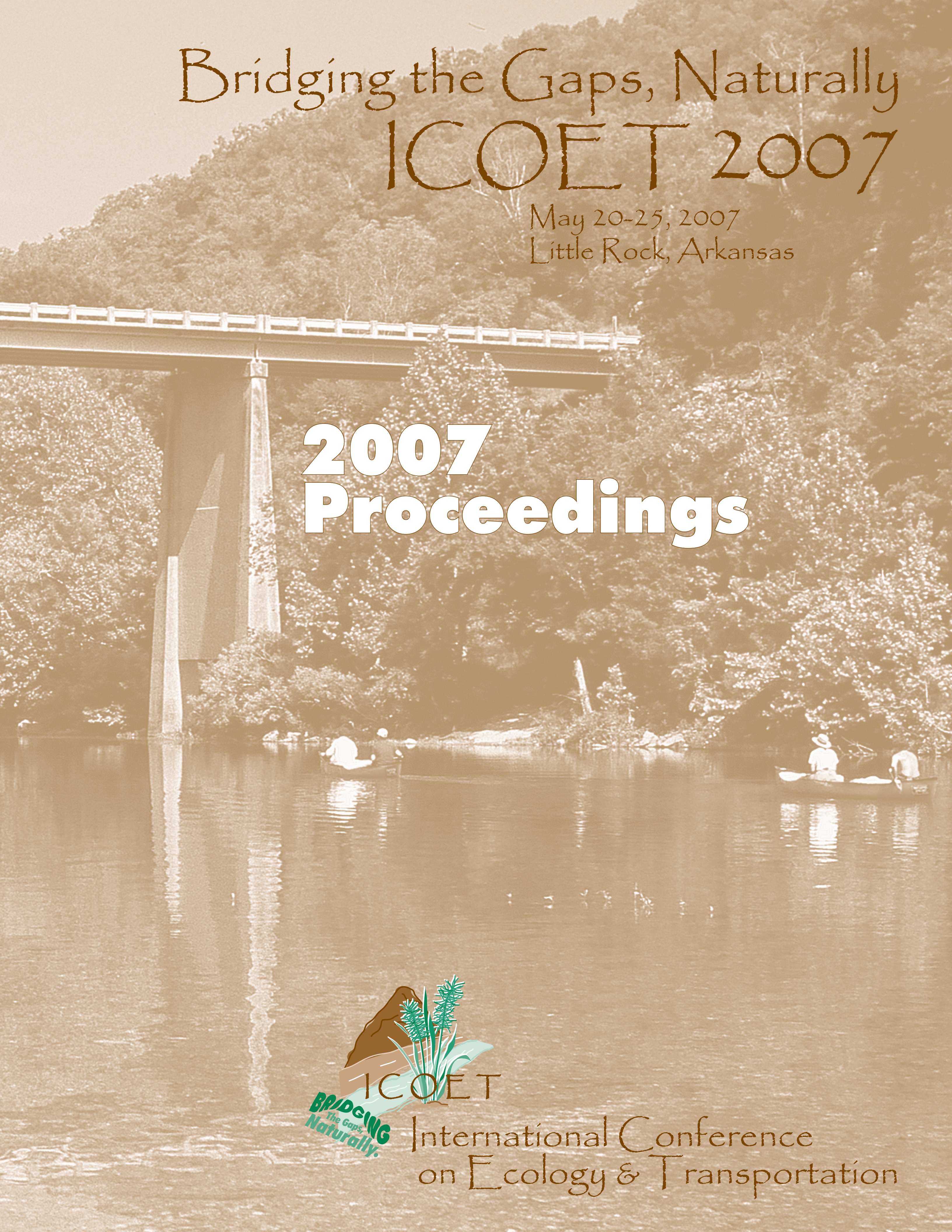


# Bridging the Gaps, Naturally

# ICOET 2007

May 20-25, 2007
Little Rock, Arkansas

# 2007 Proceedings

ICOET

BRIDGING The Gaps Naturally.

International Conference on Ecology & Transportation

# Acknowledgments

This proceedings was published by the Center for Transportation and the Environment (CTE), located at the Institute for Transportation Research and Education (ITRE), North Carolina State University (NCSU), with additional funding support provided in part by the Federal Highway Administration, U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, California Department of Transportation, University of California at Davis, Humane Society of the United States, and Defenders of Wildlife.

CTE thanks the following for their assistance with this publication:

- C. Leroy Irwin, ICOET 2007 conference chair; Debra Nelson, ICOET 2007 program committee chair; and the members of the ICOET 2007 steering, program, and abstract review committees – whose hard work and dedication to the field of transportation and ecology generated an excellent technical program, the results of which are reflected in the contents of this document.
- The Arkansas State Highway and Transportation Department (most notably Lynn Malbrough and John Harris); the Arkansas Field Office of the U.S. Fish and Wildlife Service (Mitch Wine); and the Federal Highway Administration–Arkansas Division Office (Randal Looney) – who co-hosted the conference, selected the conference theme ("Bridging the Gaps, Naturally"), designed the field trips, and prepared several posters and presentations showcasing the state's outstanding research and partnership-building efforts. The AHTD also provided the photography used on the cover of this publication.
- Kate Trapp of ITRE's Communications Office, who prepared the manuscript for print, as well as Carol Zarker, Eugene Murray, and Walt Thomas of CTE, who assisted in the development and distribution of the document.
- Finally, and most importantly, to all the authors, who in contributing their work to this conference proceedings have expanded the body of knowledge on wildlife, habitat, and ecosystem issues related to the delivery of surface transportation systems.

Note: this proceedings is not a peer-reviewed publication. The research presented herein is a compilation of the technical presentations and posters selected for presentation at the 2007 International Conference on Ecology and Transportation. Presentations were selected by the ICOET 2007 program committee based on a set of criteria that included relevance to the conference theme and national applicability of research results. Presentations included in this document may be in full paper or abstract format. Contact information for the authors is provided where possible to encourage further networking among conference participants and other professionals about current research applications and best practices in the transportation/ecology field.

**Bibliographic Citation**

Please use the following format to cite works from this proceedings:

[Author last name, first name]. ["Title of Paper"]. In Proceedings of the 2007 International Conference on Ecology and Transportation, edited by C. Leroy Irwin, Debra Nelson, and K.P. McDermott. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2007.

**Cost Statement**

150 copies of this public document were printed for a total cost of $4,240.00, or $28.26 per copy.

**To Order Additional Copies**

Additional copies of this document may be ordered through CTE for $45 (includes shipping and handling). A keyword-searchable CD-ROM version is also available while supplies last. To order, please call CTE at (919) 515-8893 or email your request to cte_email@ncsu.edu. A keyword-searchable Adobe Acrobat PDF version of the proceedings is also available on the conference Web site at www.icoet.net.



ISBN: 0-9778094-2-0

Proceedings 2007 ICOET

## Message from the Conference Chair

*C. Leroy Irwin, Mulkey Engineers & Consultants, Inc.*

We were delighted to visit the eclectic Southern city of Little Rock, Arkansas, for the 2007 International Conference on Ecology and Transportation!

The largest metropolitan area in the Natural State, Little Rock is situated along the Arkansas River and, among other cultural and recreational attractions, is home to the Big Dam Bridge—the world's longest pedestrian and bicycle bridge, built and designed specifically for that purpose. Located over Murray Lock and Dam, the bridge extends 3,463 feet across the Arkansas River, and currently ties together 17 miles of scenic river trails in Little Rock and North Little Rock. The Big Dam Bridge is one of the many unique projects in Little Rock that have been planned and built through innovative partnerships for the purpose of fostering enhanced transportation, environmental conservation, and community quality of life. Little Rock is also home to the Clinton Presidential Library and the Heifer International Headquarters, an excellent example of green construction. These sites are within walking distance or a short trolley ride from the conference hotel.

The conference theme, "Bridging the Gaps, Naturally," was generated by the host agency, the Arkansas State Highway and Transportation Department (AHTD) and speaks clearly to the state's ongoing efforts to build interagency relationships and to forge well-designed partnerships that offer the best possible solutions for the state's transportation and ecology challenges, particularly in the fast-growing Little Rock region. In fact, using partnerships as well as integrative planning to help "bridge the gaps" is a premise that underscores numerous elements of the conference program.

Each ICOET brings exciting new elements to the program thanks to the organizations that participate, and this year was no exception. Below is a list of the special events conducted at ICOET 2007, some of which are described further in the "Special Sessions" section of this proceedings.

- Arkansas Governor Mike Beebe provided the official conference welcome, along with Dan Flowers, director of the Arkansas State Highway and Transportation Department. Their remarks are available for view on the conference Web site (www.icoet.net). We thank them for their inspiring words and generous support of the conference objectives.
- ICOET hosted for the first time the 2007 FHWA Environmental Excellence Awards program ceremony. The award winners from 12 environmental categories were recognized at the Tuesday, May 22, conference luncheon. This event offered an opportunity to showcase the people, projects, and programs in the United States that excel in meeting growing transportation needs while protecting and enhancing the environment.
- In conjunction with Tuesday's Environmental Excellence awards luncheon, Little Rock Mayor Mark Stodola was presented the "Preserve America" Presidential Award. An initiative of the White House and the Advisory Council on Historic Preservation, the annual awards program recognizes exemplary accomplishments in the sustainable use and preservation of cultural or natural heritage assets; demonstrated commitment to the protection and interpretation of America's cultural or natural heritage assets; and the integration of these assets into contemporary community life, and combination of innovative, creative, and responsible approaches to showcasing historic resources in communities.
- ICOET partnered with the Society for Conservation Biology, a special conference co-sponsor in 2007. SCB conducted its North American Section meeting in conjunction with ICOET and led a concurrent session on "Reconciling Conservation Planning and Transportation Planning on a Regional Scale."
- A special plenary session on "Public-Private Partnerships (PPPs) in Transportation: Environmental Considerations" was conducted on Friday, May 25. Many organizations are now considering PPPs as the solution to meeting increased transportation needs with limited resources, although this business model is not without challenges. This session identified some recent experiences with using PPPs and explored how to best utilize PPPs, given various economic, environmental, and management concerns.

In addition to these events, ICOET 2007 featured more than 150 technical presentations, posters, and exhibits from governmental, non-governmental, university, and private sector organizations. These organizations represented the United States, Canada, Australia, France, Hungary, India, Portugal, South Korea, Spain, Switzerland, Taiwan, and The Netherlands. I wish to thank personally the members of the ICOET 2007 steering committee and all the subcommittees who worked tirelessly with these groups to generate an outstanding program. And I hope that you will use the information captured at ICOET 2007 to continue to advance your efforts to protect and enhance our environment when planning and implementing transportation programs.

It is not too early to begin planning for the next ICOET. The 2009 conference will be hosted by the Minnesota Department of Transportation. We hope to see you there!

# ICOET 2007 Proceedings Contents

# Posters

Chapter 1

# Coordination, Stewardship and Regulatory Compliance

## Geyserville: 1,000 Feet in 110 Days

**Chuck Morton** (510-286-5016, chuck.morton@dot.ca.gov), District Branch Chief, and
**Charlotte Cashin** (501-286-4879, charlotte.cashin@dot.ca.gov), Senior Transportation Engineer, California Department of Transportation, 111 Grand Avenue, Oakland, CA 94623, Fax: 510-286-4482 USA

**Abstract**

*Bridge replacement project minimized sensitive resource impacts and constructed a bridge designed to last 75 years.*

As a result of the New Years Eve/Day storm of 2005/2006, the California Department of Transportation (Caltrans) had to close to all traffic the Russian River Bridge, a two-lane conventional highway east of Geyserville due to significant structural damage. This Bridge, constructed in 1932, is a 973.5-foot-long steel pony truss bridge located on State Highway 128 and connects the Counties of Sonoma and Napa. Pier 2 of the Bridge was damaged during Russian River storm flows approaching 60,000 cubic feet per second (CFS). This damage consisted of the through and through cracking of the pier cap and web wall of Pier 2, the rotation of the pier in the downstream direction, and the dropping of the pony trusses approximately 9 inches.

The Federal Highway Administration (FHWA), at the request of Caltrans, through its Damage Assessment procedures, determined that this Bridge could be rebuilt under the Emergency Opening provisions of 23CFR771.117 (c)(9). This designation allows for a greatly reduced emphasis on NEPA, ESA, and other federal environmental rules and regulations that would be normally applied to a bridge replacement project.

In order to demolish the existing bridge a construction trestle, capable of supporting a 250-ton crane, had to be constructed across the Russian River. This crane would be utilized to construct the trestle from land, demolish the damaged pony truss bridge, and construct the new bridge. The 50'-wide trestle was supported on 24" steel pipe piles averaging 80' in length. The construction trestle, being constructed from both the east and west sides of the river, totaled 465 feet in length, and was completed in 70 days. Piles were primarily driven with a vibratory hammer or within an isolation casing, to reduce the impact on salmonids [Central California Coastal Steelhead (CCCS) (*Oncorhynchus mykiss*) and California Coastal Chinook salmon (CCCO) (*O. tshawytscha*)] which are known to inhabit this reach of the Russian River.

During the time that the trestle was being constructed, Caltrans bridge engineers, designers, and environmental personnel completed the Plans Specifications & Estimate (PS&E) for the new bridge in approximately 4 weeks.

Once construction of the trestle was completed, demolition of the existing bridge began. Demolition commenced with the removal of the concrete deck, lifting of the pony trusses, and the toppling of the old piers. These piers were founded on 12" diameter 25' long Douglas fir piles and there were 18 piles per pier. Once the piers were toppled, the Douglas fir piles were either extracted from the river bed or cut off approximately 3' below the grade of the gravel bar. To the greatest extent possible, all demolition debris was prevented from falling into the river or onto the dry river bed.

Hydroacoustic monitoring was conducted during pile driving activities within the wetted channel or within 30' of the wetted channel. Recordings of the 24" trestle piles driven with the vibratory hammer could not be distinguished from the ambient river noise which ranged up to 170 dB (re 1 μPa) RMS. Diesel hammer driving of the 24" piles resulted in readings ranging up to 190 dB peak. Driving of the 48" steel shell production pipe piles to depths of up to 140' resulted, in some cases, of readings up to 210 dB peak, even though the piles were being driven in a dewatered isolation casing.

Construction of the new bridge, on the same alignment of the damaged and demolished bridge, began on May 1, 2006. The bridge was opened to all traffic on August 18th, 2006, a total of 110 days.

Extensive coordination with the resource agencies (Army Corps of Engineers, Regional Water Quality Control Board, California Department of Fish and Game, and the National Marine Fisheries Service) was continuous throughout the entire construction period. A full time biological monitor was on site beginning in the middle of May. Caltrans personnel relocated to the main river channel trapped fish from the pools that remained after the demolition of the piers.

Deconstruction of the trestle, including the extraction of the 24" piles, was completed in 15 days.

Total construction costs were $26 million broken down as follows: $10.5 M for the trestle, old bridge demolition, and pipe piles; $14 M for the new bridge; and $1.5 M for contract change orders and landscaping.

Caltrans, as compensation for impacts to Russian River fisheries due to this project, established a $2,500,000 fund to enhance and restore appropriate salmonid fisheries habitat within the Russian River watershed.

# Justifying Environmental Stewardship: Oregon Department of Transportation's Wildlife Collision Prevention Plan Case Study

**Melinda Trask** (503-986-3504, melinda.trask@odot.state.or.us), Environmental Project Manager, Oregon Department of Transportation, Geo-Environmental Section, 355 Capitol Street N.E., Salem, OR 97301, Fax: 503-986-3407 USA

**Abstract:** Although there is widespread knowledge of the effects of roads on wildlife populations and driver safety, many transportation departments are reluctant to expend state or federal funds to research and address wildlife movement problems on their highways. For many years, Oregon lacked direction on this issue from natural resource, regulatory, and highway agencies. All groups were at the proverbial standstill for years: the natural resources and regulatory agencies urged ODOT to address the problem of highways as wildlife movement barriers, and ODOT sought guidance from natural resources and regulatory agencies to define the scope of the problem. Additionally, ODOT faced internal resistance to collecting baseline information because of the perception that it was another unfunded environmental mandate. Before the ODOT Geo-Environmental Section proposed a statewide mitigation program for wildlife movement and transportation conflicts, it was necessary to obtain direct support from external natural resources agencies. The Oregon Wildlife Movement Strategy was formed in 2006, as an interagency partnership to address wildlife movement issues in Oregon. Once external support was obtained and documented, Geo-Environmental pursued internal support, particularly from units involved in maintenance, planning, traffic, safety, and the regional technical centers. However, we are continuing to communicate with external and internal stakeholders throughout development of a Wildlife Collision Prevention program for our Agency. The program will provide guidance to ODOT stakeholders for scoping of wildlife passages during project planning and development, funding alternatives, and design considerations for key species.

## Introduction

Although the relationships among highways, wildlife mortality, and driver safety are well documented (USDA Forest Service 2005, Nietvelt 2002, Evink 2002), many transportation departments are reluctant to initiate and implement comprehensive programs to address wildlife movement across highways. The Federal Highway Administration (FHWA) supports the use of federal highway funds to improve wildlife passage across the nation's roads, and several of its programs address this issue. For example, one of the four main goals of the FHWA Eco-Logical program is to improve wildlife habitat connectivity across highways. Yet, despite recognition of the problem and the potential liability (Booth vs. Arizona 1998), many state transportation departments still encounter internal resistance to expend state or federal funds to research and address wildlife movement problems on their highways. Development of a Wildlife Collision Prevention Plan for Oregon Department of Transportation (ODOT) is a good example. It illustrates the obstacles encountered for a proactive environmental stewardship initiative, outreach and communication employed to garner internal and external support, and our resulting partnership with the Oregon Department of Fish and Wildlife (ODFW) and other stakeholders in an Oregon Wildlife Movement Strategy.

## Data Gaps

Currently, Oregon has only limited information on the scope of the wildlife passage situation along the state highway system. We have no comprehensive, statewide system for reporting animal-vehicle collisions, and the organizations involved with wildlife management in Oregon (ODFW, U. S. Fish and Wildlife, U. S. Forest Service, Bureau of Land Management) have only scattered information on wildlife movement corridors. The most comprehensive data we have on animal-vehicle collisions are Department of Motor Vehicle accident reports (AKA crash records). Oregon has 12 years of crash records in which interactions with wildlife were recorded, 1993 through 2004. We have approximately 5,000 records throughout the state over this period, averaging approximately 400 animal-vehicle collisions per year. We know this is a gross underestimate of actual animal-vehicle collisions based on localized deer carcass pick-up records. For example, in one year in a one-hundred mile segment of highway in eastern Oregon, over 500 deer carcasses were observed. Most states and national statistics use these data, and researchers have estimated that the accident reports vastly underestimate actual numbers of wildlife killed by vehicles (Bissonette 2006, Romin and Bissonette 1996, Conover et al. 1995).

The only other statewide source of information in Oregon for animal-vehicle collisions is dispatch records of carcass reports, maintained by the state police (in most of Oregon) and ODOT's Traffic Management Operations Center in northwest Oregon. There are over 30,000 data records of carcass reports statewide over the past seven years. ODOT has begun an effort to create a database from the dispatch records, and use the information to map clusters or hot spots of animal vehicle collisions. The quality of information needs to be evaluated before drawing any conclusions on how useful this will be as a representative dataset for animal-vehicle collisions in Oregon. If the carcass reports do not yield sufficient quality or complete data for the state, other options for road kill data collection need to be investigated.

Animal-vehicle collisions are just one component of the effects of roads on wildlife, and depending on species, road mortality may be a very minor component. Roads cause habitat fragmentation, direct and indirect habitat loss, and impede movement across the landscape. Forman et al. 2003, Evink 2002 and Carr et al. 2002 provide a thorough summary of many effects of roads on animals. The location of the vehicle strike or final resting place of the carcass may not be within the natural movement corridor for the animal. It is therefore important to understand wildlife movement patterns and landscape connectivity, which is how the landscape facilitates animal movement and population biology. Rather than focus on road kill, many studies utilize habitat modeling to identify locations where wildlife corridors intersect highways (AKA linkage areas) (Austin et al. 2005, Singleton and Lehmkuhl 2000). ODFW has begun investigating options for identifying habitat linkage areas for priority wildlife species in Oregon. They will be utilizing an expert option approach building on the foundation of the Oregon Conservation Strategy (described below).

**Internal Dilemmas**

The State of Oregon has laws that require fish passage and a well-supported Oregon Plan for Salmon and Watersheds to restore fish habitat and access, but these programs may only improve accessibility for aquatic organisms. There are no requirements in Oregon for providing access or passage for non-aquatic wildlife. As is the case in most U. S. states, the only regulatory basis for wildlife passage is when a listed species is involved. For example, as a condition of Section 7 Endangered Species Act consultation, the U. S. Fish and Wildlife Service required that ODOT design and install a culvert to allow for safe passage of Canada Lynx across a highway in northeastern Oregon. Management within the Geo-Environmental Section of ODOT felt that because we have no specific regulatory requirements for wildlife passage, we needed strong external support from wildlife management agencies in Oregon.

Currently, Oregon may not have a strong case for the safety aspect of animal-vehicle collisions. Based on the crash records referenced above, collisions with wildlife (including deer and elk as well as other non-domesticated wildlife) represent an average of 3% of all reported crashes in Oregon, based on the past 12 years of crash data. We have an average of 1-2 human deaths and 7-10 serious injuries per year from reported collisions with wildlife. Even though we do not believe that the crash records represent actual numbers of collisions with wildlife, ODOT's Crash Analysis Unit indicates that the crash data accurately represent human deaths and serious injuries caused by collisions with wildlife because of corresponding police reports. Compared to other causes for crashes, such as unsafe intersections or temporary work zones, animal-vehicle collisions do not appear to be a statewide highway safety priority in Oregon, at this time. Although there may be certain locations in Oregon where animal-vehicle collisions are a serious safety problem, the main impetuous for ODOT to address animal-vehicle collisions at this time appears to be for wildlife management or ecological reasons. Therefore, we need strong support from wildlife managers in Oregon.

**External Support**

Several agencies and groups outside of ODOT have been urging our Agency to address wildlife crossings, primarily due to the effects of highways on wildlife populations. This includes the Federal Highway Administration, the U. S. Fish and Wildlife Service, Portland Metropolitan Organization, and ODFW. New highway modernization projects in Oregon such as the Pioneer Mountain to Eddyville Project and the Sunrise Corridor Project were getting pressure from all of these groups to include wildlife crossing structures as part of the design. Although we have been getting external pressures for our Agency to address wildlife passage, for several years, ODOT was at a virtual stale-mate with our external partners on who should lead this effort. We sought leadership from a wildlife management agency like ODFW or the U. S. Fish and Wildlife Service because wildlife passage across highways is only one piece of a much larger puzzle on habitat connectivity. ODOT wanted assurance from our external partners that this would be a collaborative effort, and that if we were to improve wildlife passage, it would be where it was most needed for vulnerable species and where it would connect suitable and protected habitat on both sides of the highway. In other words, we do not want to build passages to nowhere. ODOT sought guidance from wildlife management agencies to identify locations of priority wildlife movement corridors or highway linkage areas.

Two things led to the break in the stale-mate. One was the completion of the Oregon Conservation Strategy by ODFW in 2006. The Conservation Strategy is Oregon's "Wildlife Action Plan," a statewide program that charts a course for the long-term conservation of our state's fish and wildlife. Wildlife Action Plans emphasize a non-regulatory, proactive approach to conservation. The Conservation Strategy identifies wildlife movement as a top conservation priority in our state, characterizing the effect of road crossings on fish and wildlife resources as one of the main wildlife management issues in Oregon. The Conservation Strategy gave ODFW authorization to help initiate and collaborate on a statewide Wildlife Movement effort.

The other ice-breaker was that Oregon's interagency forum for collaboration on transportation projects (Collaborative Environmental and Transportation Agreement for Streamlining or CETAS) recognized the lack of oversight and direction in Oregon on this topic. Wildlife Movement was added to the group's work plan in 2006. The idea was that CETAS would help organize and monitor an interagency collaboration to address wildlife movement, statewide. The CETAS work plan element gave ODOT's Geo-Environmental Section direction to initiate the collaboration, as well as direction for the development of an ODOT program on wildlife crossings.

In the summer of 2006, ODOT began meeting with our ODFW representatives, requesting their direct involvement and even leadership to address wildlife movement statewide. The result was the formation of the Wildlife Movement Strategy, an interagency working group to address wildlife movement issues in Oregon. Virgil Moore, ODFW's Director, provided written support for this partnership in a letter dated August 14, 2006. ODOT and ODFW are now co-chairing this group. The ODFW have begun identifying habitat linkages across the landscape, focusing on wildlife species most impacted by road crossings.

## Outreach for an ODOT Plan

The Wildlife Movement Strategy is a valuable interagency partnership, but is not likely to provide direction on how ODOT should manage our highway infrastructure for wildlife passage. The Geo-Environmental Section is developing a Wildlife Collision Prevention program for our Agency to address scoping of wildlife passage during project planning and development, funding alternatives, and design considerations for key species. The Wildlife Collision Prevention program requires cooperation from several groups within our Agency. A strong outreach and communication strategy is needed to gain internal support for this type of a proactive environmental initiative. One option is a top-down communication strategy, which would entail gaining support from various groups within ODOT, moving out from the section to other groups within the Agency, gaining support along the way (see figure 1). If the top down approach were the appropriate method, Leadership Teams would provide approval and direction for the initiative before it is introduced to staff in Regions and Maintenance. In this type of communication strategy, the initiative would not be introduced externally until internal support has been garnered.

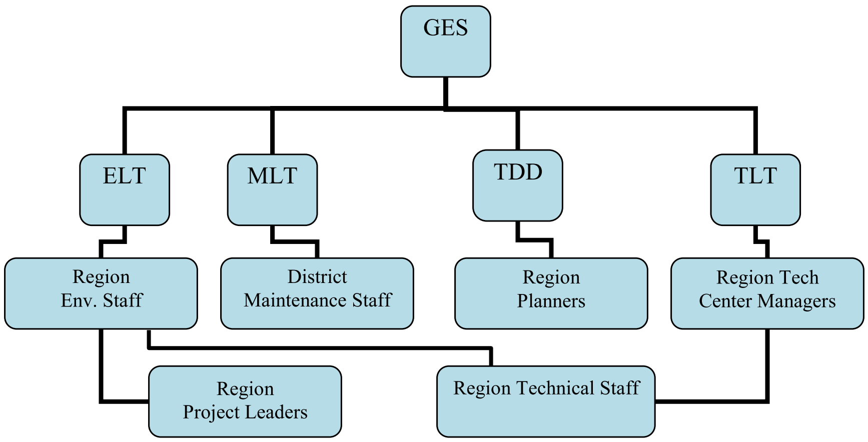



Figure 1. Conceptual top-down communication strategy for the Geo-Environmental Section.
Key: GES = Geo-Environmental Section, ELT = Environmental Leadership Team, MLT = Maintenance Leadership Team, TDD = Transportation Development Division, TLT = Technical Leadership Team.

A top-down communication strategy is not a good fit for most environmental initiatives because in order to gain support within ODOT, external outreach is needed to justify the effort. Our Section's involvement in the Wildlife Movement Strategy working group has overlapped with and sometimes preceded much of the outreach from within our Section to other stakeholders in our Agency. However, elements of the Wildlife Collision Prevention program will not be implemented without more Agency-wide support. Outreach for the Wildlife Collision Prevention program best follows a non-linear communication strategy (figure 2). The Plan will be presented to Region Environmental Managers for review and comment. These Managers will be responsible for seeking review within their units. We will also present this Plan for review within our Section, Planning and Research Sections in the Transportation Development Division, and Bridge, Roadway, Traffic, and Safety Sections within the Technical Services Division. Meanwhile, elements of the Plan will be presented at Wildlife Movement Strategy meetings for discussion.

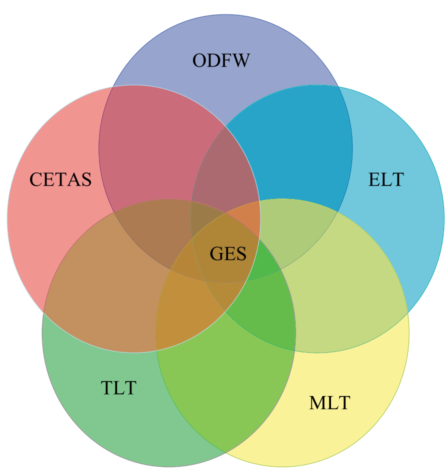



Figure 2. Conceptual model for a non-linear communication strategy.
Key: ODFW = Oregon Department of Fish and Wildlife, CETAS = Collaborative Environmental and Transportation Agreement on Streamlining, GES = Geo-Environmental Section, ELT = Environmental Leadership Team, MLT = Maintenance Leadership Team, TDD = Transportation Development Division, TLT = Technical Leadership Team.

The Wildlife Collision Prevention program is a long-term effort that requires flexibility to adapt to new information, stakeholder concerns, or potential future regulatory changes. Continued outreach will be necessary to maintain support for the program during its implementation. The main forums for outreach to stakeholders within ODOT will include periodic updates to the Biology and Region Environmental Coordinators team meetings and the Environmental Leadership Team. Other groups within ODOT will be presented with results of some of the products (such as the wildlife collision hot spots and wildlife linkage areas), including the Environmental Leadership Team, Maintenance Leadership Team, Technical Leadership Team, and Project Leaders Academy. Periodic updates will be presented to external stakeholders as well, mainly the CETAS group and the Wildlife Movement Strategy work group.

At this point, the main concept for public outreach of ODOT's Wildlife Collision Prevention Work Plan is through the Wildlife Movement Strategy. The Oregon Conservation Strategy has a newsletter that is produced by ODFW. This newsletter now has a regular column on wildlife movement, which is developed by ODFW's Wildlife Movement Strategy coordinator. The public will also be updated on the progress of the Strategy and some of ODOT's products at professional society meetings.

## Remaining Unresolved Issues

Although now we are on a clear course for initiating the Oregon Wildlife Movement Strategy and ODOT's Wildlife Collision Prevention program, there are still some challenging internal and external issues, such as conflicts with the fish passage laws, research funding, road kill data collection, design leadership, and project funding.

Oregon has state laws on fish passage, and ODOT has special funding for improving fish passage at highway crossings. We use that funding for culvert replacements and fish passage retrofits that meet strict design guidelines for fish access. Some of the fish passage improvements actually hinder passage for many or all wildlife species, particularly weirs. ODOT and ODFW have made great strides in the past few years to gain financial and institutional support for these fish passage laws. We are now challenged with considering the broader context of habitat connectivity. However, fish passage coordinators within both Agencies are hesitant to open a new "can of worms" that may set back their progress. The Wildlife Movement Strategy working group is helping to spread the message that the best way to achieve our individual goals (fish access, safety, habitat permeability) is to collaborate because solutions may be available that are most efficient and beneficial to all. Results from wildlife linkage areas and wildlife collision hot spots will help provide justification and better information on locations and types of priorities for wildlife passages across highways.

Like many other DOTs, ODOT has a Research Unit with dedicated funding for conducting research or collaborating on research that will help solve many of our highway management and operations issues. Historically, the Research funds went exclusively to engineering topics, but have been broadened to include environmental topics in the past several years. Wildlife crossing studies must compete with all other environmental proposals, and the ODOT Research Unit has contributed to only two wildlife crossing studies in the past two years, both of which are collaborative efforts with many other institutions. The Geo-Environmental Section was not able to gain Research funding to collaborate on the analysis of the dispatch records to map statewide wildlife collision hot spots. Help may be on the way, however. Oregon has a new highway research consortium (Oregon Transportation Research and Education Consortium). Geographers at Portland State University are interested in wildlife crossing topics and have developed a proposal for funding through this new consortium to answer some of the research needs of the Oregon Wildlife Movement Strategy, particularly modeling of landscape or highway features associated with wildlife collision hot spots or wildlife linkages.

The unresolved issues associated with road kill data collection, design leadership, and project funding will most likely fall upon ODOT to solve internally. We need to evaluate dispatch records to determine if they are of sufficient quality to identify wildlife collision hot spots. If not, we may need to coordinate with Maintenance Districts to develop solutions for improving data collection within the framework of continually limited funding (Oregon citizens have not voted for an increase in gas tax dollars or supported any other state funds for highway maintenance in over 10 years). When the Oregon Wildlife Movement Strategy identifies priority wildlife linkage areas, design solutions and funding will be needed. Although there are many resources on highway retrofits for safe wildlife passage (Ruediger and DiGiorgio 2007 Huijser 2006, USDA Forest Service 2005, Clevenger and Waltho 2005, Clevenger et al. 2001), engineering support will be needed within ODOT for potential standard designs or even project-specific designs. Within the existing structure of ODOT, there is no place or funding for engineering expertise on this topic.

The Wildlife Collision Prevention program needs to identify funding options for wildlife passages. If we can demonstrate a safety concern that exceeds other safety priorities, then wildlife crossing measures can be supported through Highway Safety Improvement Funds. The Enhancement Program under Federal Highway Administration seems like the most appropriate program for wildlife passage improvements and has been used in other states, but in Oregon, this program has never been successfully used to fund environmental enhancements, only other types of enhancements, such as bike-pedestrian improvements or historic preservation.

## Oregon's Successful First Steps

Oregon's transportation and wildlife managers have made fantastic strides in initiating a statewide wildlife passage program in the past year. It took years of finger-pointing among ODOT, ODFW, the U. S. Forest Service, and the U. S.

Fish and Wildlife Service to come to the final decision for ODOT and ODFW to co-lead the effort in Oregon. The collaborative effort of the Oregon Wildlife Movement Strategy has support from high levels of management in ODOT and ODFW, and is based on the Oregon Conservation Strategy which has support from Oregon's governor, Ted Kulongoski. We have an informal Charter that describes how ODOT will identify wildlife collision priorities and ODFW will identify wildlife linkage priorities on the state highway system, and collaborate with our land-use partners to characterize wildlife passage opportunities and constraints on the state highway system.

Both ODOT and ODFW have initiated our wildlife movement tasks. ODFW is currently holding meetings throughout the state to map priority wildlife linkages and ODOT hired a consultant to map wildlife collision hot spots using dispatch records. We still have some obstacles to overcome to get to the point where we are comprehensively addressing wildlife passage. But at this time, I feel that ODOT needs more information on the scope of the issue in Oregon before we decide how far and how many resources we want to invest. The information being gathered by ODOT and ODFW will help us understand if and where we have particular safety risks due to animal-vehicle collisions, priority linkage areas for wildlife species, and our stakeholder concerns.

**Biographical Sketch:** Melinda Trask is an Environmental Project Manager for the Oregon Department of Transportation, with a Master of Science in Plant Ecology from Oregon State University and a Master of Environmental and Regional Planning from Washington State University. Melinda has a broad educational and professional background in ecology of the western United States. She has taught ecology and botany laboratory classes, organized and led field survey crews for rare plant studies, conducted desert tortoise and peregrine falcon surveys, assisted with fish salvage operations, delineated wetlands, prepared numerous Biological Assessments for Section 7 Endangered Species Act consultations, monitored environmental protection measures during various types of construction projects, and developed site restoration plans. Melinda is currently the co-chair of the Oregon Wildlife Movement Strategy, an interagency working group to address wildlife passage in Oregon.

## References


Austin, J. M., K. Viani, F. Hammond, and C. Slesar. 2006. A GIS-Based Identification of Potentially Significant Wildlife Habitats Associated With Roads in Vermont. In *Proceedings of the 2005 International Conference on Ecology and Transportation*, edited by C. Leroy Irwin, Paul Garrett, and K. P. McDermott. Raleigh, 185-196. Center for Transportation and the Environment, North Carolina State University.

Bissonette, J. A. 2006. NCHRP 25-27: Evaluation of the Use and Effectiveness of Wildlife Crossings, Interim Report. Washington DC: National Cooperative Highway Research Program.

Carr, L. W., L. Fahrig, and S. E. Pope. 2002. Impacts of Landscape Transformation by Roads. In *Applying Landscape Ecology in Biology Conservation*, edited by K. J. Gutzwiller, 225-43. New York: Springer Press.

Clevenger, A. P., Chruszcz, B., and Gunson, K. E. 2001. Highway Mitigation Fencing Reduces Wildlife-Vehicle Collisions. *Wildlife Society Bulletin* 29:646-653.

Clevenger, A. P. and N. Waltho. 2005. Performance Indices to Identify Attributes of Highway Crossing Structures Facilitating Movement of Large Animals. *Biological Conservation* 121:453-464.

Conover, M. R., W. C. Pitt, K. K. Kessler, T. J. DuBow, and W. A. Sanborn. 1995. Review of Human Injuries, Illnesses, and Economic Losses Caused by Wildlife in the United States. *Wildlife Society Bulletin* 23:407-414.

Evink, G. L. 2002. NCHRP Synthesis 305, Interaction between Roadways and Wildlife Ecology: A Synthesis of Highway Practice. Washington DC: Transportation Research Board of the National Academies.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road Ecology: Science and Solutions*. Washington DC: Island Press.

Huijser, M. P., P. T. McGowen, W. Camel, A. Hardy, P. Wright, A. P. Clevenger, L. Salsman, and T. Wilson. 2006. Animal Vehicle Crash Mitigation Using Advanced Technology Phase I: Review, Design and Implementation (FHWA-OR-TPF-07-01). Washington DC: Federal Highway Administration.

Nietvelt, M. S. 2002. The Effects of Roads on Wildlife: Bibliography. Jackson, Wyoming: U. S. Forest Service, Bridger-Teton National Forest.

Romin, L.A. and Bissonette, J. A. 1996. Deer-vehicle Collisions: Status of State Monitoring Activities and Mitigation Efforts. *Wildlife Society Bulletin* 24:276-283.

Ruediger, B. and M. DiGiorgio. 2007. Safe Passages: A User's Guide to Developing Effective Highway Crossings for Carnivores and Other Wildlife. Denver, Colorado: Southern Rockies Ecosystem Project. http://www.carnivoresafepassage.org/carnivoresafepassage.pdf (accessed April 18, 2007).

Singleton, P. H. and J. F. Lehmkuhl. 2000. I-90 Snoqualmie Pass Wildlife Habitat Linkage Assessment. Wenatchee, Washington: U.S. Department of Agriculture Forest Service Pacific Northwest Research Station, Wenatchee Forestry Sciences Lab.

USDA Forest Service. 2005. Wildlife Crossings Toolkit. Arcata, California: U. S. Forest Service, Redwood Science Lab, Pacific Southwest Research Station. http://www.wildlifecrossings.info/ (last updated August 15, 2005).

## National Website for Federal Highway Administration Endangered Species Consultation

**Mary E. Gray** (360-753-9487, Mary.Gray@fhwa.dot.gov), Environmental Program Specialist, Federal Highway Administration Headquarters, 711 S. Capitol Way, Suite 501, Olympia, WA 98501 USA

This website will both improve the quality of the biological assessments and communication during consultation. Within this site will be a standard format and consistent guidance for completing a biological assessment. More importantly, this site will facilitate communication across the country. There will be the ability to share information within a project team and nationally, if necessary or desirable. For the first time, FHWA will have the ability to track progress on project consultations. This website will provide an effective way to distribute new information, answer questions, and share ideas.

# ODOT's OTIA III Bridge Program: Three Years of Environmental Stewardship

**Shelley D. Richards**, P.E. (503-587-3611, shelley.richards@hdrinc.com), Environmental Manager, HDR Engineering, Inc., 1165 Union Street, Suite 200, Salem, OR 97301 USA

**Bill Ryan** (503-986-3478, William.A.Ryan@odot.state.or.us), Program Support Manager, Geo-Environmental Section, Oregon Department of Transportation, 355 Capitol Street, N.E., Room 301, Salem, OR 97301 USA

**Abstract:** The purpose of the environmental stewardship framework is to deliver projects that are sensitive to their communities and landscape while streamlining the permitting process. After three years of implementation, we have successfully maintained the collaborative approach with regulatory partners. This has been critical to our success in avoidance and minimization of project impacts.

The OTIA III State Bridge Delivery Program (the Program) is part of the Oregon Department of Transportation's (ODOT) 10-year, $3 billion Oregon Transportation Investment Act (OTIA) program. OTIA funds will repair or replace hundreds of bridges, pave and maintain city and county roads, improve and expand interchanges, add new capacity to Oregon's highway system, and remove freight bottlenecks statewide.

Oregon Bridge Delivery Partners (OBDP), a joint venture formed by HDR Engineering Inc. and Fluor Enterprises Inc., is a private-sector firm that has contracted with the ODOT to manage the $1.3 billion state bridge program. OBDP has developed a framework to integrate the myriad of tools developed for the Program, including environmental performance standards, a joint batched-programmatic biological opinion, environmental and engineering baseline reports, and a web-based GIS. The purpose of this framework is to identify environmental concerns early in the project development process and communicate these concerns to design teams and regulatory agencies to promote environmental stewardship through impact avoidance and minimization.

Innovative and creative use of technology has been a keystone to the framework. Environmental professionals input the relevant environmental data for a project in a comprehensive, on-line Pre-Construction Assessment (PCA) form. The data are used to identify project challenges (e.g., archaeological sites or wetlands within the project footprint) and compile electronic reports to the regulatory agencies. Environmental metrics, such as exempted T&E species "take" and wetland fill quantities are tracked using the GIS database. One framework meets the needs of many stakeholders.

Now, after almost three years of execution, OBDP and ODOT have some great successes and lessons learned to share. OBDP have continued to adapt and develop tools to be successful – as well as shift the Program operating structure. The focus of this presentation will be on the framework that has been utilized to maintain compliance and strive for environmental excellence.

## Introduction and Background

The OTIA III State Bridge Delivery Program (the Program) is part of the Oregon Department of Transportation's (ODOT) 10-year, $3 billion Oregon Transportation Investment Act (OTIA) program. During the next decade, OTIA funds will repair or replace hundreds of bridges; pave and maintain city and county roads; improve and expand interchanges; add new capacity to Oregon's highway system; and remove freight bottlenecks statewide. The Program is also expected to decrease unemployment and increase economic development. About 17 family-wage jobs are sustained for every $1 million spent on transportation construction in Oregon. Each year during the OTIA program, construction projects will sustain about 5,000 family-wage jobs.

In 2003, the Oregon Legislature enacted the third Oregon Transportation Investment Act, or OTIA III. The package includes $1.3 billion for bridges on the state highway system. During the next eight to ten years, the ODOT's OTIA III State Bridge Delivery Program will repair or replace hundreds of aging bridges on major corridors throughout Oregon.

Oregonians have not seen an investment of this magnitude in highway and bridge construction since the state's interstate freeway system was built in the 1950s and 1960s. The sheer size and scope of the bridge program means that the ODOT must change how it does business. The agency hired Oregon Bridge Delivery Partners (OBDP), a joint venture formed by HDR Engineering Inc. and Fluor Enterprises Inc., to assist in the management of the program. The ODOT is making a historic shift from an agency that self-performs its design and construction projects to one that manages the transportation system.

Many of the bridges slated for repair or replacement are on Interstate 5 and Interstate 84, which are the state's economic lifeline routes. These interstate highways carry most of Oregon's commercial truck traffic. If the hundreds of aging bridges on these routes and others are not repaired or replaced, the ODOT will soon be forced to place weight limits on highway bridges that would impair Oregon's economy.

The ODOT and OBDP are utilizing this program to implement a new decision-making framework called CS3, or Context Sensitive and Sustainable Solutions. CS3 helps to preserve Oregon's scenic, aesthetic, historical, cultural, economic, environmental, and other values while building safe and enduring projects. It is community values shaping a new generation of bridges. CS3 puts communities at the heart of important project decision-making.

Through the CS3 initiatives, the bridge program will help produce a better trained workforce, prosperous communities, a stronger state economy, and bridges that take into account their impact on the natural environment.

## Collaborative Approach

The ODOT has been working collaboratively with federal and state agencies to integrate and coordinate environmental protection, permitting, enhancements, and reuse and recycling into the overall Program. The Environmental Performance Standards (EPS) have been developed to ensure safe practices with regard to hazardous materials, to protect Oregon's natural resources, and to provide economic stimulus by expediting the Program.

In 2004 and 2005, multi-disciplinary teams representing key federal and state agencies developed the EPS with the goal of creating well-integrated and consistent terms and conditions for each agency's respective regulatory process. The EPS provide consistent expectations and guidelines for design and construction teams to meet ODOT and regulatory agency requirements for completion of the bridge program, and cover expectations for the program ranging from habitat and species protection through materials reuse and recycle.

The ODOT also realized that successful program management means sustained collaboration. The regulatory partnerships needed to be maintained on the program and open communication regarding all project elements was vital. To facilitate this effort, two key regulatory partner teams have been established. The first team is the Programmatic Agreements Reporting and Implementation Team (PARIT), made up of regulatory partners from Oregon Department of State Lands (DSL), U.S. Army Corps of Engineers (ACOE), Oregon Department of Fish and Wildlife (ODFW), US Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Oregon Department of Environmental Quality (DEQ), Federal Highway Administration (FHWA), State Historic Preservation Office (SHPO), ODOT and OBDP, which meets twice a month. The second team is the Materials and Contamination team, made up of members from ODOT, DEQ, and OBDP, which meets monthly. The teams provide an avenue for open communication that allows all the agencies to work through project questions/concerns early in development and provide enhanced Program oversight.

## Permitting

The new approach to permitting for the Program includes a batched, programmatic Biological Opinion (BO), a Regional General Permit (RGP), and 401 Water Quality Certification. The EPS are the guidance to the design and construction teams to show that the intent of the programmatic permits is being met. The EPS present the intent and goals of the regulatory consultation and provides guidance on acceptable implementation methods to achieve the performance criteria. However, the permits were created for the entire State and cross many different ecological systems (ecoregions). When developing the Program, it was understood that variances to the EPS and the permits may be required. The BO outlines the required variance process to be followed if these circumstances are determined on the Program projects.

## Variances

Successful program implementation and stewardship means the continued collaboration with the regulatory partners when it is noticed that the EPS and permits may need to be varied from. There have been projects that have shown that variances can be beneficial. For one particular project, the regulatory agency partners, OBDP, and ODOT staff worked together to determine the need for a variance and all concurred in this instance the variance would be beneficial. The project clearly met the goal of the EPS with implementation methods that deviated from the pre-approved implementation methods.

During a field visit, one regulatory agency expressed concern about the applicability of the fluvial EPS to a particular site on Hardscrabble Creek in the Umpqua River basin. The consultant believed that, given the backwater effect from a main-stem river downstream, the fluvial standards could not be implemented as outlined unless a much longer bridge than would otherwise be necessary were designed.

Within a week, all Program partners met and agreed that an alternative approach was required, ultimately approving a variance request that would allow the design-build contractor to proceed. The regulatory agencies agreed that a variance was a positive solution to a unique situation, since this bridge crossing is one of very few bridges in the program that the methods within the EPS do not accurately address. The variance still meets the intent of the EPS goal, will clearly demonstrate that the design meets the fluvial EPS, and will satisfy the requirements of the Program's BO. This resulted in an overall win for the affected parties. Bringing the regulatory agencies into variance discussions as early as possible improves the overall success of the project designs.

## Avoidance and Minimization

Building projects sensitive to their communities and landscape is one of the five OTIA III Program Goals. This goal, at the heart of the OTIA III Environmental Stewardship Program, prioritizes avoidance and minimization efforts. After three years, implementation of the avoidance and minimization philosophy has been highly successful.

To date, every eligible bridge delivered through OBDP has used the programmatic permitting strategy. More than 56 bridges have been constructed and almost 70 more are in construction, with an additional 159 bridges that are in various stages of design and approaching the construction stage. ODOT/OBDP environmental staff have, to date, conducted over 800 construction monitoring/inspection visits – with no permit violations. Less than 10 percent of the program exempted "take" has been allocated for any species. The avoidance and minimization measures outlined in the EPS have been so effective that no on-site compensatory mitigation has been required. We have had equal successes implementing this framework with design-build and design-bid-build delivery. We look forward to continued success as we maintain our most effective tool – collaboration.

Wetlands and waterways are within the "Area of Potential Impact" (API) of nearly 80% of the 365 program bridges; however, less than 20% of the projects have impacted aquatic resources to date. Many of those impacts are associated with temporary structures (e.g., work area isolation, detour bridges, work platforms, containment structures) or enhancements (removal of existing fill within the floodplain or riparian corridor). There has been less than 15 cubic yards of permanent fill added and almost 300 cubic yards of fill removed from wetlands or waterways, thereby promoting natural habitat-forming processes (e.g., floodplain development and fluvial dynamics).

Nearly every bridge within the Program has habitat for some sensitive species – from birds (marbled murrelets, northern spotted owl, etc.) to fish (salmon, suckers, etc.) to invertebrates (vernal pool fairy shrimp, Fender's blue butterfly, etc.) to plants (Kincaid's lupine, Bradshaw's lomatium, etc.). The Program has a batched-programmatic biological opinion that allocated incidental "take" for 22 threatened or endangered species. To date, OBDP have determined the amount and extent of take for over 30% of the bridges, and assigned less than 1% of the "take" allocated in the BO for the Program. Looking forward, it is possible that OBDP will complete the program with less than 10% of the entire take allocation being used. After three construction seasons, there has not been any lethal take on the Program. Overall, the Program is exceeding avoidance expectations.

## Materials and Contamination

The Materials and Contamination performance standards were added to the EPS in September 2005. The Materials and Contamination Environmental Performance Standards include three primary environmental areas: 1) Management, 2) Materials Management, and 3) Contamination Discovery and Management. In an effort to meet requirements of the Governor's Executive Order on Sustainability, the ODOT is tracking information on construction and demolition waste management, recycled materials use, fuel selection, and equipment retrofitting for particulate emissions, in order to report on success in meeting Program goals.

This particular EPS identifies reuse and recycling goals for the Program as well as identifies safe handling practices for materials. Use hierarchies are discussed for all materials and outlines preferred reuse methods including on-site use all the way down to landfilling. The EPS provides guidance to the construction contractor for managing material waste streams.

## Design

Part of the success of the stewardship process is how well the program expectations are encompassed into the bridge designs. To assist in this, a series of tools are used in the design stage of the projects. These tools help to create the CS3 projects that the regulatory agencies and state partners are expecting. The ODOT created Engineering and Environmental Baseline Reports to provide an early evaluation of the project areas and identify potential areas of concern. The baseline reports help to identify resources within the project area that may be affected by the bridge construction. The resources include natural resources, wetlands, cultural and historic, materials and contamination sites, and Environmental Justice populations, among others. Engineers and designers utilize this information to aid in the design of a bridge that is not only structurally sound and safe, but also avoids or minimizes the impacts to resources near the bridge area.

The design teams utilize the EPS to determine the best path forward in creating a CS3 project package. Innovative and creative use of technology has been a keystone to the framework. Environmental professionals input the relevant environmental data for a project in a comprehensive, on-line Pre-Construction Assessment (PCA) database. The design team utilizes the baseline information, EPS, and site visit data to complete the PCA requirements.

The data are used to identify project challenges (e.g., archaeological sites or wetlands within the project footprint) and compile electronic reports to the regulatory agencies. Environmental metrics, such as exempted T&E species "take" and wetland fill quantities are tracked using the GIS database. Thus, one framework meets the needs of many stakeholders.

How to successfully implement the permits into construction contracts was a key lesson learned in the design portion of our projects. The permit and EPS requirements needed to be translated into specification language. OBDP started to receive specifications from the design A&E firms that varied widely on how they wrote up the commitments and tried to make them enforceable. At that time, OBDP determined it would be better and more cost and time efficient, and help verify that the commitments were being incorporated into the specifications if a template specification was created.

The tools used in design provide more consistent construction documents (plans and specifications) to ensure the Program permits and regulatory commitments are transferred to the construction phase of the projects.

## Construction

OBDP and the ODOT have set up a number of contractual requirements which promote environmental stewardship and collaboration with the construction sector. One such requirement is providing an environmental stewardship training session to the construction contractor's staff. In the environmental stewardship training, the basis of the Program is explained. The training includes the biological opinion, the streamlined permitting process through the PCA, and the EPS are discussed along with erosion and pollution control requirements, incident response / violation procedures, communication procedures, and project specific environmental concerns. This training lays out the roadmap construction contractors need to follow in order to remain in compliance with the program permits and the overall program goal, and lays out in detail the implications of failure to maintain compliance with the program permits. Expectations for environmental compliance are outlined: how will a site be assessed? What would a compliant item look like? What is non-compliant? Recurring issues are discussed, and the environmental stewardship training provides a forum for training and guidance to limit or prevent future recurrences. This is part of the outreach to construction contractors.

During construction the environmental stewardship framework is implemented through environmental compliance inspections. The objective of environmental compliance inspection is to document the project compliance with respect to the program permits and the construction contract and aid construction contractors in understanding the environmental concerns. A large portion of our construction compliance is to teach contractors about the Program and environmental stewardship and to grow everyone's ownership in the Oregon environment. Compliant and non-compliant items are documented as well as the corrective action and associated timelines necessary to get a project back into compliance with the project permits. Since program inception, OBDP has completed almost 800 environmental compliance inspections on 20 construction projects.

Most inspections are completed in conjunction with the construction contractor, and findings are shared with the contractor, OBDP, ODOT, and regulatory agencies through an online document management system. The most commonly observed items requiring correction are associated with erosion control and pollution control, such as improper installation of erosion control materials or minor fuel spillages. Contractors were able to quickly repair or remediate the situations before the issue resulted in a permit violation, demonstrating an increasing initiative in preventing environmental permit violations.

The inspections allow OBDP staff members to identify areas where improvement may be necessary and/or required to improve compliance with permits and to provide a larger overall benefit to terrestrial and aquatic species and habitats. Periodic inspections help the environmental staff identify problems so they can be fixed before becoming more serious and potentially result in a formal violation from a regulatory or resource agency.

The result of this collaborative environmental stewardship framework is that, to date, no regulatory or resource agency has issued a formal violation of an environmental permit. Additionally, this collaborative approach to environmental compliance inspection is changing the construction culture; construction contractors, taking a more proactive approach to environmental stewardship, are recognizing the benefit of the programmatic permits. Lessons learned during environmental compliance inspection will continue to be incorporated into future contracts for both the Program projects as well as other ODOT projects.

### Construction Waste Reuse and Recycling Stewardship

As part of our stewardship goals and the implementation of the Materials and Contamination EPS in construction, OBDP has requested that construction contractors report on the reuse and recycling efforts on their projects. There will eventually be a contractual requirement for such reporting, but for the moment, ODOT and OBDP are working with the construction contractors to raise awareness of reuse and recycling. As part of that effort, the contractors have voluntarily documented and reported on their projects.

In 2006, construction contractors reported an estimated savings over $650,000 on reuse and recycling of project materials; however, the savings are expected to be much higher as a result of substantial unreported cost savings. The program has also seen a great increase in construction contractor communication. Two projects within the same general vicinity, with two different contractors, worked together to recycle materials from one site for re-utilization as fill at the other site. This exchange saved disposal costs, trucking costs and time, and allowed the one project to save the expense of purchasing fill since the two contractors agreed to exchange the material at no cost.

On another project, approximately 90 percent of the 88 pre-stressed concrete box beams manufactured for the detour bridge were reused on detour structures at other projects. OBDP and ODOT worked together to arrange for recycled surplus pipe piles left over from construction to be transferred to a project in need of such pipes. On another occasion, "retired" signs were put to use as forms.

Another project success was not tied to the EPS. A construction contractor in need of electrical power on a remote site set up solar-powered portable traffic signals, which not only reduced negative impacts on the environment and maintained mobility commitments, but also saved time and money for the project. This is also a great example of increased contractor environmental awareness.

## Lessons Learned

As part of our continued commitment to our environmental stewardship goals, program updates based on our design and construction lessons learned are continually being incorporated into our projects. A few key lessons learned included the specification template, which was described earlier in the "Design" section of this paper, and various matters relating to construction materials.

OBDP are continuing to try new products and processes with the potential to provide a benefit to the owner and resources, at the same time recognizing that we can and probably will encounter the failures which are intrinsic to the experimentation process. Experimentation and innovation have the potential to provide more cost-effective solutions to common issues, but the potential benefits must always be weighed against the cost of failure and its ramifications.

As part of the lessons learned process, OBDP incorporates observations of successful and unsuccessful construction materials and practices into future projects. OBDP has observed that some photodegradable erosion control matting materials made with plastic materials do not entirely photo-degrade when placed adjacent to and beneath new bridges, mainly as a result of low ambient light levels. This presents a potential threat to terrestrial and aquatic animal species because the materials that usually remain are the plastic mesh, which can become entangled in limbs when traversed or transported into water systems. As a result of this observation, OBDP and ODOT worked together to create a new specification requiring contractors to utilize 100 percent biodegradable erosion control matting on OTIA III projects within 50 feet of waterways. This is also a successful knowledge transfer item in that the ODOT is in the process of modifying the Standard Specifications for Construction to require this on all ODOT projects.

As discussed earlier, translating permit commitments and conditions to construction contracts continues to be challenging. Although the environmental performance standards outline the minimum requirements for compliance with the batched programmatic biological opinion, we have found that the commitments and conditions are not being consistently presented in construction contracts. Minor changes in language could result in entirely different interpretations when in construction. Such inconsistencies have also increased review times by forcing reviewers to spend time searching through a submittal to locate EPS requirements.

Unless commitments made in the permitting packages are transferred into the construction contract, a construction change order might have to be requested or a permit modification pursued. Change orders, even ones which result in a net savings or in no additional cost, have the potential to delay a project. Permit modifications can result in more impact (within the terms of the BO) to sensitive environmental resources or additional cost to the construction contract for additional protective measures required by resource or regulatory agencies as a condition of the permit modification.

Recognizing that continued minor inconsistencies in construction contracts could result in major issues during construction, specification templates were developed to help streamline the design process with regard to environmental requirements as well as to increase the consistency of EPS incorporation into the construction contracts. In addition, the specification templates incorporate enforceable language proposed from design firms and internal sources as well as lessons learned during previous construction seasons.

OBDP are working with our design teams to better incorporate good environmental stewardship into designs and with our construction teams to promote environmental stewardship during project delivery. Ultimately, OBDP and ODOT are striving to change a culture in both design and construction, to better protect and improve the resources of the State of Oregon.

## Conclusion

Through continued collaboration and a high level of communication with Federal and State partners, ODOT and OBDP have continued to have a successful environmental stewardship program on the Program. As design and construction continue to ramp up over the next year and beyond, these principles are going to be critical for continued success.

Design continues to be completed for avoidance of environmental impacts limiting the need for mitigation on this Program. This additional benefit to the environment highlights how well the communication, programmatic permits, and EPS work to provide guidance on environmental requirements.

The construction inspection team set up on the Program continues to work with construction contractors as a "training" opportunity, not as an enforcement opportunity. The inspection team works as a partnering team with the construction community to raise awareness of the important environmental issues. This benefit is starting to be seen on non-Program projects and will continue to be the legacy of the success of the Program's environmental stewardship program.

The environmental stewardship framework developed for the Program facilitates design and construction of projects that are sensitive to their communities and landscape while streamlining the permitting process. The collaborative approach with regulatory partners has been a key success in the avoidance and minimization of project impacts and the third year of successful environmental stewardship for the Program.

**Biographical Sketches:** Shelley D. Richards, HDR Engineering. Shelley has 12 years of experience in the environmental and transportation fields and has been with HDR for five years and was at ODOT prior to that. As the Environmental Manager for the Oregon Bridge Delivery Partners, Shelley oversees program design and construction oversight staff – operating throughout the State. Prior to the Program, Shelley was a Project Manager for challenging transportation projects, including rail and highway.

William A. Ryan, Oregon Department of Transportation. Bill has 18 years of experience in the environmental and transportation fields and has been with ODOT since 1996. As Permitting and Mitigation Manager and later Environmental Program Manager, Bill directed and oversaw development and implementation of the environmental stewardship and streamlining strategy for the OTIA III State Bridge Delivery Program, including the programmatic-batched BiOp that is the subject of this paper. Bill is currently overseeing multiple environmental streamlining efforts at ODOT's Salem Headquarters including stormwater permitting and ODOT's mitigation banking program.

## References


Neil, Jason., Zak Toledo, and Robb Kirkman. 2005. Managing Environmental Compliance for ODOT's OTIA III State Bridge Delivery Program: Many Regulations, One Framework. Paper presented at the ICOET 2005 International Conference on Ecology and Transportation, August 29-September 2, in San Diego, California.

Oregon Department of Transportation (ODOT). 2006. *Annual Monitoring Report for Materials and Contamination Environmental Performance.*

Oregon Department of Transportation (ODOT). 2006. *Annual Programmatic Monitoring Report*

Oregon Department of Transportation (ODOT). 2006. *Environmental Performance Standards.*

Oregon Department of Transportation (ODOT). 2006. *Materials and Contamination Performance Standards Manual.*

Oregon Department of Transportation (ODOT). December 2006, January 2007, February 2007. *OTIA III Bridge Delivery Program. Monthly Progress Report.*

# Oregon Strategies for Transportation Compliance with the Migratory Bird Treaty Act

**Chris C. Maguire** (503-986-3385, christine.c.maguire@ODOT.state.or.us), Geo-Environmental Section, Oregon Department of Transportation, 355 Capitol Street N.E., Salem, OR 97301 USA

**Abstract:** The Migratory Bird Treaty Act (MBTA), a federal law enforced by the U.S. Fish and Wildlife Service (USFWS), has no provision for incidental (i.e., unintentional) take of migratory birds during transportation projects. Because more than 400 species of migratory birds live in Oregon and more than 300 of them nest in highway right-of-ways and on bridges, Oregon Department of Transportation (ODOT) is at risk of non-compliance with the MBTA as the agency carries out its mission 'to provide a safe, efficient transportation system.' Although the MBTA is one of the oldest laws in the nation to protect species and natural resources (enacted in 1918), state DOTs have not been provided with guidance at the federal level on how to resolve transportation conflicts with migratory birds when they arise. In the absence of take permits for unintentional harm to migratory birds, ODOT has implemented a multi-faceted migratory bird strategy that not only increases migratory bird protection during transportation projects, but also minimizes the risk of prosecution should an ODOT MBTA violation inadvertently occur.

Initially, ODOT developed a MBTA Highway Division Directive. The purpose of the Directive is to provide agency personnel involved in project delivery, construction, and maintenance with guidelines and strategies to ensure that appropriate and reasonable measures are taken to prevent injury to and death of migratory birds. The Directive emphasizes that all employees must practice due diligence to safeguard migratory birds while they carry out ODOT's transportation mission. Subsequently, ODOT signed inter-governmental agreements with USDA-APHIS-Wildlife Services (U.S. Department of Agriculture – Animal Plant Health Inspection Service). Wildlife Services is authorized by Congress to conduct animal control activities. When ODOT contracts with Wildlife Services for migratory bird management on projects, incidental take is covered under Wildlife Services' take permits. Currently, ODOT is developing an Avian Protection Plan (APP), a voluntary agency-specific program of best management practices designed to protect and conserve migratory birds that is endorsed by USFWS. USFWS Enforcement has MBTA prosecutorial discretion, and an agency operating under an APP is allowed to fulfill its mission without the need for formal USFWS concurrence on every action that has potential to impact migratory birds. ODOT will implement its APP following development of an agency-wide bird mortality tracking system.

## Background

The United States recognizes that migratory birds are a shared resource with other nations, and as such has ratified four international, bilateral conventions for the conservation of migratory birds: Convention for the Protection of Migratory Birds with Great Britain on behalf of Canada (1916), Convention for the Protection of Migratory Birds and Game Mammals with Mexico (1936), Convention for the Protection of Birds and Their Environment with Japan (1972), and Convention for the Conservation of Migratory Birds and Their Environment with the former Union of Soviet Socialist Republics (1978). The United States implements these international conventions through the Migratory Bird Treaty Act (MBTA, 16 USC 703-712), one of the oldest environmental laws in the nation.

The primary motivation for the 1916 treaty with Canada and the passage of the MBTA in 1918 was to stop the indiscriminate slaughter of migratory birds by market hunters. However, the MBTA reaches far beyond intentional kill of migratory birds for profit. Under the MBTA it is illegal for anyone to take, possess, import, export, transport, sell, purchase, barter, or offer for sale, purchase or barter, any migratory bird, or the parts, nests, or eggs of such a bird except under the terms of a valid permit issued pursuant to Federal regulations. 'Take' under the MBTA means to pursue, hunt, shoot, wound, kill, trap, capture, collect, or possess migratory birds, their eggs or young, or to attempt to do any of these (50 CFR 10.12). Habitat destruction, inactive nest removal, and harassment that do not result in the injury or death of a migratory bird are not violations of the MBTA.

The United States Fish and Wildlife Service (USFWS) is the principal federal agency responsible for conserving, protecting, and enhancing fish, wildlife, plants, and their habitats. The MBTA authorizes the USFWS to issue migratory bird take permits for 11 categories of activities: import/export, scientific collecting, taxidermy, waterfowl sale and disposal, educational use, falconry, raptor propagation, rehabilitation, depredation, special purpose, and a special Canada goose permit. Unlike the federal Endangered Species Act (ESA, 16 USC 1531-1544), the MBTA has no provision for incidental take permits. 'Incidental take' is take that results from, but is not the purpose of, carrying out an otherwise lawful activity. Although road projects may be authorized to proceed under permits issued by the USFWS pursuant to the regulations in 50 CFR Parts 13 and 21 (National Research Council 2005), many state transportation agencies, including Oregon Department of Transportation (ODOT), have been largely unsuccessful at obtaining MBTA permits.

The MBTA is a 'strict liability law,' which means that a party can be convicted under the statute without demonstration of specific intent or guilty knowledge. Generally, American criminal laws seek to punish only those who act with specific intent or knowledge of their actions and their consequences (Jenkins 1997). But legislatures may dispense with the traditional notions of criminal intent in most if not all environmental crimes, including MBTA violations (Jenkins 1997). Highlights of USFWS Enforcement investigations into MBTA violations are available in the annual reports of the USFWS Division of Law Enforcement and in 'The Federal Wildlife Officer,' a publication of the Federal Wildlife Officers Association.

The Migratory Bird Treaty Reform Act of 2004 (MBTRA, 118 Statute 2809), the most recent amendment to the MBTA, required the USFWS to provide a list of avian species *not* covered under the MBTA. The MBTRA excludes coverage to species not considered native to the United States when the MBTA was enacted in 1918, i.e., species that have been introduced by humans everywhere they occur in the nation (70 FR 12710). Regardless, the most recent USFWS list of avian species proposed for MBTA protection identifies 972 species (71 FR 50194). Approximately 400 of these species are found in Oregon, and more than 300 of them breed in the state. In effect, all species of wild birds in Oregon are protected by the MBTA with the exception of European starling (*Sturnus vulgaris*), rock dove (i.e., feral pigeon, *Columba livia*), house sparrow (*Passer domesticus*), and mute swan (*Cygnus olor*).

Migratory birds are routinely associated with transportation projects. Conflicts are most likely to occur during the nesting season when active nests (i.e., nests containing eggs or young) may be present. Adult birds are capable of leaving a project site when threatened by construction or maintenance activities, but eggs and flightless young are not. These early life stages of birds may be directly impacted by activities such as clearing and grubbing vegetation, and cleaning, painting, reconstructing, and demolishing bridges. In Oregon, many of these activities occur concurrent with migratory bird nesting because of off-season weather constraints, temporal restraints of other environmental regulations (e.g., in-water work periods to protect fisheries resources, ODFW 2000), and the numerous species of birds that collectively produce active nests more than half of the year.

Because of the high probability of encountering active nests on transportation construction and maintenance projects, no MBTA incidental take permits, and the strict liability aspect of the MBTA, ODOT considers the MBTA to be one of the most difficult environmental laws with which to comply as the agency carries out its mission 'to provide a safe, efficient transportation system.' To date, the Federal Highway Administration (FHWA) has not provided state transportation departments with official guidance for MBTA compliance.

In 2001, President Bill Clinton signed Executive Order 13186 which outlines 'Responsibilities of Federal Agencies to Protect Migratory Birds' (FR Doc. 01-1387). Under the Executive Order, "Each Federal agency taking actions that have, or are likely to have, a measurable negative effect on migratory bird populations is directed to develop and implement, within two years, a Memorandum of Understanding (MOU) with the Fish and Wildlife Service that shall promote the conservation of migratory bird populations" (Sec. 3(a)). In addition, "Each agency shall ... support the conservation intent of the migratory bird conventions by integrating bird conservation principles, measures, and practices into agency activities and by avoiding or minimizing, *to the extent practicable* [italics added], adverse impacts on migratory bird resources when conducting agency actions" (Sec. 3(e)(1)). Six years after the Executive Order, only the Department of Defense and the Department of Energy have signed migratory bird MOU agreements with USFWS (http://www.fws.gov/migratorybirds/). FHWA has developed a draft MOU, but it has not been accepted by USFWS.

With high risk for MBTA non-compliance and the absence of national level guidance for state transportation departments, each state faces the risk of MBTA non-compliance individually. Rather than wait for national direction, ODOT has been developing and implementing a multi-faceted MBTA compliance strategy that increases migratory bird protection during transportation projects and minimizes the risk of prosecution should incidental take occur. The three strategies are described below.

### <u>ODOT MBTA Highway Division Directive</u>

Although roads may inhibit the presence and breeding of some avian species (e.g., Reijnen et al. 1995, Rottenborn 1999, Forman and Deblinger 2000, Forman et al. 2002), transportation corridors and structures provide attractive habitat for other species. For example, raptors may use roadsides more often than adjacent habitat because of the greater availability of perch sites (Knight and Kawashima 1993, Meunier et al. 2000) and less energy-demanding hunting behavior because of landscape openness (Meunier et al. 2000), while ravens and other avian scavengers may concentrate along highways because of vehicle-generated carrion (Knight and Kawashima 1993, Forman et al. 2003). Some bird species appear to favor foraging and nesting on managed roadsides rather than adjacent fields (Laursen 1981), and a variety of birds nest on bridges (e.g., Hobson and Wilson 1985, Cade and Bird 1990, Stenzel et al. 1995, Brown and Brown 1996, Airola and Grantham 2003).

Because migratory birds are common along highways and encounters with them are frequent on transportation projects, ODOT staff, consultants, and contractors have been seeking guidance on how best to pursue compliance with the MBTA. In response to this need, ODOT developed a MBTA Highway Division Directive (http://www.oregon.gov/ODOT/HWY/GEOENVIRONMENTAL/index.shtml) and began implementing it in January 2006. The purpose of the Directive is to provide agency personnel involved in project delivery, construction, and maintenance with guidelines and strategies to ensure that appropriate and reasonable measures are taken to prevent injury to and death of migratory birds. The Directive emphasizes that all employees are expected to practice due diligence to safeguard migratory birds while they carry out ODOT's transportation mission in ways that protect and enhance the environment.

Recognizing that each transportation project has its own unique set of MBTA compliance challenges, the ODOT Highway Directive is not prescriptive. Instead, it identifies general construction and maintenance situations where migratory bird conflicts commonly occur, and for each situation, a suite of possible actions are identified that could be implemented on projects to eliminate or minimize injury to birds. Conservation of bird habitat also is addressed. For example, the migratory bird goal for snag removal in the MBTA Directive is to avoid felling snags that contain active nests. One suggestion for meeting this goal is to avoid removing snags unless necessary for safety or project implementation. The Directive also acknowledges that for some projects, none of the proposed strategies may be practicable. Under these circumstances, ODOT staff is directed to develop project-specific measures to prevent migratory bird harm and to minimize harm when prevention is not practicable.

With the intention of being pro-active rather than reactive, the Highway Directive expects project development teams to consider possible sources of migratory bird conflict significantly in advance of project implementation. If sources of conflict can be identified early in project development, projects can be intentionally designed to minimize harm to migratory birds instead of modifying projects after-the fact. In the long run, this approach saves transportation projects time and money while providing superior benefits to the avian resource. Additionally, the Directive requires individuals involved in project delivery to identify and incorporate migratory bird conservation principles and practices into ODOT projects and contracts through collaboration with appropriate federal, state, and non-governmental groups during planning efforts. This Directive expectation is largely accomplished through continuous dialogue with the 15 liaisons that ODOT funds with state and federal regulatory agencies.

Migratory bird conservation at the project planning stage focuses on habitat. ODOT has four habitat-centric approaches: (1) preservation – to ensure that project activities are designed such that migratory bird habitat will not be disturbed unnecessarily during project implementation and that nesting habitat will not be disturbed during the nesting season; (2) restoration – to ensure that migratory bird habitat that will be negatively impacted during project implementation is restored where feasible; (3) enhancement – to improve migratory bird habitat within project areas if feasible and reasonable; and (4) mitigation – to enhance bird habitat off-site when on-site preservation, restoration, and enhancement opportunities are limited.

The MBTA Highway Division Directive is a valuable first step in raising awareness within the ODOT community about migratory birds and their protection, and in providing ODOT employees with a suite of strategies to guide project decision-making regarding MBTA compliance. In addition, the Directive makes it an employee duty to protect avian resources to the greatest extent practicable. If the Directive guidelines and strategies are followed and incidental take occurs in the absence of a USFWS authorized permit, ODOT, rather than the individual, will be accountable (Oregon Department of Administrative Services Policy Number 125-7-202).

**Inter-Governmental Agreements with Wildlife Services**

ODOT's second MBTA compliance strategy was to remove the risk of take and take liability from the agency by entering into Inter-Governmental Agreements (IGA) with USDA-APHIS-Wildlife Services (U.S. Department of Agriculture – Animal Plant Health Inspection Service – Wildlife Services). Wildlife Services is the congressionally-authorized federal agency that conducts animal control activities and enters into cooperative programs for animal conflict management with government agencies, public or private institutions, organizations, and associations (7 USC 426c; WS Policy Directives 1.210 and 3.101). Wildlife Services also has the federal responsibility to respond to migratory bird conflicts and to provide assistance in resolving the conflicts upon request from either the public or private sector (WS Policy Directive 2.301). By being involved in the management of ODOT wildlife conflicts, Wildlife Services helps ensure that wildlife management activities are environmentally sound and conducted in compliance with applicable federal, state, and local laws and regulations.

The State Directors of Wildlife Services negotiate annually with the appropriate USFWS regional migratory bird offices for authorized levels of take associated with their permits, including migratory bird take. Take limits are for all Wildlife Services activities within a state and they usually are modest. Furthermore, third parties that have contracted with Wildlife Services are not covered by the permits. These permit conditions are important to ODOT for several reasons. Because Wildlife Services take permits are non-transferrable, only take incurred by Wildlife Services employees, not ODOT personnel, is covered. Additionally, because the permit limits on take are modest, the primary strategy of Wildlife Services for migratory bird management on ODOT projects is active nest prevention. Although nest prevention is a time and labor intensive endeavor, it benefits the avian resource by minimizing the risk of take.

ODOT entered into two IGAs with Wildlife Services in March 2006. One provides for a Wildlife Services liaison to manage ODOT MBTA compliance performed by Wildlife Services personnel across Oregon. The second IGA covers time and materials. To date, Wildlife Services has had its most significant influence in the ODOT OTIA III (Oregon Transportation Investment Act III) State Bridge Delivery Program. In 2003, the Oregon State Legislature passed House Bill 2041 which provides $1.3 billion over a 10-year period for the replacement and repair of more than 300 bridges on Oregon state highways. Several species of migratory birds that routinely nest on bridges can be problematic for ODOT from a MBTA compliance perspective. Barn swallows (*Hirundo rustica*) and cliff swallows (*Petrochelidon pyrrhonota*) are particularly challenging because of their tenacious, communal nesting habits (Jackson and Burchfield 1975, Brown and Brown 1996).

Most bridges being replaced or repaired in Oregon are over water, and the Oregon Department of Fish and Wildlife (ODFW) regulates the timing of in-water work to minimize potential impacts to fish, wildlife, and habitat resources (ODFW 2000). In most instances, recommended in-water work periods overlap with the swallow nesting season. Consequently, nesting on bridges must be prevented until the repair work is done or the structure is demolished. Wildlife Services conducts most of the nest prevention work for ODOT and for many of ODOT's contractors.

The particular method that Wildlife Services utilizes to prevent nesting on a bridge depends on characteristics of a bridge such as height, length, structural complexity, and intensity of bird use. On bridges where nest locations are relatively accessible, partial nests and inactive nests are removed using extendable poles. When nests are relatively inaccessible, partial and inactive nests are shattered with paintballs. Paintball color is given low priority on bridges scheduled for demolition, but clear paintballs are a high priority on historic bridges being repaired or upgraded. Bridges with inaccessible nest sites or bridges that have a history of intense swallow nesting usually are netted to exclude birds from the structure, but only if the nets will not impact the safety of the traveling public.

In addition to assistance on ODOT bridge projects, Wildlife Services has assumed responsibility for migratory bird management on a number of projects that involve vegetation removal during the nesting season. Although vegetation removal outside the nesting season is always the preferred option to prevent birds from nesting in vegetation, it is not always the practical option. Winter is the season when most precipitation occurs in Oregon. If vegetation cover is absent during the rainy season, significant erosion is likely to occur, particularly when mountainous terrain is involved. As with nesting prevention on bridges, Wildlife Services initiates nest prevention measures prior to the nesting season. Because nesting birds can be difficult to locate in vegetation, particularly if the vegetation is structurally complex or the area is large, nest prevention in vegetation is inherently more challenging than nest prevention on bridges and the risk of take is greater.

Despite the challenges Wildlife Services has faced while assisting ODOT with MBTA compliance, the value of the collaboration between the two agencies is indisputable. In 2006, Wildlife Services assumed the responsibility of migratory bird management on more than 50 ODOT projects. Across all these projects, take was limited to 17 eggs and three chicks. More than half of the take was a direct result of third party tampering with bird-exclusion netting on a bridge that allowed swallows to nest successfully on the structure. This year (2007), Wildlife Services is involved in more than 80 ODOT projects.

## Avian Protection Plan

Despite the success of ODOT's collaboration with Wildlife Services on migratory bird management, there are/will be occasions when Wildlife Services is/will be unable to provide project assistance. These situations are uncommon, but the following are some examples: a bridge cannot be accessed because construction of a temporary work bridge is delayed; the structural design of a bridge makes it impracticable to access nests and use of bird-exclusion netting is not a viable option; or vegetation must be cleared unexpectedly during the nesting season and no nest prevention activities were undertaken. Situations such as these highlight the need for an ODOT Avian Protection Plan (APP).

An APP is a voluntary agency-specific program of best management practices designed to protect and conserve migratory birds that is endorsed by the Enforcement Branch of USFWS. USFWS Enforcement has MBTA prosecutorial discretion, and an agency operating under an APP is allowed to fulfill its mission without the need for formal USFWS concurrence on every action that has potential to impact migratory birds. The APP is not an incidental take permit, nor does it result in a take permit. Rather, it is an agency's demonstration that it is doing its best to fulfill the intent of the MBTA, migratory bird protection and conservation.

In 2003, USFWS and the utility industry agreed to develop a process whereby the industry could voluntarily and without the need for formal service concurrence address avian electrocutions and strikes (FWS/AMP/DMBM/020719). The result was the development of a template for an APP that was agreed to by the utility industry and endorsed by USFWS (APLIC and USFWS 2005). Numerous utility companies have developed company-specific APPs since the template became available, and workshops are routinely held across the nation to train utility company personnel in avian protection and APP development.

Given that USFWS actively encourages utility companies to develop APPs as an acceptable way to demonstrate commitment to migratory bird protection and conservation, ODOT made a decision in 2005 to collaborate with USFWS in the development of a transportation-centric APP. The framework for ODOT's APP comes directly from the strategies and guidance contained in the MBTA Highway Division Directive. Additional best management practices and mitigation measures identified by others (e.g., Gucinski 2000, Carey 2004, Jacobson 2005) are being evaluated for possible inclusion in the APP, and Wildlife Services is sharing with ODOT its extensive knowledge of migratory bird conflict resolution as the APP develops. ODOT is targeting 2007 for completion of its APP following development of an agency-wide bird mortality tracking system.

## Summary

ODOT is committed to taking appropriate and reasonable measures to prevent injury to and death of migratory birds while carrying out its mission to provide a safe and efficient transportation system. This commitment is demonstrated by a multi-faceted MBTA compliance strategy that ODOT has been developing and implementing to increase migratory bird protection during transportation projects. ODOT initially developed a MBTA Highway Division Directive. The Directive requires due diligence to safeguard migratory birds as ODOT personnel carry out their assigned duties. The Directive also includes a suite of strategies to protect avian resources for possible implementation on transportation projects. Subsequent to the Highway Directive, ODOT entered into inter-governmental agreements with USDA-APHIS-Wildlife Services for migratory bird conflict resolution. As the federal agency responsible for responding to migratory bird conflicts, Wildlife Services has USFWS authorized bird take. Following the lead of the utilities industry, ODOT currently is developing an APP. An APP is a voluntary, agency-specific, USFWS endorsed program of best management practices designed to protect and conserve migratory birds. ODOT is sharing information about its MBTA compliance strategy in the hope that it will provide ideas to other transportation agencies struggling with MBTA challenges.

**Biographical Sketch:** Chris Maguire is the Terrestrial Biology Program Coordinator for the Oregon Department of Transportation (ODOT). She has held this position since January 2005. Prior to ODOT, Chris had academic appointments in biology/ecology/wildlife at Oregon State University, Western Washington University, Unity College in Maine, and Rutgers University and Bloomfield College in New Jersey. Chris has also held research positions with the U.S. Environmental Protection Agency in Oregon and the U.S. Forest Service in Washington. Chris has a Masters and a PhD in Animal Ecology from Rutgers University, and she is a Certified Wildlife Biologist.

## References


Airola, D.A. and J. Grantham. 2003. Purple martin population status, nesting habitat characteristics, and management in Sacramento, California. Western Birds 34:235-251.

Airola, D.A. and U.S. Fish and Wildlife Service (USFWS). 2005. Avian Protection Plan Guidelines. http://www.fws.gov/migratorybirds/

Brown, C.R. and M.B. Brown. 1996. Coloniality in the Cliff Swallow: the Effect of Group Size on Social Behavior. University of Chicago Press, Illinois. 566 pp.

Cade, T.J. and D.M. Bird. 1990. Peregrine falcons, *Falco peregrinus*, nesting in an urban environment: a review. Canadian Field-Naturalist 104:209-218.

Carey, M. 2004. Bridges and wildlife: issues and solutions. Proceedings of the 2003 International Conference on Ecology and Transportation, edited by C.L. Irwin, P. Garrett, and K.P. McDermott, pp 392-393. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina, USA. 688 pp.

Forman, R.T.T. and R.D. Deblinger. 2000. The ecological road-effect zone of a Massachusetts (USA) suburban highway. Conservation Biology 14:36-46.

Forman, R.T.T., B. Reineking, and A.M. Hersperger. 2002. Road traffic and nearby grassland bird patterns in a suburbanizing landscape. Environmental Management 29:782-800.

Forman, R.T.T. and 13 additional authors. 2003. Road Ecology: Science and Solutions. Island Press, Washington, D.C. 481 pp.

Gucinski, H., M.J. Furniss, R.R. Ziemer, and M.H. Brookes. 2000. Forest roads: a synthesis of scientific information. USDA Forest Service General Technical Report PNW-GTR-509. 117 pp.

Hobson, K.A. and D. Wilson. 1985. Colony establishment by pelagic cormorants on man-made structures in southwest coastal British Columbia. The Murrelet 66:84-86.

Jacobson, S.L. 2005. Mitigation measures for highway-caused impacts to birds. In USDA Forest Service General Technical Report PSW-GTR-191,Volume I and II, edited by C.J. Ralph and T.D. Rich, pp 1043-1050. Forest Service, U.S. Department of Agriculture. 1294 pp.

Jackson, J.A. and P.G. Burchfield. 1975. Nest-site selection of barn swallows in east-central Mississippi. The American Midland Naturalist 94:503-509.

Jenkins, D. 1997. Criminal prosecution and the Migratory Bird Treaty Act: an analysis of the constitution and criminal intent in an environmental context. Boston College Environmental Affairs Law Review 24(3). 20 pp.

Knight, R.L. and J.Y. Kawashima. 1993. Responses of raven and red-tailed hawk populations to linear right-of-ways. Journal of Wildlife Management 57:266-270.

Laursen, K. 1981. Birds on roadside verges and the effect of mowing on frequency and distribution. Biological Conservation 20:59-68.

Meunier, F.D., C. Verheyden, and P. Jouventin. 2000. Use of roadsides by diurnal raptors in agricultural landscapes. Biological Conservation 92:291-298.

National Research Council. 2005. Assessing and Managing the Ecological Impacts of Paved Roads. The National Academies Press, Washington, D.C. 294 pp.

Oregon Department of Fish and Wildlife (ODFW). 2000. Oregon guidelines for timing of in-water work to protect fish and wildlife resources. 12 pp.

Reijnen, R., R. Foppen, C. ter Braak, and J. Thissen. 1995. The effects of car traffic on breeding bird populations in woodland. III. Reduction of density in relation to the proximity of main roads. Journal of Applied Ecology 32:187-202.

Rottenborn, S.C. 1999. Predicting the impacts of urbanization on riparian bird communities. Biological Conservation 88:289-299.

Stenzel, L.E., H.R. Carter, R.P. Henderson, S.D. Emslie, M.J. Rauzon, G.W. Page, and P.Y. O'Brien. 1995. Breeding success of double-crested cormorants in the San Francisco Bay Area, California. Colonial Waterbirds 18 (Special Publication 1):216-224.

## Regulatory Compliance on Multistate and Multimodal Projects: Bridging the Gaps Between States and Among NEPA Co-leads

**Heather Gundersen** (360-816-2199, gundersen@columbiarivercrossing.org), Environmental Project Manager, Columbia River Crossing Project, Oregon Department of Transportation, 700 Washington Street, Vancouver WA 98660, Fax: 360-737-0294 USA

**Jeff Heilman** (503-736-4806, jheilman@parametrix.com), Director of Environmental Planning, Parametrix, 700 NE Multnomah, Suite 1000, Portland, OR USA

**Abstract:** The I-5 Columbia River Crossing (CRC) project is a highway and transit project located on Interstate 5 (I-5) along a five mile corridor between Vancouver, Washington and Portland, Oregon. Spanning two states, cities and counties, the CRC project has many different jurisdictional boundaries that can include different ideologies, requirements, and established practices. Two Metropolitan Planning Organizations and transit organizations also play a primary role for the transit side. In total, the project has eight project sponsors, including the Oregon and Washington Departments of Transportation.

The project includes both major highway and major transit elements, and therefore two federal lead agencies – the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) – jointly oversee the National Environmental Policy Act (NEPA) process. The federal co-lead status for developing the Environmental Impact Statement (EIS) often presents challenges that will be discussed. On the regulatory side there are obvious complications from the bi-state nature of the project because each state has its own regulations and policies that can be inconsistent and sometimes contradictory to the other. The purpose of this paper is to explain the CRC approach to environmental streamlining for the NEPA process and the lessons learned that could apply to complex or even smaller transportation projects.

### Project Challenges

The complex structure of this project with two states, two United States Department of Transportation lead agencies and two major transportation modes, create some of the key regulatory and NEPA challenges for this project. It is further challenged by a high public profile and an ambitious schedule. These demands have led the project to develop innovative and efficient measures for combining and balancing disparate and sometimes conflicting requirements and objectives in the environmental process.

### CO-NEPA Leads

FTA and FHWA are co-lead agencies for the NEPA process of CRC. While a co-led project is not new, it is uncommon and introduces complexities as the project must follow the regulations and policies of both agencies and determine appropriate reconciliation for discrepancies or contradicting direction. For a large project such as CRC that already faces additional complexities, advanced consideration of potential differences, and predetermined approaches for dealing with these, were necessary to meet the project's ambitious schedule. The primary technique for determining and addressing potential differences in co-leads' expectations and policies were the development of Methods and Data Reports (MDRs) that specify how each Technical Report will be prepared. Letters of deferral have also been used to consolidate key interagency processes.

An MDR was recently drafted for each Technical Report discipline that will be prepared in support of the Draft EIS. Each MDR defines regulations and policies applicable to the respective discipline, and data sources and methodologies for identifying direct, indirect and cumulative effects within that discipline. Technical specialists and management staff from FTA and FHWA reviewed each MDR and provided feedback to the project team. The final drafts of these reports memorialize an approach for fully satisfying the policies and expectations of both agencies.

FTA and FHWA have different experience and approaches for complying with federal regulations such as the Clean Air Act (CAA) and the Endangered Species Act (ESA). Reconciling these differences was expedited by establishing which of the co-lead agencies would lead the process of determination of compliance with these regulations. Thus far, FTA has deferred the consultation process of Section 7 of the ESA, conducting conformity analysis under the CAA and 4(f) documentation. In each case, deferral simply determines the project's process of ensuring compliance and does not change or remove legal obligations of the co-lead agencies.

FHWA and FTA also differ in how they address project funding during the NEPA process. FTA administers the New Starts process (Section 5309) for funding major transit investments, and integrates a portion of the New Starts analysis and documentation with the NEPA process. FHWA's NEPA process does not integrate any such analysis. Travel demand, traffic analysis, and costs are extremely important in the New Starts evaluation criteria. Because the CRC project proposes major highway improvements, it complicates the analysis of how the transit proposal is evaluated. However, because the EIS evaluates both major highway and transit proposals, the New Starts analysis also combines these components.

### Regulatory Agencies

For CRC, a major challenge with having two participating states is that each of the state and federal resource agencies bring its own mission, standards, permitting requirements, consultation procedures, documentation approaches, communication protocols, institutional histories and personalities to the table. This challenge is even present within the same federal agency that has separate offices in each state, such as the Army Corps of Engineers. This can lead to contradictory and inconsistent direction from jurisdictions within each state, and inconsistent or compounding requirements from the co-lead agencies.

CRC will ultimately require a permit or approval from these state and federal agencies with jurisdiction over environmental regulations so it is a major benefit for the project to coordinate early and often with these agencies during the NEPA process. The project established the Interstate Collaborative Environmental Process (InterCEP) Agreement to coordinate an approach with state and federal regulatory agencies to streamline regulatory reviews and permitting functions by these agencies. The following agencies signed the InterCEP Agreement:

| | |
|---|---|
| Federal High Administration | Federal Transit Administration |
| Oregon Department of Transportation | Washington Department of Transportation |
| National Marine Fisheries Service | Oregon Department of Land Conservation and Development |
| US Environmental Protection Agency | Oregon State Historic Preservation Office |
| US Fish and Wildlife Service | Oregon Department of State Lands |
| US Army Corps of Engineers | Washington Department of Archaeology and Historic Preservation |
| Oregon Department of Environmental Quality | Washington Department of Fish and Wildlife |
| Oregon Department of Fish and Wildlife | Washington Ecology |

A primary function of the InterCEP Agreement is the establishment of key points during the project's development where the signatory agencies are requested to provide concurrence on a proposed decision, such as the range of alternatives for evaluation in the DEIS. Concurrence points are important tools for the project team and the regulatory agencies. Receiving concurrence on a decision allows the project team to move forward confident that their current direction is aligned with state and federal regulations. Likewise, these opportunities for formal approval provide the regulatory agencies the ability to alert the project early of any problems that could later hinder the agencies' issuance of necessary permits.

The concurrence and formal comment points for InterCEP are:

- Project Purpose and Need (Concurrence)
- Screening Criteria for Alternatives (Concurrence)
- Methods for analyzing impacts (Comment)
- Range of Alternatives to carry into the Draft Environmental Impact Statement (DEIS) (Concurrence)
- Preliminary DEIS (Comment)
- Final DEIS (Comment)

InterCEP served as a key advisory group in the development of the aforementioned MDRs. In addition to determining approaches amenable to both NEPA co-lead agencies, the project team sought to craft methodologies to assess environmental effects in a fashion that would satisfy each InterCEP agency. InterCEP provided detailed feedback, ranging from identifying appropriate laws, regulations and policies the team should consider, to refinements in how impacts should be assessed.

The approach toward expediting environmental permitting outlined in the InterCEP Agreement should not just speed the project's development, but ultimately lead to a better product that meets or exceeds state and federal environmental expectations. Early and frequent coordination between the project team and representatives from InterCEP agencies has allowed these agencies to provide input during the development and evaluation of potential alternatives. For example, InterCEP agencies directly influenced the development of evaluation criteria for use in analyzing potential alternatives. Several agencies requested substantive changes to the wording of environmental criteria on the basis that these changes better reflect the goals of the regulations they enforce. Monthly meetings and even more frequent conversation and information exchange with these agencies has allowed the project team to continually monitor project development to ensure decisions are made that can be met with approval from InterCEP agencies.

## SAFETEA-LU

The latest transportation reauthorization bill, Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), amended how transportation projects seeking federal funding must engage tribal governments, regulatory agencies and other stakeholder groups. Many of these requirements are intended to ensure these projects genuinely and thoroughly engage all groups and individuals with potential interest in the projects' outcomes.

One of the more significant changes included in SAFETEA-LU is the establishment of a Participating Agency group that is defined as federal, state, tribal, regional, and local government agencies that may have an interest in the project. For CRC, this requirement caused some initial confusion amongst the project team and these groups because it overlaps with other venues of involvement. For example, there are already state and federal requirements for robust coordination with tribal governments that provide tribes with more substantial opportunity to influence the project. Tribes were confused when the project team sent invitations to them for involvement as Participating Agencies, and asked how this related to the consultation they would already receive as a tribal government. However, the formation of a Participating

Agency group has involved several local agencies that would not have otherwise have been invited to regularly meet with the project team and provide input beyond avenues already open to the public.

**Lessons Learned**

The CRC project is rightfully subject to scrutiny and regulation from a variety of stakeholders, agencies, and jurisdictions. Determining the best solution for improving the traffic and transit connection along I-5 between Vancouver, Washington, and Portland, Oregon, is a major decision that should not just comply with, but exceed expectations and requirements. Furthermore, the need for a solution is pressing. Involving with a wide range of local, state and federal agencies, developing a unified approach amongst co-lead agencies, and early collaboration with regulators has allowed the project to progress rapidly toward its goals.

Frequent coordination with the federal leads is key for successful project implementation. The federal leads are required by federal statutes to, at a minimum, play an oversight role for transportation projects, but generally cannot actively participate in projects because they are constrained by limited staff expertise and funding. Consequently, deferral to the states is mutually beneficial for the project and federal agencies. Unfortunately, federal agencies cannot defer legal responsibility to the state; therefore, deferral can only work well if the state maintains constant communication with the federal leads. CRC meets bi-weekly with the federal leads to discuss large project issues, followed by a session to discuss NEPA related activities. It is helpful for the federal agencies to know they have a direct line to the project, and are offered a venue to openly discuss concerns.

In a co-lead project it is important to obtain approval to follow one federal agency's environmental process, but be specific about what 'deferral' actually means. For CRC, deferring environmental process to FHWA did not represent what was anticipated. FTA, though they deferred process, expected to be involved in every step for section 106 and ESA compliance. This was mainly problematic because FTA would be excluded from specific meetings with resource agencies and in turn be frustrated with the project because of it. Ultimately, it was clear that the states, FHWA and FTA each had differing expectations for deferral. The confusion would easily be avoided through explicitly outlining the deferral process.

Concurrence is over-rated; comment points are adequate and preferable for obtaining regulatory agency feedback for projects in the NEPA process. Concurrence gives resource agencies a sense of veto power over the project because if an agency submits a 'non-concur' at the specific concurrence point then the project is halted and the issue elevation process is initiated. The perceived veto power can be counter-productive to the spirit of early collaboration. The purpose of InterCEP is to provide a forum for early agency coordination and collaboration, but when the issue elevation process is initiated because an agency doesn't agree with project direction it can cause unnecessary distrust and adds strain to the collaborative environment. Comment points offer the same opportunity for agency input, but adds a layer of inherent trust between agencies.

Frequent communication and meetings with the state and federal resource agencies is critical to discuss progress on the project. As mentioned several times, CRC has a very aggressive schedule that tends to keep the project in a constant state of flux. The project direction can change quickly causing frustration for stakeholders who minimally participate, but need to maintain a heightened level of awareness because they are critical for moving through decision points. Many resource agencies have limited time for CRC because they are responsible for several different projects. Consequently, the onus for facilitating agency involvement is on the project staff. Regular monthly meetings, with the appropriate project staff, provide the agencies an opportunity to maintain an ongoing dialogue with the project prior to concurrence and comment points. The positive result of frequent meetings is evident in the limited number of agency comments submitted during formal comment and concurrence periods because the project was able to address the majority of comments or concerns prior to the agency's formal submittal.

SAFETEA-LU provides a useful framework for engaging agencies, tribes and other stakeholders. Though it is not explicit in SAFETEA-LU, many state transportation departments are interpreting the new provisions as a red light to dissolve or revisit 404 merger agreements that center on concurrence. SAFETEA-LU does not differentiate between permitting agencies or other local 'interested' stakeholders in requirements to engage these parties as 'participating agencies'. Currently, the CRC has several different stakeholder groups that meet on various occasions, and the project could benefit from a more streamlined approach that incorporates several stakeholders in one process.

Every transportation project will have unique characteristics and challenges. The CRC is a very complex project that requires innovative techniques in the environmental process that will not be directly applicable to other projects. However, the positive impacts of frequent communication and inclusive collaboration with stakeholders can be directly applied to any project, transportation or otherwise.

## Stewart Airport Ecosystem – Taking off with Innovative Approaches

**Debra A. Nelson** (518-485-5479, dnelson@dot.state.ny.us), Water/Ecology Section Head, New York State Department of Transportation, Environmental Analysis Bureau, 50 Wolf Road, POD 41, Albany, NY 12232, Fax: 518-457-6887 USA

**Lisa D. Weiss** (845-431-5853, lweiss@dot.state.ny.us), Downstate Environmental Zone Manager, New York State DOT, 4 Burnett Boulevard, Poughkeepsie, NY 12603, Fax: 845-431-5890 USA

**Abstract:** The Stewart Airport Access Improvement Project (SAAIP) embraces the essence of New York State Department of Transportation's (NYSDOT) environmental ethic. The objectives of the project are to provide safe, efficient and improved access to Stewart International Airport, while stimulating the local economy and minimizing environmental impacts. In the end, in addition to meeting the project needs, the project results in the establishment of the nearly 7,000-acre (2,833-hectare) Stewart State Forest; preservation of the 8-acre (3.2 hectare) Colden Mansion ruins; creation of 13 acres (5.3 hectares) of wetland; preservation of a large population of a rare plant and establishment of a seed bank for its propagation; incorporation of wildlife crossings into the highway design to maintain habitat connectivity; conservation of federally-endangered Indiana bat potential maternity roosts and suitable summer roosting habitat; and creation and long-term monitoring of twelve vernal pools as breeding habitat for herptiles. This stewardship approach evolved over ten years, through partnerships, collaboration, innovation, as well as NYSDOT's willingness and support to improve the environmental conditions.

### Project Setting

Stewart International Airport is located in the towns of New Windsor and Newburgh, Orange County, New York. The airport is located near the junction of the NYS Thruway and Interstate 84, and is approximately 60 miles (97 km) north of midtown Manhattan in New York City. Metropolitan New York supports an estimated population of 18.8 million people. Orange County, in which Stewart International Airport is located, is one of New York State's fastest growing counties and is losing natural tracts of land to commercial, industrial and residential development.

Stewart Properties is located adjacent to the Stewart International Airport, providing approximately 8,000 acres (3237 hectares) of open space. These lands were acquired by the Metropolitan Transportation Authority (MTA) in 1971 for the purposes of "accommodating expanded airport operations and airport compatible development" (NYSDOT, 2000).

In 1974, the MTA entered into a temporary agreement with the New York State Department of Environmental Conservation (NYSDEC) that resulted in the formation of the Stewart Airport Cooperative Agreement for specific western portions of the properties. This cooperative agreement opened these lands to public fishing, hunting, trapping, as well as recreational uses such as hiking and biking (NYSDOT, 2000). These lands and the cooperative agreement were transferred to NYSDOT in 1982.

The Stewart Park and Reserve Coalition (SPARC) is a grass roots organization founded in 1987 "to protect the 7,000 acres (2833 hectares) west of Drury Lane adjacent to Stewart Airport in Newburgh as open space" (SPARC website). As noted on their website, "through the years SPARC has served as a watchdog over Stewart Airport development and has steadfastly lobbied to influence the planning process. SPARC does not oppose airport expansion and development; its focus is to preserve the 7,000 acres (2833 hectares) west of Drury Lane" (SPARC website). SPARC was an active stakeholder throughout the development of the Stewart Airport Access Improvement Project.

### Project Description

In 1992, New York State Thruway Authority (NYSTA) was authorized and directed by the State Legislature to construct the Stewart Airport Access Improvement Project "to provide direct access to Stewart International Airport from interstate eighty-four in the vicinity of the airport." (NYSDOT, 2000). In 2000, New York State Department of Transportation (NYSDOT), in cooperation with the NYSTA, completed an Environmental Impact Statement (EIS) for the Stewart Airport Access Improvement Project.

The Stewart Airport Access Improvement Project (SAAIP) includes an interstate interchange; widening, improvements and realignments to an existing local road (Drury Lane); and a new airport access road. The objectives of the project are to: provide infrastructure improvements which improve access to the Stewart International Airport (SIA), taking into consideration the SIA Master Plan Update; provide a safe and efficient highway system, including minimization of the effect of interstate traffic to and from the SIA on local roadways; stimulate the local economy consistent with local comprehensive plans; minimize environmental impacts (NYSDOT, 2000). Project elements include interchange construction, 4 new bridges, 3.1 miles (5 km) of roadway reconstruction, 1.9 miles (3.1 km) of new roadway construction, and 6.5 acres (26.3 hectares) of wetlands impact.

### Exemplary Ecosystem

This project goes beyond merely meeting the transportation objectives. Many innovative measures were incorporated into the project to protect the local ecosystem from proposed and future impacts and go well beyond typical regulatory requirements.

The 7,000-acre (2833-hectare) Stewart Properties and its associated watchdog organization, SPARC, combined with NYSDOT's creative and innovative project team at the height of NYSDOT's Environmental Initiative presented an unprecedented environmental stewardship opportunity. The end result is an exemplary ecosystem, as recognized by the Federal Highway Administration (FHWA).

The components of the exemplary ecosystem include establishing a 7,000-acre (2833-hectare) state forest, preserving Indiana bat habitat, creating 13 acres (5.3 hectares) of wetland habitat, preserving a rare plant population and establishing a seed bank, creating 12 vernal pools, installing 7 wildlife crossings, reclaiming a shale quarry, and preserving an 8-acre (3.2-hectare) historic property.

The SPARC organization has been supportive of NYSDOT's efforts, writing in their Spring 2007 newsletter, "Overall, there seems to be a good faith effort to be as sensitive and protective of the surrounding wet woodland environment as possible. How very gratifying" (SPARC News, 2007). This epitomizes the goals of NYSDOT's Environmental Initiative to "promote an environmental ethic throughout the Department, advance state and federal environmental policies and objectives, and strengthen relationships with environmental agencies and the public" (NYSDOT, 1999).

**State Forest Establishment**

An integral component of the project is the establishment of the Stewart State Forest.  Approximately 5,300 acres (2145 hectares) of the Stewart Properties was transferred to NYSDEC by NYSDOT in 1999 to establish the Stewart State Forest. The transportation department, recognizing the ecological value of the Stewart Properties, believed that the environmental resource agency was best suited to own and manage the lands as a natural resource, thus relinquishing future development opportunities for the benefit of the natural system. In 2006, NYSDOT transferred an additional 1,600 acres (648 hectares) of fields, wetlands and forests to the NYSDEC to ensure the protection of valuable habitat for several terrestrial species, including the federally endangered Indiana bat (*Myotis sodalis*).

As noted in the Stewart State Forest Unit Management Plan, "The land supports diverse wildlife, including increasingly rare grassland and shrub land bird species, amphibians and reptiles. The old roads and fields provide superior access for hiking, biking, horseback riding and carriage driving, bird watching, snowmobiling, cross-country skiing and snowshoeing, and casual recreation" (NYSDEC, 2006).

By establishing the 7,000-acre (2833-hectare) Stewart State Forest, the future functions and values of the large tract of forested and open lands are retained in an area experiencing heavy development pressure. This tract of natural land provides valuable habitat of many terrestrial and wetland species. The state forest is managed by NYSDEC for plant and wildlife habitat preservation, farming, passive recreation and hunting.

**Indiana Bat Habitat Preservation**

The Indiana bat (*Myotis sodalis*) is a federally-listed endangered species found within the central portion of the eastern United States, from Vermont to Wisconsin, Missouri and Arkansas and south and east to northwestern Florida. The Indiana bat is one of nine bat species found in New York.

Ongoing research by NYSDEC and USFWS in New York has provided a better understanding of the summer foraging and roosting habits of the Indiana bat. Consequently, in 2005, during consultation with NYSDEC and USFWS for a wetland permit modification, concerns regarding possible affects of the project on Indiana bat were raised.

According to NYSDEC, in New York, knowledge of the Indiana bat distribution is limited to known wintering locations - caves and mines in which they hibernate. There are eight hibernacula currently known in Albany, Essex, Warren, Jefferson, Onondaga and Ulster Counties. It is certain that the summer range of this species extends well beyond these counties since the animals disperse to breeding areas and other habitats to feed and raise their young (NYSDEC Fact Sheet).

The Indiana bat was one of the mammals included on the original federal list of Endangered Species. In New York, approximately 13,000 Indiana bats are known to exist in 8 of the 120 sites searched to date (NYSDEC Fact Sheet). While the USFWS has learned a great deal about the wintering population on Indiana bat with standardized biennial counts organized by the NYSDEC Endangered Species Unit, USFWS is continuing to study Indiana bat migratory patterns and summer habitat use within the State (USFWS, 2006).

The Stewart Airport Access Improvement Project area is located approximately 25 miles (40 km) from the closest documented Indiana bat hibernaculum.  Based on information provided by NYSDEC, the closest documented maternity roosting areas to the project are located approximately three miles (five kilometers) from the project corridor (Louis Berger Group, 2005).

After the initial transfer of 5,300 acres (2145 hectares) of Stewart Properties to NYSDEC for the establishment of Stewart State Forest, NYSDOT had retained 2,100 acres (850 hectares) of land to support airport related economic development. In 2006, in response to concerns regarding Indiana bat habitat, NYSDOT, working with the NYS Office of the Attorney General, transferred an additional 1,600 acres (648 hectares) of fields, wetlands and forests to the

NYSDEC to supplement the state forest, thus ensuring the protection of valuable habitat for several terrestrial species, including the federally endangered Indiana bat (*Myotis sodalis*).

This additional land transfer satisfies the USFWS and NYSDEC concerns regarding potential direct, indirect, and secondary impacts of the project and ensures that potential maternity roost trees and summer roosting habitat for the Indiana bat will be sustained. The NYSDOT will retain 600 acres (243 hectares) for future airport-related development and transportation use in close proximity to the new interstate and interchange.

The addition of the 1,600 acres (648 hectares) to the Stewart State Forest integrates environmental concerns into the overall transportation planning process, increases the amount of land available for pedestrian and bicycle recreational use, and demonstrates a commitment to integrating environmental considerations into the NYSDOT's project development process.

**Wetland Protection and Establishment**

*Avoidance and Minimization*

The SAAIP incorporates significant context sensitive measures to avoid and minimize wetland impacts. The alignment of the new road avoids an expansive great blue heron rookery and incorporates measures to avoid and reduce wetland impacts.

The utilization of standard design practices created an impact of over 14 acres (5.7 hectares) of wetland and open water impacts. Employing wetland and terrain context sensitive design measures, the Department was able to reduce the wetlands and open water impacts to 6.5 acres (26.3 hectares). Measures included a change in the standard diamond interchange design to a partial diamond and partial loop ramp, steepening of the roadway slopes, and incorporation of retaining walls to minimize the filling of wetlands.

NYSDOT redesigned the Interstate 84 (I-84) eastbound exit ramp and the I-84 eastbound entrance ramp for Drury Lane as loop ramp configurations to be constructed in the southeast quadrant of the proposed interchange. This eliminated the I84 eastbound exit ramp in the southwest quadrant of the interchange and avoided impacts to approximately 1.3 acres (0.53 hectares) of wetlands within the quadrant.

Along Drury Lane, NYSDOT redesigned the profile and lowered the roadway in several areas to minimize impacts to the wetland system, steepened the embankment slopes to 1-on-1.5 and modified the toeoffill treatments. Additionally, the width of the Drury Lane median was reduced to a minimally acceptable width of four feet in all areas of wetland impact. These changes resulted in a reduction of approximately 1.52 acres (0.62 hectares) of impacts to wetlands.

NYSDOT shifted portions of the alignment of the new airport access roadway north to further avoid and minimize impacts to wetlands along its route and to keep the alignment of the road as close to the existing Crestview Lake causeway as possible, thereby further reducing impacts to open water. Retaining walls and 1-on-1.5 slopes are being utilized to reduce impacts to wetlands even more. The combination of these modifications results in a reduction of approximately 4.52 acres (1.83 hectares) of wetland impact.

The portion of the new airport access road which impacts a large wetland will be constructed using retaining walls to minimize the footprint of the roadway. NYSDOT had evaluated the feasibility of bridging these areas, however, the significant additional cost (additional $10.331 million for a reduction of 1.26 acres (0.5 hectares)) made this option not practicable. The final project design was able to reduce the wetland and open water impacts by more than half (14 acres to 6.5 acres (5.7 hectares to 26.3 hectares)), demonstrating design with natural concepts.

*Wetland Creation/Restoration*

To compensate for the unavoidable wetland impacts, the project team identified suitable sites for compensatory mitigation within the same watershed as the project impacts. Compensatory mitigation included the construction of 11.03 acres (4.46 hectares) of wetlands, 2.0 acres (0.8 hectares) of open water, and 1.37 acres (0.55 hectares) of vernal pools, resulting in an overall mitigation ratio of 3:1.

The wetland mitigation site restores 13 acres (5.3 hectares) of a drained pasture and cropland within the Stewart State Forest. This location provides greater long-term protection to the constructed wetlands and diversity to the overall environment of the state forest. By restoring the wetland within existing state lands, the site requires no additional private land purchase and will be protected in perpetuity under NYSDEC management.

**Rare Plant Protection and Propagation**

Subsequent to the final wetland mitigation site design, a rare plant, purple milkweed (*Asclepias purpurascens*), was identified in the wetland mitigation area. Though not regulated as a rare plant by state or federal resource agencies, purple milkweed is considered rare in the northeast. The Stewart State Forest population represents the area's largest known concentration.

Recognizing the importance of this population, NYSDOT revised the design plans to avoid the majority of the plants. To sustain the plant population, the NYSDOT worked in partnership with the NYSDEC to locate and collect seeds from individual plants that would be lost. On July 21, 2006, representatives of the NYSDOT, NYSDEC, and other volunteers were onsite to transplant the purple milkweed generated from the seed bank into the wetland mitigation area. NYSDEC is currently using this NYSDOT-generated seed bank to grow purple milkweed for transplanting into other portions of the Stewart State Forest.

**Vernal Pool Creation**

To restore the vernal pool system critical for the breeding success of several species of salamanders, NYSDOT consulted with the resources experts to design and create twelve vernal pools throughout the intact forest system. These vernal pools were strategically located within the protected buffer area of state-regulated wetland systems to ensure continued protection of the resource. Each site is located within a secondary growth, mixed oak/sugar maple hardwood forest community (Samanns and Zacharias, 2003).

NYSDOT designed and created vernal pools throughout the intact forest system to facilitate breeding success of several species of salamanders, including Jefferson salamander (*Ambystoma jeffersonianum*), spotted salamander (*Ambystoma maculatum*), and wood frog (*Rana sylvatica*). The twelve vernal pools range in size from 0.04 to 0.33 acres (0.01 to 0.13 hectares), with a combined total area of 1.37 acres (0.55 hectares).

In an effort to encourage colonization and establishment of biotic communities within vernal pools, several essential habitat components were developed and incorporated into the vernal pool design plan. These features are intended to provide amphibians with breeding and developmental microhabitat crucial to successful mitigation efforts (Sammans and Zacharias, 2003).

The design of 12 vernal pool sites incorporates innovative construction techniques to enhance functional value, including the placement of brush piles for cover; tree snags for cover and structure for egg laying; restricting construction operations to avoid disruption to resident populations; and incorporation of leaf litter and organic substrates from impacted wetlands to inoculate the pools with organic matter, micro-flora and fauna as the basis of the vernal pool food chain.

**Wildlife Passage/Habitat Connectivity**

To sustain the natural connectivity of the habitat north of the new airport access road (on the airport runway side of the road) to the vast forest south of the access road, NYSDOT planned and designed wildlife crossing structures under the road. Two oversized conspan structures are included in the road design to allow large mammals, such as white tailed deer, to cross between the forested tracts. Additionally, box culverts have been installed to maintain hydraulic connection between the systems and to provide passage of amphibians, reptiles, and small mammals. The wildlife underpasses and amphibian crossings maintain habitat connectivity for amphibians and larger mammals and are intended to minimize wildlife-vehicle collisions.

*Amphibian Box Culverts*

Three box culverts measuring 4 ft x 4 ft (1200mm x 1200mm) will be installed to connect the wetland systems in the western portion of the new airport access road and to provide safe passageways for breeding amphibians. Amphibian barriers will be installed adjacent to each culvert opening to divert migrating amphibians into the culverts rather than across the roadway (Louis Berger Group, 2002). The culverts will be installed partially below ground surface and filled with native soil material to meet existing ground elevation to provide a substrate suitable for amphibian use. The position of the culverts at the low point in the landscape and opening to an existing wetland should improve the potential for salamander use of the culvert by increasing the soil moisture within the culvert (Samanns and Zacharias, 2003).

Amphibian barriers will be installed in conjunction with each culvert opening to divert migrating amphibians into the culverts rather than across the roadway. The amphibian barriers will extend an average of 164 feet (50 meters) to tie into elevated upland forest sites. The barriers are designed to provide a minimum height of 14 inches (450mm), and the terminal ends of the barrier will be turned back toward the culvert at 45-degree angles. The barrier will be constructed of reinforced concrete to both reduce the need for maintenance and to provide structural support to the roadway embankment (Samanns and Zaccharias, 2003).

*Wildlife Conspans/Culverts*

Two wide conspans 12 ft x 7 ft (3600mm x 2100mm) will be located within the large easternmost wetland system along the new airport access road. Two reinforced concrete pipe (RCP) culverts (3 foot) (900mm) will also be located within the same wetland system, one slightly to the east of the conspans and one slightly to the west. While amphibians may use these culverts in addition to the box culverts, the general culverts are intended to provide passage to a wider assortment of wildlife that may include mammals, reptiles, invertebrates, and fish where permanent water flows (Louis Berger Group, 2002).

The structures will be three sided to provide a natural substrate. The conspans and culverts are located within the western portion of the new airport access road where it crosses through a valley containing a large emergent and forested wetland. In this section, the roadway footprint has been minimized to reduce wetland impacts through the use of retaining walls. The roadway will be approximately 20 feet (6 meters) high above the adjoining ground, forming an effective barrier for wildlife movement. The wildlife passages are expected to provide adequate sites for wildlife movement. The two conspans provide an openness ratio of 0.85, indicating that these structures will be suitable for use by deer, the largest mammal likely to use these crossings (Samanns and Zacharias, 2003).

**Site Reclamation**

One of the goals of the NYSDEC is to reclaim areas within the forest that are not consistent with a forest ecosystem. One such area is an old shale quarry located within the boundary of the Stewart State Forest.

In order to restore the forest ecosystem, the NYSDOT used soil excavated from the wetland mitigation areas (as well as additional off-site soil sources) to bring the former quarry to a more natural grade. The area was seeded with a native seed mix in an effort to integrate the reclaimed land with the surrounding ecosystem and habitat. The natural surrounding topography was used to determine the proposed grading, allowing nature to dictate the proposed grading of the reclaimed land. The final limits, proposed grading, and seed mix were determined through a collaborative effort between NYSDOT and NYSDEC.

After NYSDOT finished the construction portion of the reclamation, NYSDEC began developing a plan to monitor and manage the area. The reclamation of the abandoned shale quarries promotes the restoration and preservation of the Stewart State Forest's ecosystem integrity and function.

**Historic Preservation**

The historic significance of the Stewart Properties is sustained in the preservation and proposed restoration of an eight-acre (3.24-hectare) Colden mansion property as a Scenic and Historic Resource of the State. NYSDOT collaborated with the state Office of Parks, Recreation and Historic Preservation (OPRHP) and the Town of Montgomery to preserve and restore the ruins of a 1767-era mansion associated with the Colden family, one of the preeminent families in New York State history. Constructed of local stone, the Colden Mansion was thought of as the "finest Georgian Home" in the area.

In addition to the mansion, the property contains other sites of historic importance, including ruins of a cook house (summer kitchen), a cistern, barns, wells, and a cemetery. NYSDOT will transfer the property to the town. The OPRHP will work with the town to list the site in the National Register of Historic Places and secure funding for future stabilization and interpretation activities.

The property is commercially-zoned and was previously subdivided for development, but was never sold or developed. The NYSDOT is in the process of transferring ownership of the property to the Town of Montgomery who will proceed with the preservation and stabilization of this significant historic resource. This acquisition and transfer embodies NYSDOT's sensitivity to historic, cultural and community values, and displays innovative opportunities with planning and project development by utilizing the State's ability to acquire a sensitive property for its preservation. The town will ultimately operate the property as a park enhancing the understanding of the unique heritage of the site as well as supporting tourism.

**Collaboration**

The environmental stewardship approach of the project resulted from collaboration with resource agency staff to develop innovative approaches, provide environmental benefits, and offset the environmental impacts resulting from this airport access improvement project. Consistent with the Department's Environmental Initiative efforts, NYSDOT initiated discussions with state biologists from NYSDEC to discuss proactive enhancements such as incorporating wildlife crossings into the project design. During these discussions, NYSDOT biologists and landscape architects offered that vernal pool creation and wildlife brush piles to create suitable habitat for herptiles and small mammals would be positive enhancements in line with the Department's environmental ethic. Discussions with state and federal biologists also resulted in collaborative approaches to protect and sustain suitable endangered Indiana bat habitat and rare purple milkweed populations.

Likewise, the transfer of over 7,000 acres (2833 hectares) of forested and open lands to the state resource agency showed initiative and partnering at its best. Recognizing the value and contribution of these open lands to the surrounding landscape, NYSDOT worked with NYSDEC to transfer these lands to the resource agency that is charged with managing state lands for its natural resources value. This collaboration has resulted in thousands of acres of land available to the people of the state of New York to enjoy and appreciate.

**Ecosystem Benefits**

The people and the area surrounding Stewart Airport have benefited from innovative and proactive efforts on behalf of NYSDOT. The tangible benefits include valuable habitat preservation and creation and historic property preservation. It is important to acknowledge that these achievements stem from the willingness and creativity of talented engineers working closely with Department environmental and landscape architecture staff and resource/regulatory agency biologists. Though environmental professionals may envision innovative solutions, it is the project engineers that are able to make these ideas come to fruition in the design and construction of the project. This multi-disciplinary team approach is essential to the success of a project.

Ecosystem benefits are not free and not everything can be done. Each decision needs to consider the associated cost and the value of the resource. When the multi-disciplinary team of engineers, environmental staff, landscape architects, and program managers work well together, the project team can make well-informed, fiscally wise, balanced, and environmentally sensitive decisions, resulting in exemplary ecosystems.

## Future Research Opportunities

NYSDOT has made a commitment to follow through on each element of the ecosystem initiative for this project. In addition to the standard 5-year monitoring period for the wetland mitigation site, NYSDOT has committed to a 10-year monitoring program for the vernal pool sites and wildlife passages.

To address issues relating to herptile crossings, NYSDOT initiated a four year research project. In the spring of 2005, the State University of New York College of Environmental Science and Forestry (SUNY-ESF) was awarded a contract entitled "Effects of New York State Roadways on Amphibians and Reptiles: Research and Adaptive Mitigation Program." This research project is funded through the Federal Highway Administration (FHWA) Statewide Planning and Research (SPR) program. The study duration is scheduled for four years; NYSDOT's share of the project cost is $189,000 (Nelson, et al., 2005). NYSDOT is also looking to collaborate with a local university to conduct research into the function and amphibian colonization of the created vernal pools.

## References


Louis Berger Group, 2002. Stewart International Airport Access Improvement Mitigation Monitoring Plan. June 2002.

Louis Berger Group, 2005. A Biological Assessment of the Stewart Airport Access Improvement Project, New York State Department of Transportation Region 8. August 24, 2005.

Nelson, D. A., M. E. Papin and T. Baker, 2005. Quick Fixes: Working Together to Address Herptile Road Mortality in New York State IN: Proceedings of the 2005 International Conference on Ecology and Transportation, Eds. Irwin, L., Garrett, P., McDermott, K. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 90-93.

NYSDEC, 2006. Stewart State Forest Unit Management Plan, Towns of Montgomery, New Windsor and Hamptonburgh and the Village of Maybrook. December 2006.

NYSDEC Fact Sheet. Indiana Bat Fact Sheet. http://www.dec.ny.gov/animals/6972.html

NYSDOT, 1999. Engineering Instruction (EI) 99-026, Environmental Initiative Guidelines and Procedures. July 1999.

NYSDOT, 2000. Final Environmental Impact Statement for Stewart Airport Access Improvement Project.

Samanns, E. and S. Zacharias, 2004. Mitigating potential impacts of herpetile habitat loss and fragmentation from new roadway construction in Southern New York State. IN: Proceedings of the 2003 International Conference on Ecology and Transportation, Eds. Irwin, L., Garrett, P., McDermott, K. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 450-466.

SPARC News, 2007. The Stewart Park and Reserve Coalition Bulletin, Spring 2007.

SPARC Web site. Stewart Park and Reserve Coalition. http://www.frontiernet.net/~sparc/

USFWS, 2006. Indiana Bat Project Review Fact Sheet, New York Field Office, July 2006.



**Acknowledgements:** The authors would like to thank Bill Gorton, Region Design Engineer, Rashid Shariff, Engineer-in-charge and Ed Samanns, Louis Berger Group for their support and involvement in the project and assistance in preparation of this paper and presentation.



**Biographical Sketch:** Debra Nelson joined NYS Department of Transportation in 1992 and is the manager of the water/ecology section of the NYSDOT Environmental Analysis Bureau in Albany, NY. Debra is a Certified Ecologist, Professional Wetland Scientist, and member of the Transportation Research Board Committee on Ecology and Transportation.

Lisa Weiss is the Environmental Zone Manager for the Downstate Zone of NYSDOT and Regional Landscape Architecture/Environmental Unit Supervisor for NYSDOT Region 8 in Poughkeepsie, NY. Lisa is a Registered Landscape Architect.

## Streamlining ESA Section 7 Consultations: Bedell Street Bridge Project, Del Rio, Texas

**Allison Arnold** (512-490-0057, Allison_arnold@fws.gov), Section 7 Lead, Austin Ecological Services Field Office, U.S. Fish and Wildlife Service, 10711 Burnet Road, Suite 200, Austin, TX, Fax: 512-490-0074 USA
**Clarence Rumancik**, Environmental and Transportation Planning Engineer, FHWA, Austin, TX USA
**Charlotte Kucera**, Fishery Biologist and Oregon Department of Transportation Liaison, NOAA-Fisheries, Portland, OR USA

Pursuant to the 2005 transportation bill, Texas and four other states developed strategies to streamline transportation consultations with environmental regulatory agencies. In 2006, the U.S. Fish and Wildlife Service (Service) proposed and utilized a stepwise expedited timeline for the Bedell Street Bridge Replacement project where the Federal Highway Administration and the Texas Department of Transportation (FHWA/TxDOT) would develop appropriate Section 7 documents through collaboration and through a series of checks and balances with the Service along the way. The intent was to significantly expedite the Section 7 consultation essentially placing the control of the consultation schedule and most of the workload with FHWA / TxDOT. This partnership-based approach was designed to streamline the consultation process.

The project site is located on Bedell Street adjacent to Moore Park at San Felipe Creek in the City of Del Rio, Val Verde County, Texas. TxDOT proposed to replace an existing one lane bridge on Bedell Street, which crosses San Felipe Creek adjacent to the U.S. 277 bridge. The project area includes the entire bridge (figure 1).

The existing bridge, originally constructed in 1935, is a one lane bridge with structural deficiencies that include cracking and scaling of the deck and superstructure, scour of the substructure and has a substandard bridge sufficiency rating. Primarily, the existing bridge services the adjacent city park and nearby residents.

The purpose of the project was to construct a structure that provides for two-lane traffic, guardrails, sidewalks for pedestrian traffic, and a safer and more efficient stream crossing. The new structure will span San Felipe Creek and consist of pier and beam construction.

Devil's River minnows (*Dionda diaboli*), a threatened species, are known to occupy the project area and could be adversely affected by sedimentation and turbidity resulting from the deconstruction of the existing structure and installation of the new structure, which necessitated formal section 7 consultation pursuant to the Endangered Species Act of 1973, as amended (ESA).

FHWA, TxDOT, and Service staff met early in the process to discuss the project design and potential effects to the Devil's River minnow. It was at this time that the Service, TxDOT, and FHWA determined that this project would be a good candidate for the proposed pilot streamlining consultation process being developed. The project was small in geographic scope and not complex, effects were anticipated to be minimal, there was no significant risk of jeopardy to the species, and there was an urgency to complete consultation quickly to meet the letting date.

Figure 1. Bedell Street Bridge with U.S. 227 in the background.

A minimal number of personnel were assigned to this consultation representing the TxDOT Laredo District, TxDOT Environmental Affairs, Service Section 7, and environmental coordination from FHWA, or four in all. Designating only a few staff greatly facilitated communication and efficient processing of documents through each agency's appropriate chain-of-command. Any other parties interested in the project communicated through their appropriate agency contact.

Overall, the pilot strategy worked efficiently and significantly expedited the Section 7 consultation from the traditional 135 days to 45 days, collectively. Based on the results of this consultation, an anticipated schedule was created (table 1). Due to the focused communication and collaborative efforts among the four agency/office representatives, duplication was avoided and other steps in the process were abbreviated and achieved much faster.

Table 1: Anticipated Schedule of Consultations Utilizing the Streamlined Process

| | Time | Primary Responsibility |
|---|---|---|
| Picking a Project | 15 - 30 days | TxDOT / FHWA (some Service) |
| Requesting concurrence for No Jeopardy | **15 - 30 days** | TxDOT / FHWA (some Service) |
| Issuing Concurrence for No Jeopardy | **2 days** | Service |
| Completing BA in BO format | **30 days** | TxDOT w/ Service Guidance & FHWA Review |
| **Steps in bold simulate the typical 135 days allotted to the Services pursuant to ESA and are effectively under the control of FHWA / TxDOT (max 78 days)** | | |
| Service review of draft BA prepared by TxDOT | **5 days** | Service |
| Service review of final BA submitted by FHWA | **10 days** | Service |
| FHWA / TxDOT review of draft BO | 10 days | TxDOT / FHWA |
| Issue final BO | **1 day** | Service |

In summary, the pilot process produced direct benefits to all parties, fostered collaboration, established a better understanding of each a agency's process and mandate, and is a good process for projects that may cause some, but not substantial, take to listed species. Many routine transportation projects could utilize this process and reduce the consultation time significantly. By streamlining the consultation process for routine projects, more time can then be spent on more complex transportation projects.

The Service and TxDOT reported these results to FHWA to facilitate discussions on whether FHWA would be interested in implementing this process statewide and to discuss strategies on how all agencies can better facilitate consultations over the long term. Results from this streamlined pilot project were also presented through a panel compiled of Service, FHWA, and TxDOT staff at TxDOT's 2006 Environmental Coordinator's Conference. The pilot project and streamlining process was well received and is an excellent example of cooperative conservation.

Currently, an additional transportation project is utilizing this process. Pending that consultation, the Service, FHWA, and TxDOT will continue to meet to discuss potential statewide implementation of this process.

**Biographical Sketches:** Allison Arnold, USFWS, Austin, Texas. Completed a B.S. in Wildife and Fisheries Sciences from Texas A&M University, College Station, Texas and an M.S. in Wildlife Science from New Mexico State University, Las Cruces, New Mexico. Allison is currently the Section 7 lead for the Service's Austin Ecological Services Field Office and is the primary point of contact for transportation planning efforts involving the Service in Texas.

Clarence Rumancik, FHWA, Austin, Texas. Received a B.S. from the University of Texas in Civil Engineering in 1991. Clarence is a licensed professional engineer in California and Texas. Currently, Clarence serves as an environmental and transportation planning engineer for the Houston and Austin metropolitan areas for the Federal Highway Administration.

Charlotte Kucera, NOAA-Fisheries / ODOT (formerly TxDOT), Portland, Oregon. Holds a B.S. in Biology from the University of Notre Dame and an M.S. in Marine Science from the University of Texas. Charlotte worked for the Environmental Affairs Division of the Texas Department of Transportation as a statewide Environmental Specialist for four and a half years (2002-2006) before joining the National Marine Fisheries Service. She is currently a Fishery Biologist with the NMFS and an Oregon Department of Transportation liaison in Portland, Oregon.

Chapter 2

# Ecological Impacts of Other Modes

## Impacts of Ferry Terminals on Juvenile Salmon Movement along Puget Sound Shorelines

**R.M. Thom** (360-681-3657, ron.thom@pnl.gov), staff scientist; **S.L. Southard; G.D. Williams; J.D. Toft; C.W. May; G.A. McMichael; J.A. Vucelick; J.T. Newell;** and **J.A. Southard**; Battelle Memorial Institute, Pacific Northwest Division, 1529 West Sequim Bay Road, Sequim, WA 98382, Fax: 360-681-3681 USA

**Abstract**

This study was sponsored by the Washington State Department of Transportation and conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

This study used both standardized surveys and innovative fish tagging and tracking technologies to address whether WSF terminals alter the behavior of migrating juvenile salmon, and if so, which attributes mediate abundance patterns or behavioral changes. Results showed that juvenile salmon were observed most frequently adjacent to ferry terminals, but were also observed far from and underneath the terminals. In some situations, juvenile salmon aggregated near the edge of the ferry terminal OWS. Variations in habitat, as mediated by tidal stage (affecting current magnitude and direction, light under structures, water level) and time of day (light level, sun angle, cloud cover), likely affect salmonid movement. Juvenile chum were observed to remain on the light side of a relatively sharp light-dark “edge” over a short horizontal distance (e.g., five meters). These observations demonstrate that the shading caused by ferry terminals and other OWS characteristics can deter or delay juvenile salmonid movement, and that this effect may be decreased at low tides when ambient light can better filter beneath the terminal structure. Recommendations are made concerning the design and operation of WSF terminals with regard to minimizing the undesirable impacts of OWS on juvenile salmonid movement as well as additional research.

The full report can be viewed at: http://www.wsdot.wa.gov/Research/Reports/600/648.1.htm

# Kennedy Space Center (KSC) Launch Pad Avian Abatement Efforts Including Related KSC Road Kill Reduction Effort

**Roland Schlierf** (321-867-5827, Roland.Schlierf-1@nasa.gov), NASA Project Manager, UB-E, Kennedy Space Center, FL 32899 USA

**Ron Hight** (321-861-0667, Ron_Hight@fws.gov), Refuge Manager, Merritt Island NWR, P.O. Box 6504, Titusville, FL 32782 USA

**Stephen Payne** (321-861-9322, Stephen.J.Payne@nasa.gov), Shuttle Test Director, Launch and Landing Division, PH-L, Kennedy Space Center, FL 32899 USA

**John Shaffer** (321-867-8448, John.P.Shaffer@nasa.gov), NASA Environmental Program Branch, TA-C3, Kennedy Space Center, FL 32899 USA

**Brad Missimer** (321-476-3722, William.Missimer-1@ksc.nasa.gov), Manager, Facility Support Services, Space Gateway Support, SGS-5030, Kennedy Space Center FL 32899 USA

**Christopher (Glenn) Willis** (321-861-6290, Christopher.Willis@jbosc.ksc.nasa.gov), Entomologist, Pest Management/KSC Landfill/Bridge Tenders, Yang Enterprises, Inc., P.O. Box 21003, Yang-336, Kennedy Space Center, FL 32815-0003 USA

**Abstract:** While birds might seem harmless, there's a good reason for the concern. During the July 2005 launch of Discovery on mission STS-114, a vulture soaring around the launch pad impacted the shuttle's external tank just after liftoff. With a vulture's average weight ranging from 3 to 5 pounds, a strike at a critical point on the Shuttle -- like the nose or wing leading thermal protection panels -- could cause catastrophic damage to the vehicle. The foam chunk that fatefully struck Columbia's wing in 2003 weighed only 1.7 pounds. (Cheryl L. Mansfield "Bye Bye Birdies" 2006) To address this issue, NASA formed an "Avian Abatement Team". The team goal is to have safer Shuttle missions by reducing the vulture population at KSC near the pad area thereby reducing the probability of another vulture strike during a Shuttle launch. (Linda Herridge "It's a Jungle Out There" 2006, Photo Courtesy of NASA)

One key strategy is to monitor and understand bird activity at KSC. Existing KSC bird monitoring programs were studied and enhanced by adding biologist bird observations near the launch pads. New radar and video imaging systems were added to electronically monitor and track birds at the pads. These new systems now help the KSC Shuttle launch director determine if it is safe to launch based on bird count and location.

Another key strategy is to reduce the bird population at the launch pads. New sound deterrent systems were evaluated and tested for potential installation at the pads to scare large flying birds away from the pads just before launch. Since it was a vulture that the shuttle struck back in 2005 and since the KSC vulture population is unusually high, a special emphasis was placed on reducing the KSC vulture population. A vulture trap and release program was tested, but results were inconclusive. Vulture experts considered this trapping to be potentially detrimental because the related baiting could attract even more vultures to KSC. NASA abandoned this part of the vulture reduction effort. Other efforts like the use of effigies and chemical repellants also failed. The team consulted with experts at Walt Disney World and the Avon Park Air Force Range, and focused on why the vulture population was so high at KSC in the first place. The answer appears to be an excess road kill food supply.

KSC is overlaid with 140,000 acres of the Merritt Island National Wildlife Refuge. This is a good arrangement because both organizations need a lot of remote land. However, this land overlay has significantly contributed to refuge loss of wildlife. Vehicle collisions are the number one killer of Florida's wildlife and over 12,000 KSC employees must drive through the wildlife refuge to get to work. In the summer of 2006, KSC found that this generates an incredible amount of road kill and excess vulture food supply averaging over 100 dead animals at over 1000 pounds every month. KSC began an effort to prevent and quickly remove road kill. Through attrition, KSC plans to bring their vulture population back to normal levels. KSC began educating their workforce about this problem via e-mails, bulletins, posters, stickers, call-in badge cards, educational/entertaining videos, meetings, road signs, educational outreaches, and a central web site (http://environmental.ksc.nasa.gov/projects/roadkill.htm). The workforce appears to be responding strongly because KSC road kill numbers declined sharply in July, but other unknown environmental factors may be contributing. The workforce is also calling in road kill for rapid pickup. For the remainder of the Shuttle Program, a KSC contractor picks up road kill within 2 hours of each call-in during first shift five days a week. The contractor also patrols the roads and picks up road kill for 2 hours every morning independent of call-ins. The contractor marks each road kill with GPS for future analysis and potential roadway wildlife mitigations like dry culverts, wildlife over passes, fencing, or wildlife crossing sign positioning. Wildlife crossing signs have already been specially designed and in April 2007 were strategically placed based on KSC road kill "hot spot" GPS data.

Road kill is something that the Refuge has wanted to reduce for over 40 years. NASA is now clearly on board to help achieve that goal, but NASA ultimately cares about avoiding future Shuttle bird strikes. It will be hard to measure vulture reduction at KSC and overall bird reduction at the pads. However, we have very positive early anecdotal results. Some employees have reported seeing fewer vultures at KSC and seeing more vultures in their neighborhoods. Employees that clean bird mess off the launch pads report it takes them 75% less time to clean the mess, indicating there are likely fewer birds at the pads. The Shuttle has not hit any birds during subsequent launches. The avian abatement team effort appears to be making some long lasting differences toward both Merritt Island National Wildlife Refuge mission success and NASA mission success, but only time will tell.

**Project Background**

I have always had a strong passion for nature and the great outdoors, so during my 20 years with NASA at the Kennedy Space Center (KSC) I have always enjoyed and been keenly aware of the KSC overlay of land with the Merritt Island National Wildlife Refuge (MINWR). Every morning as part of my daily commute to work, my favorite part is the drive across the Banana River from Cape Canaveral Air Force Station to the Kennedy Space Center. This is also one of the four entrances to the MINWR where our work force gets a daily spectacular view of the launch pads, Vehicle Assembly Building (VAB) with it's large American Flag and NASA emblem painted on its side, and all of our abundant wildlife like alligators, manatees, dolphin, otter, fish, ducks, ospreys, hawks, bald eagles, wild hogs, and deer on both sides of the NASA Parkway as far as the eye can see. As part of the NASA Leadership Development Program (LDP) Class of 2005/2006, I had the unique opportunity, as a NASA engineer and project manager, to work outside of my own agency in a completely different field. Understandably, I was ecstatic when Mr. Ron Hight, Refuge Manager of the US Fish & Wildlife Service (US FWS) Merritt Island National Wildlife Refuge (MINWR), agreed to take me under his wing in partnership with the NASA LDP Program. I was finally on the other side of the fence, so to speak, in the long standing NASA/ US FWS MINWR partnership. My diverse assignment was to be the US-FWS representative to NASA for the STS-121 "Avian Abatement Team" which sought to reduce the probability of another Shuttle vulture strike which had occurred on the previous STS-114 Shuttle mission.

**Avian Abatement Team & Related Tasks**

Our multi-agency/multi-company team was led by Steve Payne, a NASA test director in the Shuttle Processing directorate. Concerning our team, Steve has been quoted in NASA articles as saying "We don't want the vehicle to get damaged in any way and while this program does have some 'chuckle factor' to it, we do take it seriously." Our team included Space Gateway Support, Yang Enterprises, InDyne Inc., United Space Alliance, ASRC Aerospace, Dynamac Corp., and the U.S. Fish and Wildlife Service. Even a veterinary pathologist, Dr. Scott Terrell, from Disney's Animal Kingdom in Florida, which has a bird control program, was invited to the center to share wildlife management expertise. Air Force Avon Park experts were also consulted on how they moved vulture roosts. This team assessed, developed, and implemented new radar systems that can now track birds at the pad, new software for bird tracking based on camera images from remote cameras that have been placed around the launch pads to track the vultures, and new non-lethal sound systems that scare flying birds away just before launch. Our team also tested a new effigy program, chemical deterrent program, and new vulture trap and release program all of which were eventually found to be ineffective and were abandoned. Many people have asked us why we just don't shoot the vultures near the pad. First of all, shooting vultures close to launch time would not be a good idea because of all of the explosive propellants in the area at that time. But ultimately, vultures are protected under the Migratory Bird Treaty Act. It is illegal to harass, or in any way harm vultures without a permit from the Fish and Wildlife Conservation Commission. For this reason, only non-lethal deterrents were attempted. Several failed, some are in use, but their effectiveness is still under evaluation. As a side note for those who would argue to kill all the vultures, we must remember that vultures are a critical part of our environment. Robert Koenig wrote a very interesting and alarming article for Science Magazine where he describes "a catastrophic die-off of vultures in South Asia and recent sharp declines in some populations in Africa which have focused research on this often reviled but majestic bird". He also describes what continents around the globe like Europe are doing to save certain species of these critical birds "by establishing sanctuaries, 'vulture restaurants', and monitoring campaigns". (Koening, Robert "ORNITHOLOGY: Vulture Research Soars as the Scavengers' Numbers Decline" 2006)


**Monitoring and Understanding KSC Bird Activity**

After forming our team, an important first step was to monitor and understand the bird activity at KSC. Existing KSC bird monitoring programs were studied and enhanced by adding biologist bird observations near the launch pads. New radar systems were added to electronically monitor and track birds at the pads. These new radar systems now help the KSC Shuttle launch director determine if it is safe to launch based on bird count and location.

**Detecting Birds Using New Radar Capability**

By far the best final line of defense is bird detection radar, already proven effective for aviation, where the threats posed by bird strikes have long been a problem.

The image at the right is the avian radar in position at Launch Complex 39. It offers the ability to monitor either of the two shuttle launch pads during a countdown. Technicians adjust the system's two customized marine radars that provide both horizontal and vertical scanning. (Photo Courtesy of NASA of test unit used during STS-121 and STS-115; permanent unit is larger and was used for STS-116)

The vultures are more active during the day as they search for food and circle high into the bright blue Florida sky, soaring on the thermal gradients. To mitigate the danger, an avian radar system known as “Aircraft Birdstrike Avoidance Radar” is in position to track their movement around the launch area and relay the data to launch control experts. The system was developed by a company called DeTect of Panama City, Fla., which primarily has served the commercial aviation industry and the military.

The image at the right was taken inside the Launch Control Center at the Kennedy Space Center. Data relayed from the avian radar aided by camera images will help controllers recognize when any large birds are in dangerously close proximity to the vehicle and hold the countdown when necessary. (Photo Courtesy of NASA. The left laptop shows the tracking camera display and the right laptop is for the horizontal radar display.)

The goal is to provide the launch team with real-time detection for on-the-spot launch decisions up to one minute before liftoff. To do that, the system uses two customized marine radars -- one for horizontal scanning and one for vertical scanning. While vultures have been identified as the main threat, the radar system has enough power to detect even small birds.

After 3 separate standalone tests, the STS-121, STS-115, and STS-116 missions provided the first successful uses for the technology during actual shuttle launches. The unit’s location will allow it to monitor either of the launch pads at Launch Complex 39 during future space shuttle launches, providing a new margin of safety for astronaut crews. (Cheryl L. Mansfield “Bye Bye Birdies” 2006)

**Detecting and Tracking Birds Using New Video Imaging Software Capability**

Using existing video cameras at the pad, a novel system was developed that captures video, processes the images, identifies birds, combines together the data from all video sources, and presents the 3D positions of the birds in real time to allow birds to be monitored and tracked within the pad perimeter. This system is complementary to the new radar system described above. Using cameras, the new software can distinguish pad structure from moving objects like large birds. The new system is able to provide azimuth, elevation, distance, and direction in real time. The resultant trajectory data are presented in a variety of formats, including a 2D overhead view (similar to radar) and 3D view with pan and zoom capabilities similar in style to that of Google Earth. The system has the capability to record the time-tagged 3D positions of birds for subsequent analysis or playback. The system can easily be scaled up by including additional camera views. This project development was led for our team by John Lane and Chris Immer who work for ASRC Aerospace, one of our on-site contractors.

**Monitoring to Measure the Baseline Problem and to Measure the Effectiveness of our Mitigation Efforts**

Rebecca Bolt, DYNAMAC Wildlife Ecologist, is leading our team effort to measure our vulture activity at our two shuttle launch pads. Her group counted vultures sitting and flying in the pad perimeter for approximately the past year. I asked her if we could make any conclusions yet on bird reduction at the pad, but as is often the case with animal activity, the jury is still out. It often takes years to find any conclusive results in wildlife activity. The data will continue to be collected and only time will tell.

**Educational Awareness**

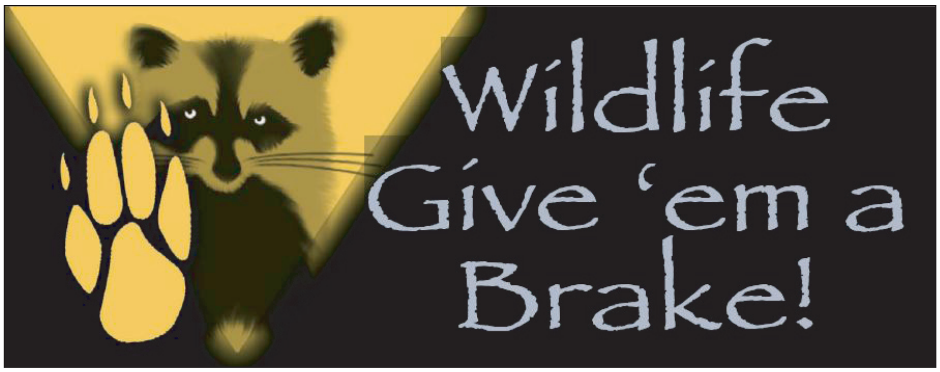
I volunteered to lead our team’s educational awareness effort to the KSC workforce and local visitors concerning the existence of the wildlife refuge overlay of land with KSC property, related road kill prevention, and road kill call-in to help reduce our excess vulture population and avoid another Shuttle bird strike. I collected and analyzed road kill data, designed and installed new strategically placed wildlife crossing signs, and designed and distributed road kill prevention and call-in stickers, posters, and badge cards. (See the NASA designed call-in poster/sticker image on the right and the raccoon road kill prevention poster/sticker image & call-in badge card design below)

**Get Your Leaders Trained Properly First!**

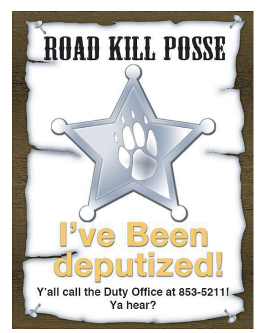

Early in my assignment I received some critical training at the USFWS National Conservation Training Center in Shepherdstown, West Virginia. It was a 3-day course entitled “Innovative Approaches to Wildlife/Highway Interactions” put on by Glenn Gravatt and instructed by Sandra Jacobson, Wildlife Biologist, and Terry Brennan, Forest Engineer. A valuable part of the training was having instructors simultaneously providing insights from both the biological sciences/human behavior and civil engineering perspectives along with having fellow classmates from all over the country providing their own positive and negative experiences. Some of this training was directly applied for our road kill monitoring and wildlife crossing efforts in the short term. Any potential long term mitigations like dry culverts, overpasses, or underpasses will require more data to ensure effectiveness and funding. Two very helpful websites were provided during this training. The first website was the “Wildlife Crossings Toolkit” found at http://www.wildlifecrossings.info/. This site was designed for professional wildlife biologists and engineers faced with integrating our highway infrastructure and wildlife resources. The second website was the “Critter Crossings” website found at http://www.fhwa.dot.gov/environment/wildlifecrossings/index.htm. This site was built for anyone interested in protecting wildlife along highways and the habitats that sustain them. Another source of inspiration for me and the potential of our new effort was an article on the success Canada has had in some of their Road Kill reduction efforts as described by Lawrence Herzog in "Road kill: cars and animals don't mix" in Canadian Driver dated April 7, 2005. (Ref. http://www.canadiandriver.com/articles/lh/roadkill.htm)

**Use of Humor, Shock, and a Tug at the Heart**

It helps to have great creative people. Early in our educational awareness program, we asked Lynda Brammer, KSC Contractor from InDyne Inc., to help us design our related posters, stickers, and call-in cards. In "Shuttle/Vulture," a cartoon-like sticker/poster design, our team used humor to inspire our target audience to call in road kills at KSC for rapid pickup. In the "Raccoon" design (Image provided by NASA), we tugged at the heart to inspire our drivers to be more careful not to "impact" our imperiled wildlife. In February 2007, our "Raccoon" design that declares "Wildlife Give 'em a brake!" won the local Gold ADDY® Award and is moving on to compete at the regional and National level. The ADDY® Awards are sponsored by the American Advertising Federation (AAF) and honor excellence in advertising and cultivate the highest creative standards in the industry.




We used humor as our team became affectionately called "The Road Kill Posse" as we daily "Deputized" our workforce into action. When folks teased me about sending the road kill to the cafeteria, I just let them peruse my copy of "The Original Road Kill Cook Book" by D.R. "Buck" Peterson published in 1985 that I picked up during a hike on the Appalachian Trail. A link to a short French humorous video was shown to our workforce during our educational outreach activities. It shows an innovative way to help wildlife cross the highway and can be found at http://www.florida-habitat.org/wiki/pdf/transportation-infrastructure-and-wildlife-conservation/ecoalternatief.asf/view. The popular GEICO Squirrel commercial was also referenced and can be found at http://video.google.com/videoplay?docid=-149271128122026657.



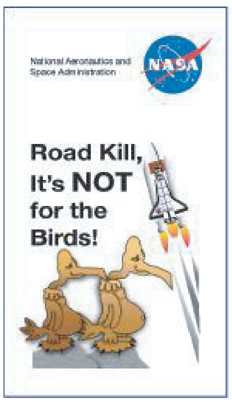

During my "Highway/Wildlife Interactions" training, our class viewed a video where an artist, fed up with excess road kill, used actual road kill to cast his artwork. Many visitors to his gallery were shocked. We also tried some shock tactics. I think many of us can become complacent about road kill and just accept it as a part of life in the modern world, but the cumulative effect can be staggering once measured and put out in the open. We sent e-mails and posted data in our main building lobbies and our web site concerning our cumulative road kill at KSC. We sometimes averaged killing over 100 animals a month weighing over 1000 pounds. This information often shocked some of our target audience. Hopefully we shocked some of them out of complacency and into action such as responsible driving and recruitment of other drivers to do the same. Road kill will never be zero in our modern society, but it can certainly be reduced through educational awareness, change of driving habits, and changes in our roadways.

**Multi-Media Approach**

One key strategy that I learned during my "Wildlife/Highway Interactions" training was to create a consistent image and message and to promote it in many different ways. I created and presented a humorous educational multi-media slide show on the subject. I designed and led an educational, interpretive 3-table display and brought it to all of the major KSC building lobbies via our "Road Show". During our "Road Shows", we distributed Merritt Island National wildlife refuge fliers found at http://www.fws.gov/merrittisland/publications/mrtcon.pdf. We distributed Refuge fliers and displayed taxidermy animals like otters, alligators, and turtles. We provided information on the nearby overlaid U.S. Park Service National Seashore and provided their web link found at http://www.nps.gov/cana. We displayed and discussed our road kill map and statistics (See Appendix A) and overlaid them on an area map using the GPS data. We also displayed and promoted our new wildlife crossing sign design and positioning. With the recruitment and help of fellow NASA employees and Merritt Island Wildlife Association volunteers like Ed Ronco, Al Brayton, and Jim Stahl, we talked to over 1000 people throughout the area on this important Shuttle safety issue and how we can improve safety by driving carefully to reduce road kill and to report any road kill that we see. These same volunteers also distributed our stickers at the MINWR Visitor Center so that the general public who had access to drive on the public portion of the Refuge and KSC would also be aware of and support our effort. With the help of our graphics department, we designed and distributed in total over 2000 of each sticker, over 2000 badge cards, and over 500 of each poster. Enlarged posters were created and displayed in the building lobbies. Our web site was visited over 5000 times. These visits are not entirely from within our gates. Our web site has generated e-mails and requests for stickers from several teachers in classrooms from around the country and even some international activity.

I wrote two local articles on the subject. The first article was for the KSC Spaceport News entitled "National Wildlife Refuge, KSC peacefully coexist, and it can be found at http://www.nasa.gov/centers/kennedy/pdf/156371main_sep-1color.pdf. The second article was for the "Habi-Chat" Newsletter of the Merritt Island Wildlife Association entitled "To Kill or Not to Kill, That is the Question" and it can be found at http://www.nbbd.com/npr/miwa/Habi-Chat/06summer-habichat.pdf. KSC also has a weekly bulletin and daily news e-mail that were used regularly to continue sending our message to our workforce drivers. There was also a related interview of my US FWS mentor, Marc Epstein, and myself conducted by Lyn Millner that aired for the National Public Radio program "Weekend America". There were also several local news programs and related interview with our Team Members by local newscasters. Most of these are ways to "push out" information. In order to provide a means for our workforce drivers to "pull out" information, we also created a dedicated web site. A graphic of our web site can be found in Appendix B and at (http://environmental.ksc.nasa.gov/projects/roadkill.htm). At this web site we promoted our main message of "You've Been Deputized!" Visitors to this site could view our video, go to related links, order stickers, posters, and badge cards, and study our latest road kill data & see our wildlife crossing sign design.

**Collecting Road Kill and Road Kill Data at KSC**

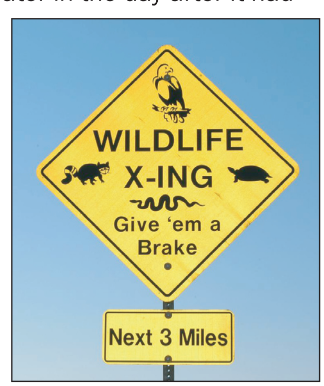




All KSC and Cape Canaveral Air Force Station (CCAFS) road kills are now being picked up, double-bagged, disposed of, and the road kill site is logged in a database using Global Positioning System (GPS) information so that animal/driver interactions can be even better understood. This way even more effective mitigations can be implemented and measured over time. I came to learn about these latest tools and methods of map marking and overlaying GPS waypoints by working with the brave firefighters of the MINWR who use a similar system to track and more effectively fight fires.

Since May 2006, the workforce has been calling in road kill for rapid pickup. For the remainder of the Shuttle Program, our KSC contractor now picks up road kill within 2 hours of each call-in, during first shift, five days a week. The contractor also patrols the roads and picks up road kill for 2 hours every morning independent of call-ins. The contractor marks each road kill with GPS for future analysis and potential roadway wildlife mitigations like dry culverts, wildlife over passes, fencing, or wildlife crossing sign positioning. Wildlife crossing signs have already been specially designed and will be strategically placed based on KSC road kill "hot spot" GPS data.

This portion of the effort is being led by Yang Enterprises entomologist Glenn Willis on KSC, Derick Fowler on Cape Canaveral Air Force Station, and Space Gateway Support Manager Brad Missimer. This portion of our team is affectionately called "The Road Kill Posse" and ideally includes every driver on the refuge as we encourage them to drive carefully to avoid road kill, but to call it in if they see any. A road kill reporting call-in number was put into effect and displayed at our KSC gate entrance marquees. One of our drivers even captured and distributed via e-mail a photo taken of several vultures sitting on our marquee sign, as if they were protesting our efforts to pick up their breakfast. This image is displayed on our web site. Business cards were also designed and handed out with our logo design and call in number. In April 2007, we completed our 1st complete year of this program and the related data are summarized below. Upon sending me this latest report covering our first year, Glenn noted that "As you can tell from the data, (See Appendix A) we have picked up a substantial quantity of carrion during our first year and our success has benefited greatly from the daily calls by KSC drivers. We have calls every day that help us to pinpoint vulture activity and dead animals that could contribute to an increased vulture population. Callers have really helped us locate and prioritize high profile incidents before vultures have an opportunity to locate them. I recall one instance when an unfortunate otter generated over 5 calls before we could get out and remove it. We even received calls later in the day after it had been picked up!" I personally remember that day because I received over 20 calls that day because so many people knew that I was leading the overall effort. Otters must really have a special place in the hearts of our workforce! Glenn also said that "The wildlife awareness program has generated generous support of this Shuttle flight safety program and I fully expect that it will continue."




**Strategically Designing and Placing Wildlife Crossing Signs**

During my "Wildlife/Highway Interactions" training, I learned that the effectiveness of wildlife crossing signs is marginal. The placement of a single deer crossing sign at the site of 1 accident is not likely to take care of a major wildlife crossing problem. I learned that it is critical that the design and placement of the signs be targeted for the specific wildlife crossing situation and even then it is hard to achieve significant results. It was obvious that the couple of deer crossing signs sprinkled throughout our Center/Refuge was not going to influence our drivers significantly for our "Avian Abatement Team" effort. Based on the road kill data I designed a custom wildlife crossing sign.

At the top of our wildlife crossing sign is the image of a bald eagle. Our Center/Refuge employees are very aware and proud of the fact that we have always had several eagle nests in our area. Gladly, no bald eagles are believed to have been killed by vehicles on the MINWR recently. However, while working at the Refuge, I read a report that said "At least 5 adults and 1 fledgling have been recovered in the past 27 years in the vicinity of Merritt Island (MINWR Annual Narrative Reports [1963-1990]) that were known or thought to have died of injuries resulting from vehicle collision; all occurred during the nesting season. (Hardesty/Callopy "History, demography, distribution, habitat use, and management of the Southern Bald Eagle on Merritt Island National Wildlife Refuge, Florida, 1990) This is probably somewhat due to the fact that bald eagles have been seen sometimes feeding on carrion while holding a circle of vultures at bay. I witnessed this myself my first week working on the Refuge. (Reference image below taken and provided by Rodney Ostoski of United Space Alliance [USA] with permission)

On the left side of our sign is the image of a raccoon. Since we started collecting and tracking our carrion, we collected 281 dead Raccoons and discovered that Raccoons account for 26% of our road kill.

On the right side of our sign is the image of a turtle. During my assignment at the Refuge, I met Richard A. Seigel, Ph.D. He has been studying reptiles at the MINWR for years. He informed me that the MINWR also has one of the highest national populations of the nearly threatened Gopher tortoise. Gopher tortoise is a State listed species of special concern. We have an estimated 2000 of them here. Their population density is the highest near the launch pads, so we designed and installed 3 special "Tortoise Crossing" signs in that area. For this reason, and because other turtles are impacted throughout the area a turtle image was also used on our more general "Wildlife Crossing" sign.

Dr. Seigel also informed me that some people actually try to run over snakes. Since our Center/Refuge also hosts many threatened eastern indigo snakes, the image of a snake was placed at the bottom of our "Wildlife Crossing" sign.

During my "Wildlife/Highway Interactions" training, I also learned that it is better to bound the wildlife crossing area with a mileage indication if the data support it. Wildlife has been killed in many areas of the Center/Refuge, but our early data indicated several "Hot Spots": One by the Visitor Center, one in the Industrial Area, one by Launch Complex 39, and some others, so our signs were placed strategically and marked with mileage based on this early data.

**Investigating Other Non-Lethal Deterrents & Methods for Moving Vultures and Other Large Birds**

Besides the carrion reduction and removal program, our team also explored other options for moving vultures and other large birds away from our launch pads for flight safety. Charles Stevenson of NASA and Tracy Gibson and Rubiela Vinje of ASRC led several efforts to determine the effectiveness of other non-lethal deterrents.

Standard bird sound deterrents (bird X system), chemical deterrents, & effigies were tested and found to be ineffective on vultures. The potential use of falcons was also considered as one of the deterrents; however, it was determined to be a lower priority and is awaiting funding and testing. Other areas that were evaluated with some degree of success were a large bird cannon and a long range acoustic device (LRAD).

The large bird cannon is an acetylene operated device that produces a strong pressure and sound wave. The unit is 18 ft. tall and 3 ft. in diameter. It is mounted on a trailer and can be operated manually and remotely. Early indications are that this device may be useful for moving birds that are at rest or on the ground. The LRAD is a sound projection device that produces a very focused parabolic sound wave. Pre-recorded sounds were loaded into the system and projected towards the vultures. Our team hopes that this device proves to be useful at deterring large birds that are in flight. These two devices are still under evaluation for potential use at the pads during the Shuttle Launch.

**Trapping & Releasing Vultures was Deemed Ineffective and Too Risky**

NASA wanted to test a vulture trap and release program. The FWCC did not think that a test and release program would be effective and was concerned that baiting a trap might even attract more vultures to the area of concern. A depredation permit was issued to NASA from FWCC for 1 test. The test results were inconclusive and there were other concerns such as what would be done if a bald eagle got into the trap or what if we had trapped some vultures and then the launch begins to delay and scrub day by day. As concerns mounted, the trap and release program was abandoned.

### Moving Roosts Away From the Launch Pad was Deemed Too Risky

There are at least 4 vulture roosts within a few miles of the Shuttle launch pads each containing hundreds of vultures. Our team consulted with Vicki Davis and Troy Hershberger, Wildlife Biologists at the Avon Park Air Force Range, on the potential of moving these KSC vulture roosts farther away from the Shuttle launch pads. We found out that the Air Force has successfully accomplished this at Avon Park with some difficulty using various loud sound and bright light techniques consistently at their roosts in the evenings as the vultures come to try and settle in for the night. The movement of roosts at KSC carries significant risk and is still under evaluation.

## Avian Abatement Team Results

It is very hard to measure our ongoing and final effectiveness on workforce and visitor driving and on our vulture population at the launch pads. We only have 1 year of road kill information (see appendix A) and most experts say that at least 2 years of data is needed when assessing wildlife related changes like this. For example our Road Kill posse thinks our numbers may be higher when it rains, but we have not proven that potential correlation. The grounds are being mowed less often allowing the grass to grow taller closer to the roadways. Our wildlife crossing signs just recently were erected. Most of what we have is anecdotal information, but the initial word back is compelling. The crew that cleans the pads before launch usually needs 2 days to clean up the mess left by birds. Since our efforts it only took ½ day and the launch pad was the cleanest they have ever seen it. Long time MINWR Refuge Biologists like my mentor, Marc Epstein, said they used to see 60 vultures flying around the Vehicle Assembly Building (VAB) and now they say they only see 20 or 30. Employees to the north, west, and south of KSC have reported new colonies of vultures in their neighborhoods. This is a good indication that the vultures are starting to diffuse and disperse in order to get back to normal levels at KSC. Most importantly to NASA, the shuttle has not hit another vulture or large bird since the earlier incident. Besides this obvious NASA benefit, preserving wildlife through road kill prevention strongly supports the US FWS mission to all Americans. Every Scrub Jay, Gopher Tortoise, Otter, Bobcat, or other animal that is not run over, is one more that can ensure that species is around for the next generation of earth and space explorers to enjoy. Our team feels that our Center wide/Refuge wide program which includes awareness training, carrion removal, bird monitoring, and potential sound deterrents will be effective in the long run, but only time will tell. We also hope that by making our effort, data, results, and points of contact more available, that others may provide us additional ideas to try or potentially be able to apply our efforts to their own situations.

## Merritt Island National Wildlife Refuge (MINWR) Overview

### Refuge Facts and Natural History

Dorn Whitmore, MINWR Visitor Services Manager, describes this area as "an island in a sea of urban development". The MINWR was established in 1963. The land is owned by NASA, but the overlaid Refuge is managed by Ron Hight with a 27-person US FWS staff. Its headquarters is located five miles east of Titusville on State Road 402. The MINWR also administers the Lake Wales Ridge NWR and the St. Johns NWR as part of the complex. The Refuge has approximately 500,000 visitors annually excluding visits to the FWS exhibit at NASA's Visitor Center. The Refuge operated on a $1.9 million budget in FY05. Approximately one-half of the refuge's 140,000 acres consists of brackish estuaries and marshes. The remaining lands consist of coastal dunes, scrub oaks, pine forests and flatwoods, and palm and oak hammocks. The coastal location of MINWR, seven distinct habitat types, and position between the subtropic and temperate climatic zones, contribute to the refuge's importance as a major wintering area for migratory birds. Over 500 species of wildlife inhabit the refuge with 10 being listed as federally threatened or endangered. Several wading bird rookeries, 11 active bald eagle nests, numerous osprey nests, up to 400 manatees during spring months, and an estimated 2,500 Florida scrub jays can be found on the refuge. Richard A. Seigel, Ph.D., has been studying reptiles at the MINWR for years. He says that the MINWR also has one of the highest national populations of the nearly threatened Gopher tortoise. Gopher tortoise is a State listed species of special concern. We have an estimated 2000 of them here. For more information on Dr. Seigel's and others work can be found in "Amphibians and Reptiles of the John F. Kennedy Space Center, Florida: A long-term assessment of large protected habitat (1975-200)" (Seigel 2002).

### Refuge Objectives

The Refuge objectives are to provide habitat for migratory birds, provide habitat and protection for endangered and threatened species, provide habitat for natural wildlife diversity, provide opportunities for environmental education and interpretation, and wildlife oriented recreation.

### Refuge Public Use Opportunities

The MINWR has a Visitor Information Center. It has five hiking trails ranging from 1/4-mile to 5 miles in length. There is a Manatee observation deck. There is also a 7-mile auto tour route (Black Point Wildlife Drive) with observation towers for wildlife observation and photography. The Refuge also provides environmental education, guided tours, fishing, waterfowl hunting, boating, and canoeing. The Refuge also contains sections of "The Great Florida Birding Trail". Details of this statewide trail can be found at http://www.floridabirdingtrail.com/.

**Refuge Management Tools**

The Refuge uses several management tools to achieve these objectives. MINWR staff manages water levels within the refuge's 76 impoundments for migratory birds, wading birds, shorebirds, and other native species of plants and wildlife. Staff firefighters use prescribed fire to maintain fire dependent/fire influenced communities. They perform chemical and mechanical control of exotic plants and thinning of pine stands to improve bald eagle nesting habitat. Public education and outreach is provided to help instill conservation ethics. Active law enforcement patrols protect wildlife, habitat and the visiting public. They also maintain productive partnerships with NASA, state agencies, other Federal and local agencies to further refuge goals and objectives.

Note: Most of this "Merritt Island National Wildlife Refuge (MINWR)" section text was taken from the MINWR Fact Sheet which can be found at http://www.fws.gov/southeast/pubs/facts/mrtcon.pdf.

**NASA & MINWR Continued Partnering for Mission Success**

A large part of the Avian Abatement Team success is due to the ongoing partnership of personnel, technologies, and funding between NASA/KSC and the USFWS/MINWR and other entities. Without this partnership much of our task would not have been achievable. In my KSC Spaceport News article titled "Can Space Centers and Wildlife Refuges peacefully coexist?", I asserted that most people would agree that a wildlife refuge and a space center can share the same property. After all, both require a lot of land and minimal urban development. But the good longstanding partnership between NASA and the US Fish & Wildlife Service does not come without constant concerns for both agencies. So who exactly are these Refuge employees, what are they doing at KSC, and how does their mission affect and integrate with the KSC mission.

How many of you can remember when Florida went up in flames in 1998? In some ways, recent draught conditions in 2006 were even worse than in 1998. But changes in fire suppression and fire management have begun to make a difference in restoring the landscape and preventing catastrophic fires. Refuge employees are coordinating and performing more controlled burns so that wildfire smoke does not contaminate KSC sensitive space flight hardware. Other past joint efforts include KSC reduction of shoreline lighting for endangered sea turtles; boat motor modifications for threatened manatees, and Shuttle Landing Facility modifications to deter birds from impacting the Shuttle during landing. Migrating bird patterns have recently been evaluated to determine if new power generating wind turbines could be built and operated within the KSC Exploration Park development. The Refuge did not concur with that plan and it is currently on hold. But how can everyday people who might live near a National Wildlife Refuge, or who may occasionally visit one, or who, like me, may even physically work on one, better support a peaceful coexistence and partnership with that Refuge? If you ask Refuge employees, two BIG ideas are usually expressed: Don't Speed and Don't Feed!

**Don't Feed!**

Jim Lyon, a biological science technician at the Refuge, gets nuisance wildlife calls from KSC employees routinely. One day during my 3 month assignment with US FWS, I was called out with Jim to the Shuttle launch pad to rescue trapped mottled ducklings from certain death. On another day, Jim told me how he finds himself smacking his head on the beams in the Vehicle Assembly Building (VAB) while helping disoriented birds get back outside. On another day he showed me a dead Starling that a NASA employee found inside the Shuttle. So one day as I was preparing to perform some Refuge educational awareness outreach activities, I asked Jim, "What do you think is the most import thing that I should be sure to tell people about visiting and working on a Wildlife Refuge. Jim told me, "Don't feed the wildlife. It's illegal and you're not doing them any favors." Jim sees the KSC workforce feeding the Refuge wildlife donuts and such. Wildlife that is fed loses its natural ability to feed itself and loses its fear of people. Because of this, many of these wild animals die or must be destroyed. Just remember, fed wildlife is dead wildlife.

**Don't Speed!**

Vehicle collisions are the number 1 killer of Florida's imperiled wildlife. Dr. Seigel, who also studies our threatened eastern indigo snakes, says that snake researchers in Louisiana have found that 30% of drivers will change lanes to deliberately kill a snake and 10% will back up over the snake to ensure that it is dead. This is a serious driver education concern. Threatened Florida scrub-jays have been picked up by the KSC "Road Kill Posse" and employee vehicles have been severely damaged by larger animals like alligators, hogs, and deer. In the last 10 years there have been over 400 reported accidents with animals on the Refuge. Each reported accident averaged $884 in vehicle damage and together they total over $350,000! With over

12,000 employees driving to KSC every day, it's a tough mix. In the first 9 months since we started keeping track, over 800 dead animals have been picked up weighing over 11,000 pounds! Refuge Biologist Marc Epstein said that "it is like the NASA 500 out here." But when the vultures are added to the equation, all of a sudden, NASA mission success and Refuge mission success once again become tightly aligned. After all, the shuttle hit that vulture in 2005 and the new joint "Avian Abatement Team" is still working hard on the related issues. I was recently driving home late at night from KSC, under the speed limit, and still was not able to avoid an Armadillo. Road kill prevention is a tough local, state, and national problem and speed is a huge factor! The KSC "Road Kill Posse" team hopes that our continuing road kill reduction effort and related road kill data will help us and others get smarter on this very tough issue.

## References


Hardesty, Jeffrey L., Callopy, Michael W. "History, demography, distribution, habitat use, and management of the Southern Bald Eagle on Merritt Island National Wildlife Refuge, Florida, 1990) Final Report to The National Fish and Wildlife Foundation, Washington D.C., Log. Reference No. 88-43, pp 112

Herridge, Linda (2006) "It's a Jungle Out There!" http://www.nasa.gov/mission_pages/shuttle/behindscenes/roadkill.html

Koenig, Robert (2006) "ORNITHOLOGY: Vulture Research Soars as the Scavengers' Numbers Decline" Science Magazine 16 June 2006: Vol. 312. no. 5780, pp. 1591 - 1592

Mansfield, Cheryl L (2006) "Bye Bye, Birdies" http://www.nasa.gov/mission_pages/shuttle/behindscenes/avian_radar.html

Seigel, Richard (2002) "Amplibians and Reptiles of the John F. Kennedy Space Center, Florida: A long-term assessment of large protected habitat (1975-2002)" Made in the United States of America, Reprinted from Florida Scientist Vol. 65, No.1 , Winter 2002. Copyright by the Florida Academy of Sciences, Inc. 2002

Schlierf, Roland (2006) "To Kill or Not to Kill, That is the Question" Habi-Chat Newsletter of the Merritt Island Wildlife Association, Summer 2006 http://www.nbbd.com/npr/miwa/Habi-Chat/06summer-habichat.pdf.

Schlierf, Roland (2006) "National Wildlife Refuge, KSC peacefully coexist" Spaceport News article September 1, 2006 Vol. 45 No. 17 pg 8. (Schlierf) http://www.nasa.gov/centers/kennedy/pdf/156371main_sep1color.pdf

## Appendix A – Road Kill Data

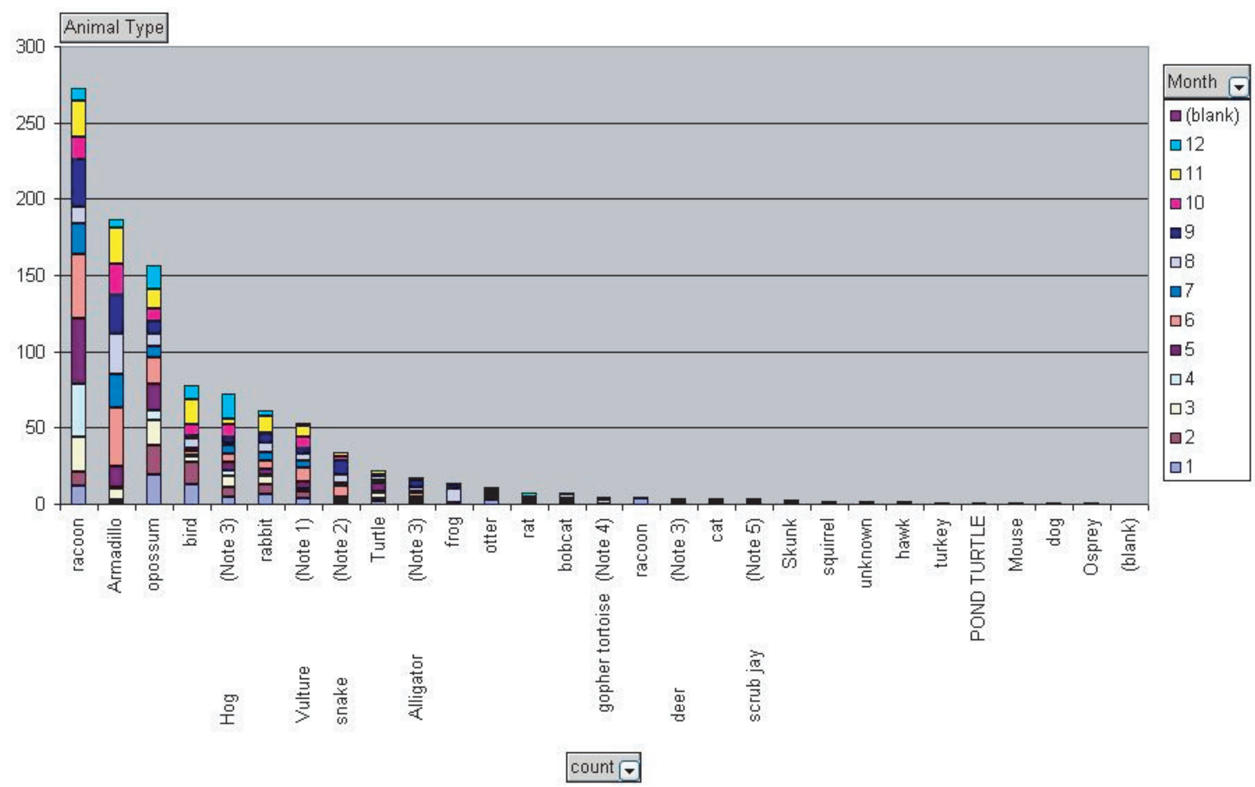
Sample Road Kill Data Entry Form

| Date / Time | Date | Lat / Long | Month | | Type of Animal | Weight | Responder |
|---|---|---|---|---|---|---|---|
| 02-APR-07 8:23:07AM | 02-APR-07 | N28.49974 W80.59080 | 4 | 2007 | opossum | 5 | Francisco |
| 02-APR-07 8:38:02AM | 02-APR-07 | N28.54071 W80.61722 | 4 | 2007 | bird | 4 | Francisco |
| 03-APR-07 8:17:09AM | 03-APR-07 | N28.52606 W80.71383 | 4 | 2007 | hog | 75 | Francisco |
| 03-APR-07 9:20:01AM | 03-APR-07 | N28.48533 W80.67732 | 4 | 2007 | racoon | 8 | Francisco |
| 03-APR-07 10:02:35AM | 03-APR-07 | N28.52693 W80.77904 | 4 | 2007 | ARMADILLO | 4 | Francisco |
| 03-APR-07 10:02:35AM | 03-APR-07 | N28.52693 W80.77904 | 4 | 2007 | racoon | 8 | Francisco |
| 04-APR-07 9:20:12AM | 04-APR-07 | N28.60227 W80.60383 | 4 | 2007 | racoon | 5 | Francisco |
| 04-APR-07 10:01:17AM | 04-APR-07 | N28.51211 W80.66858 | 4 | 2007 | opossum | 5 | Francisco |
| 04-APR-07 10:36:26AM | 04-APR-07 | N28.70427 W80.72638 | 4 | 2007 | hog | 215 | Francisco |
| 05-APR-07 7:15:20AM | 05-APR-07 | N28.53925 W80.61780 | 4 | 2007 | rabbit | 4 | Francisco |
| 05-APR-07 8:50:26AM | 05-APR-07 | N28.52624 W80.71587 | 4 | 2007 | opossum | 5 | Francisco |
| 05-APR-07 7:20:16AM | 05-APR-07 | N28.64825 W80.70003 | 4 | 2007 | bird | 0.3 | Shaw |
| 02-APR-07 7:21:33AM | 02-APR-07 | N28.57710 W80.65595 | 4 | 2007 | opossum | 3 | Shaw |
| 02-APR-07 7:27:33AM | 02-APR-07 | N28.58961 W80.65916 | 4 | 2007 | bird | 2 | Shaw |
| 02-APR-07 8:21:58AM | 02-APR-07 | N28.71170 W80.73230 | 4 | 2007 | opossum | 1 | Shaw |
| 02-APR-07 9:08:09AM | 02-APR-07 | N28.70062 W80.72418 | 4 | 2007 | opossum | 3 | Shaw |
| 02-APR-07 9:27:39AM | 02-APR-07 | N28.64043 W80.77399 | 4 | 2007 | racoon | 10 | Shaw |
| 03-APR-07 7:41:59AM | 03-APR-07 | N28.56722 W80.65378 | 4 | 2007 | opossum | 5 | Shaw |
| 03-APR-07 8:58:20AM | 03-APR-07 | N28.71210 W80.73288 | 4 | 2007 | bird | 0.1 | Shaw |
| 03-APR-07 9:13:31AM | 03-APR-07 | N28.62885 W80.78706 | 4 | 2007 | bird | 0.5 | Shaw |
| 03-APR-07 9:18:01AM | 03-APR-07 | N28.64298 W80.76256 | 4 | 2007 | snake | 0.1 | Shaw |
| 03-APR-07 9:27:33AM | 03-APR-07 | N28.64333 W80.75454 | 4 | 2007 | snake | 0.2 | Shaw |
| 03-APR-07 9:48:07AM | 03-APR-07 | N28.58824 W80.65881 | 4 | 2007 | fish | 0.2 | Shaw |
| 03-APR-07 9:51:23AM | 03-APR-07 | N28.57837 W80.65595 | 4 | 2007 | Alligator | 15 | Shaw |
| 03-APR-07 9:55:58AM | 03-APR-07 | N28.56317 W80.65590 | 4 | 2007 | bird | 0.1 | Shaw |
| 05-APR-07 7:20:17AM | 05-APR-07 | N28.64825 W80.70003 | 4 | 2007 | rabbit | 1 | Shaw |
| 05-APR-07 7:37:21AM | 05-APR-07 | N28.66825 W80.71265 | 4 | 2007 | hog | 176 | Shaw |
| 05-APR-07 8:02:53AM | 05-APR-07 | N28.67738 W80.71807 | 4 | 2007 | racoon | 1 | Shaw |
| 05-APR-07 8:50:52AM | 05-APR-07 | N28.64298 W80.76591 | 4 | 2007 | racoon | 5 | Shaw |
| 05-APR-07 8:50:52AM | 05-APR-07 | N28.48160 W80.68054 | 4 | 2007 | coyote | 36 | Shaw |
| 06-APR-07 7:46:08AM | 06-APR-07 | N28.63821 W80.69353 | 4 | 2007 | opossum | 5 | Shaw |
| 06-APR-07 7:56:44AM | 06-APR-07 | N28.66390 W80.70987 | 4 | 2007 | ARMADILLO | 1 | Shaw |
| 06-APR-07 8:05:28AM | 06-APR-07 | N28.69484 W80.72171 | 4 | 2007 | opossum | 3 | Shaw |
| 06-APR-07 8:08:32AM | 06-APR-07 | N28.70236 W80.72518 | 4 | 2007 | racoon | 4 | Shaw |
| 06-APR-07 10:35:31AM | 06-APR-07 | N28.52278 W80.65738 | 4 | 2007 | racoon | 5 | Shaw |

(Images above courtesy of NASA thru Brad Missimer, SGS)

## First 12 Months of KSC/Refuge & CCAFS Road Kill Data
(Sorted by Animal Count)

| Animal Count | | | | *months 1-3 are 2007* *months 4-12 are 2006* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | (All) | | | | | | | | | | | | | |
| | Apr-06 | May-06 | Jun-06 | Jul-06 | Aug-06 | Sep-06 | Oct-06 | Nov-06 | Dec-06 | Jan-07 | Feb-07 | Mar-07 | | |
| Animal Type | | | | | | | | | | | | | | |
| count | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | (blank) | Grand Total |
| racoon | 35 | 43 | 42 | 20 | 11 | 31 | 15 | 23 | 9 | 12 | 9 | 23 | | 273 |
| Armadillo | 1 | 14 | 38 | 22 | 27 | 25 | 20 | 24 | 6 | 1 | 2 | 7 | | 187 |
| opossum | 6 | 18 | 17 | 7 | 9 | 8 | 8 | 13 | 15 | 19 | 19 | 17 | | 156 |
| bird | | 1 | 3 | 2 | 6 | 2 | 7 | 17 | 9 | 13 | 14 | 4 | | 78 |
| Hog (Note 3) | 4 | 5 | 6 | 5 | 2 | 4 | 8 | 4 | 16 | 5 | 6 | 7 | | 72 |
| rabbit | 1 | 4 | 5 | 6 | 6 | 6 | 1 | 11 | 3 | 6 | 7 | 5 | | 61 |
| Vulture (Note 1) | | 5 | 9 | 4 | 5 | 4 | 7 | 7 | 2 | 4 | 4 | 2 | | 53 |
| snake (Note 2) | 1 | 1 | 7 | 2 | 5 | 9 | 3 | 3 | | 1 | | 2 | | 34 |
| Turtle | 1 | 6 | 2 | | 2 | 1 | | 3 | | 2 | 2 | 3 | | 22 |
| Alligator (Note 3) | 2 | 2 | 2 | 1 | 3 | 5 | | | 1 | | 1 | | | 17 |
| frog | | | | 1 | 9 | 3 | | 1 | | | | | | 14 |
| otter | 1 | | | | 1 | | 1 | 2 | 1 | 3 | 1 | 1 | | 11 |
| rat | | 1 | | | | 2 | 1 | 1 | 2 | | | | | 7 |
| bobcat | | | 2 | | 2 | | 1 | | | 1 | | 1 | | 7 |
| gopher tortoise (Note 4) | | | | | 3 | 1 | 1 | | | | | | | 5 |
| racoon | | | | | | | | | | 4 | 1 | | | 5 |
| deer (Note 3) | | | 1 | | | 1 | 2 | | | | | | | 4 |
| cat | | 1 | | | 1 | 2 | | | | | | | | 4 |
| scrub jay (Note 5) | | 1 | 1 | | 1 | 1 | | | | | | | | 4 |
| Skunk | | | | | | 1 | 1 | | | | 1 | | | 3 |
| squirrel | | | | 1 | | | | | | | | 1 | | 2 |
| unknown | | 2 | | | | | | | | | | | | 2 |
| hawk | | | | | 1 | | | 1 | | | | | | 2 |
| turkey | | | | | | | | | | | | 1 | | 1 |
| POND TURTLE | | | | | | | | | 1 | | | | | 1 |
| Mouse | | | | | | 1 | | | | | | | | 1 |
| dog | | | | | 1 | | | | | | | | | 1 |
| Osprey | 1 | | | | | | | | | | | | | 1 |
| (blank) | | | | | | | | | | | | | | |
| Grand Total | 53 | 104 | 135 | 71 | 95 | 107 | 76 | 110 | 65 | 71 | 67 | 74 | | 1028 |



Note 1: These vultures were likely killed while feeding on other road kill. Sometimes a bald eagle will join in on the feast. 6 bald eagles have been documented as killed at KSC by vehicles, probably while feeding on other road kill. Vehicle collisions are the greatest known source of adult eagle mortality usually while feeding on road kill in the middle of a circle of vultures. Our goal is to reduce our road kill in order to move our vultures away from our roadways and away from our launch pads, and back to a normal distribution across the state.

Note 2: A snake researcher in Louisiana found that 30% of drivers will deliberately change lanes to run over a snake. 10% will stop and back-up over it to ensure that it is dead. KSC is a refuge for threatened Indigo Snakes and we really need all of our snakes to help keep down our state rodent population and related disease.

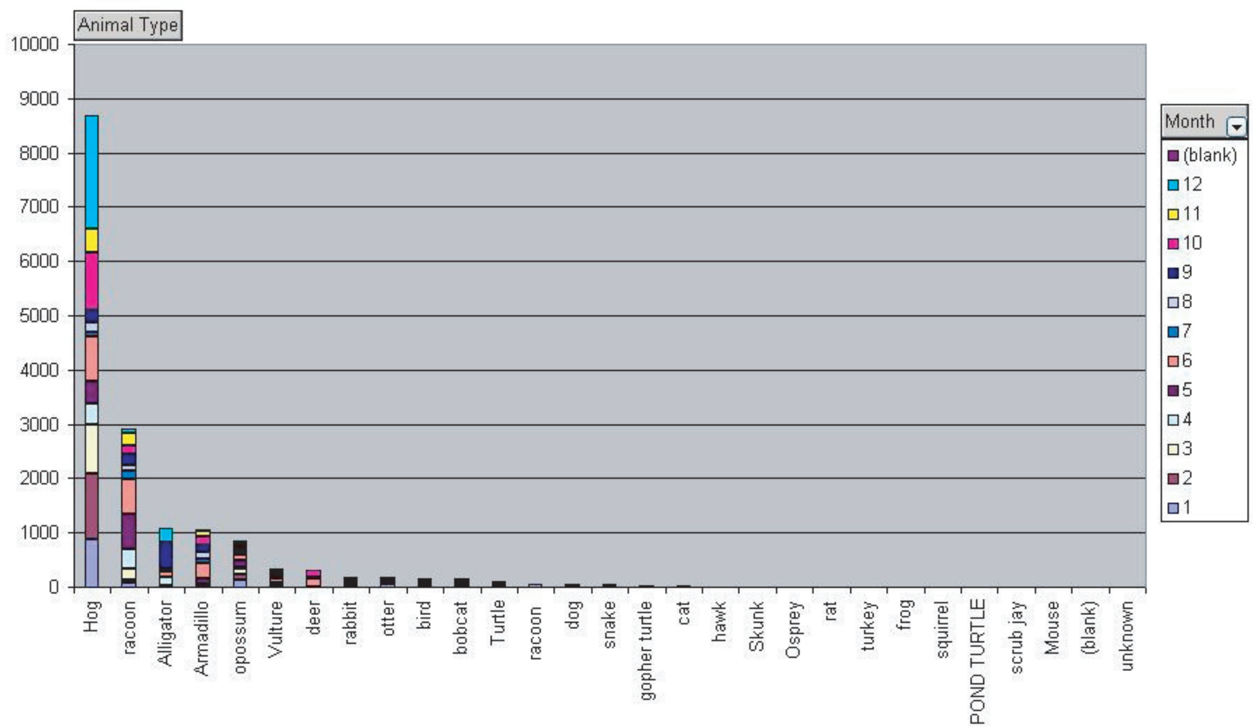
Note 3: Animals like alligators, hogs, and deer can weigh in the 100s of pounds and total your vehicle! Since 1996, 400 reported animal collisions out here have averaged $884 in vehicle damage and together have totaled to over $350,000 in vehicle damage. We average 10 reported hog accidents a year and we had 56 hog related accidents reported in 1995. The 2006 KSC hog population is estimated as being as high as 12,000.

Note 4: We have one of the highest populations of the nearly threatened gopher tortoises near our launch pads. Tortoise crossing road signs are planned for that area, but they can be found throughout the refuge.

Note 5: Our threatened Florida Scrub-Jays can be easily seen flying across our roadways, so please keep an eye out for them and slow down for them.

## First 12 Months of KSC/Refuge & CCAFS Road Kill Data
(Sorted by Animal Weight in Pounds)

| Animal Weight | | | *months 1-3 are 2007* *months 4-12 are 2006* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | (All) | | | | | | | | | | | | | |
| | Apr-06 | May-06 | Jun-06 | Jul-06 | Aug-06 | Sep-06 | Oct-06 | Nov-06 | Dec-06 | Jan-07 | Feb-07 | Mar-07 | | |
| Animal Type | | | | | | | | | | | | | | |
| Sum | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | (blank) | Grand Total |
| Hog | 400 | 410 | 830 | 83 | 165 | 225 | 1060 | 455 | 2080 | 878 | 1204 | 898 | | 8688.00 |
| racoon | 359.5 | 651 | 641 | 163 | 96 | 215 | 138 | 253 | 76 | 71 | 60 | 199 | | 2922.50 |
| Alligator | 140 | 13 | 90 | 3 | 50 | 511 | | | 250 | | 30 | | | 1087.00 |
| Armadillo | 10 | 97 | 293 | 71 | 137.5 | 138 | 131 | 125 | 17 | 1 | 13 | 24 | | 1057.50 |
| opossum | 23 | 133 | 106 | 29 | 33 | 43 | 35 | 49 | 64 | 127 | 113 | 99 | | 854.00 |
| Vulture | | 24 | 77 | 26 | 21 | 20 | 33 | 30 | 32 | 33 | 21 | 10 | | 327.00 |
| deer | | | 160 | | | 20 | 140 | | | | | | | 320.00 |
| rabbit | 0 | 8 | 25 | 21 | 16 | 21 | 5 | 41 | 9 | 13 | 19 | 15 | | 193.00 |
| otter | 32 | | | | 15 | | 10 | 40 | 10 | 44 | 10 | 15 | | 176.00 |
| bird | | 2 | 5.25 | 4 | 9.6 | 4 | 24 | 51.3 | 17.2 | 17.4 | 16.2 | 4.2 | | 155.15 |
| bobcat | | | 55 | | 40 | | 10 | | | 10 | | 40 | | 155.00 |
| Turtle | 5 | 36 | 6 | | 7 | 3 | | 8 | | 10 | 11 | 23 | | 109.00 |
| racoon | | | | | | | | | | 47 | 15 | | | 62.00 |
| dog | | | | | 60 | | | | | | | | | 60.00 |
| snake | 0.5 | 1 | 7 | 2 | 1.2 | 17.1 | 9 | 3 | | 1 | | 0.2 | | 42.00 |
| gopher turtle | | | | | 27 | 4 | 2 | | | | | | | 33.00 |
| cat | | 2 | | | 5 | 8 | | | | | | | | 15.00 |
| hawk | | | | | 3 | | | 5 | | | | | | 8.00 |
| Skunk | | | | | | 3 | 2 | | | | 2 | | | 7.00 |
| Osprey | 5 | | | | | | | | | | | | | 5.00 |
| rat | | 0.4 | | | | 2 | 1 | 0.1 | 1.5 | | | | | 5.00 |
| turkey | | | | | | | | | | | | 5 | | 5.00 |
| frog | | | | 0.1 | 0.9 | 1.5 | | 0.1 | | | | | | 2.60 |
| squirrel | | | | 1 | | | | | | | | 1 | | 2.00 |
| POND TURTLE | | | | | | | | | 2 | | | | | 2.00 |
| scrub jay | | 0.5 | 0.5 | | 0.1 | 0.5 | | | | | | | | 1.60 |
| Mouse | | | | | | 0.1 | | | | | | | | 0.10 |
| (blank) | | | | | | | | | | | | | | |
| unknown | | 0 | | | | | | | | | | | | 0.00 |
| Grand Total | 975 | 1377.9 | 2295.75 | 403.1 | 687.3 | 1236.2 | 1600 | 1060.5 | 2558.7 | 1252.4 | 1514.2 | 1333.4 | | 16294.45 |



**Appendix B**

**Web page - http://environmental.ksc.nasa.gov/projects/roadkill.htm**

JOHN F. KENNEDY SPACE CENTER

FIND IT @ NASA : + GO

+ KSC HOME | + SITE SEARCH | + MULTIMEDIA | + FAQ/CONTACT US | + NASA CENTERS

+ NASA Home
+ Center Home

Environmental Program Branch

ROAD KILL ROUNDUP CALL 853-5211

+ PROJECTS & PLANNING HOME
+ CULTURAL RESOURCES MANAGEMENT
+ ENERGY PROGRAM
+ NATURAL RESOURCES
+ NEPA
– ROAD KILL POSSE
+ POINTS OF CONTACT
+ EPB HOME

SEARCH KENNEDY + GO

WELCOME TO THE ROAD KILL POSSE WEBSITE

In July of 2005, the Space Shuttle Discovery hit a vulture during ascent. To address this issue, NASA formed the "Avian Abatement Team" which includes YOU! At this site, you can view an educational/entertaining video, order free related materials like stickers/posters, and find the latest updated information on our efforts.

AVIAN ABATEMENT TEAM – ROAD KILL PREVENTION

- Latest Road Kill Statistics
- It's a Jungle Out There! (article)
- Bye Bye, Birdies (article)
- Canaveral National Seashore
- Merritt Island National Wildlife Refuge
- General Public Critter Crossing Information
- Professional Wildlife Crossing Information
- Fox News Birds & the Shuttle Launch (video)
- National Wildlife Refuge, KSC Peacefully coexist (see pg 7 of 8) (article)

**Please watch for these Wildlife Crossing signs - coming to a KSC intersection near YOU!**

WILDLIFE X-ING Give 'em a Brake
Next 4 Miles

RELATED SITES

Order any of the below free posters, stickers, bumper stickers or badge card by sending an email here.
*click on the image to enlarge*

Badge Card/Double Sided

4"x 10" Raccoon Sticker

4"x 4" Vulture Sticker

8 ½" x 11" Raccoon Poster

8 ½" x 11" Vulture Poster

FIRSTGOV Your First Click to the U.S. Government

A product of:
Information Technology & Communication Services Directorate
Michael J. Bolger, Director
Web Development: JBOSC Web Development Team

Editor: Alice Smith
NASA Official: Diane Callier
Last Updated: October 24, 2006
+ Contact Kennedy

+ NASA Privacy Statement, Disclaimer, and Accessibility Certification

# Quantifying Risk Associated with Potential Bird-Aircraft Collisions

**Laurence M. Schafer** (360-753-9884, laurence.m.schafer@aphis.usda.gov), United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, 720 O'Leary Street, NW, Olympia, WA 98502 USA

**Bradley F. Blackwell**, United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center, Ohio Field Station, 6100 Columbus Avenue, Sandusky, OH 44870 USA

**Michael A. Linnell**, United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, PO Box 26976, Salt Lake City, UT 84126 USA

**Abstract:** Bird-aircraft collisions (hereafter, bird strikes) pose substantial hazards to aviation safety. The most common method employed to objectively quantify bird hazards on airport property is a point-count survey. However, we questioned the adequacy of point counts in prioritizing bird-strike hazards. Our objectives were to 1) quantify relative risk associated with potential bird strikes at Seattle-Tacoma International Airport (SEA) based on data from point counts and a supplemental survey of species time spent within runway protection zones (RPZs) for active runways; and 2) contrast risk based on each survey method against airport-specific bird-strike statistics obtained from the U.S. Federal Aviation Administration (FAA). We defined risk as the product of an index of frequency of use and a damage metric associated with a bird strike. We referenced observational data collected by USDA Wildlife Services biologists (over 50 weeks between 10 June 2003 and 11 June 2004) and assigned 51 species observations to 14 groups based on American Ornithologist's Union classification and bird-strike data obtained from the FAA. Ranks for risk within survey method were similar between surveys for 9 of 14 groups. Waterfowl (excluding Canada geese, *Branta canadensis*, but including double-crested cormorants, *Phalacrocorax auritus*), Corvidae, gulls (Laridae), and Canada geese ranked among the top 5 groups for risk in both surveys. Notably, raptors ranked 4th in risk based on the RPZ survey, but 9th based on point-count survey. Strike statistics for SEA indicate that gulls and some passerine species tied for the most strikes/year (1990-2005), followed by ties among raptors, shorebirds (Laridae), and swallows/swifts (Hirundinidae/Apodidae). Data from the RPZ survey indicate that raptors posed a greater bird-strike risk at SEA than indicated by point-count data. This risk associated with a potential raptor strike was corroborated by strike statistics at SEA.

## Introduction

Wildlife, particularly birds, poses substantial hazards to aviation. From 1990 through 2005, 66,392 wildlife collisions with aircraft were reported to the U.S. Federal Aviation Administration (FAA); 97.5 percent of these incidents involved birds. The approximate cost to the civil aviation industry in the USA due to collisions between aircraft and birds (hereafter, bird strikes) exceeded $600 million annually in direct monetary losses and associated costs (Cleary et al. 2006). Recent work by Dolbeer (2006) shows that for bird strikes ≤152.4 m above ground level (AGL), passerines, gulls/terns (Laridae), doves/pigeons (Columbidae), and raptors (excluding owls) were the species groups most frequently struck. For strikes >152.4 m AGL, waterfowl (Anatidae), gulls/terns, passerines, and vultures were the species groups most frequently struck. Blackwell and Wright (2006) found that 82 percent of strikes involving red-tailed hawks (*Buteo jamaicensis*) occurred at or below 30.5 m AGL and nearly 63 percent occurred while the aircraft was operating on the ground. Approximately 29 percent of strikes involving vultures occurred at or below 30.5 m AGL and 17 percent occurred while the aircraft was operating on the ground (Blackwell and Wright 2006). Relative to strikes resulting in substantial damage to the aircraft (see Dolbeer et al. 2000, Clearly et al. 2006), 67 percent occurred at ≤152.4 m AGL (Dolbeer 2006). These data indicate that most bird strikes occur on or in immediate proximity to the airport (i.e., air operations area, AOA), and they highlight the need for further development of wildlife-management methods to reduce strikes that are applicable to the AOA.

The AOA comprises areas designated for takeoff, landing, and surface maneuvers of aircraft (see 14 CFR Part 139, Subpart D) and falls within FAA siting criteria for certificated airports (i.e., within 1.5 km of a runway for airports servicing piston-powered aircraft only and within 3.0 km of a runway for airports servicing turbine-powered aircraft; FAA 2004). Management programs to reduce wildlife strikes have traditionally concentrated on species-specific hazards (Dolbeer et al. 2000; Cleary and Dolbeer 2005). Hazardous wildlife species are those species causing strikes with aircraft that result in structural damage to the aircraft and, potentially, result in damage to airport facilities and the environment (Dolbeer et al. 2000, Cleary and Dolbeer 2005). Damage resulting from a bird strike, for example, is related to body mass and velocity at impact; damage data are readily available through the U.S. Federal Aviation Administration (FAA) National Wildlife Strike Database for U.S. civil airports (Cleary et al. 2006).

Effective prioritization of species management on airports entails an assessment of the realistic potential for damage associated with those hazards (i.e., risk, the product of an index of frequency and a damage metric). However, airport habitats vary and, subsequently, affect how, when, and which avian species use these habitats. In turn, how the biologist perceives bird use of airport habitats will affect the prioritization of species management.

A common method for quantifying relative use of airport environments by avian species (i.e., a component of an airport wildlife hazard assessment) is a 3-minute point-count survey (Cleary and Dolbeer 2005) based on the field methods of the North American Breeding Bird Survey (Robbins et al. 1986). The survey also allows airport biologists to identify areas used by non-avian wildlife species, and thereby direct management at a variety of actual and potential hazards posed to aviation safety. However, airport managers and wildlife managers frequently inquire as to the risk of bird strikes associated with birds observed near, while not actually recorded as crossing a runway. In addition, to point count surveys, USDA Wildlife Services (WS) at Seattle-Tacoma International Airport (SEA) supplement point-count surveys with surveys within the runway protection zone (RPZ). The RPZ, encompassing airspace used on approach or departure, is a trapezoidal area centered on the runway centerline and beginning approximately 61 m beyond the end of the area usable for takeoff or landing (fig. 1). Airport owners are required to protect RPZs from incompatible land uses and obstructions, including avian hazards to aviation safety (FAA 1989). The RPZ survey was designed specifically to quantify species time within the airspace used for takeoffs (near the point of rotation by the aircraft) and landings (i.e., to identify species posing an immediate hazards to aviation safety). Importantly, the RPZ survey does not link an avian species or group to a particular airport resource, in contrast to point-count surveys.

Our purpose was to determine whether point-count surveys at SEA adequately identify species posing the greatest risk of bird strike. Our objectives were to 1) quantify risk associated with potential bird strikes at SEA based on data collected during point-count and RPZ surveys, respectively; and 2) contrast risk based on each survey method against airport-specific, bird-strike frequencies obtained from the FAA.

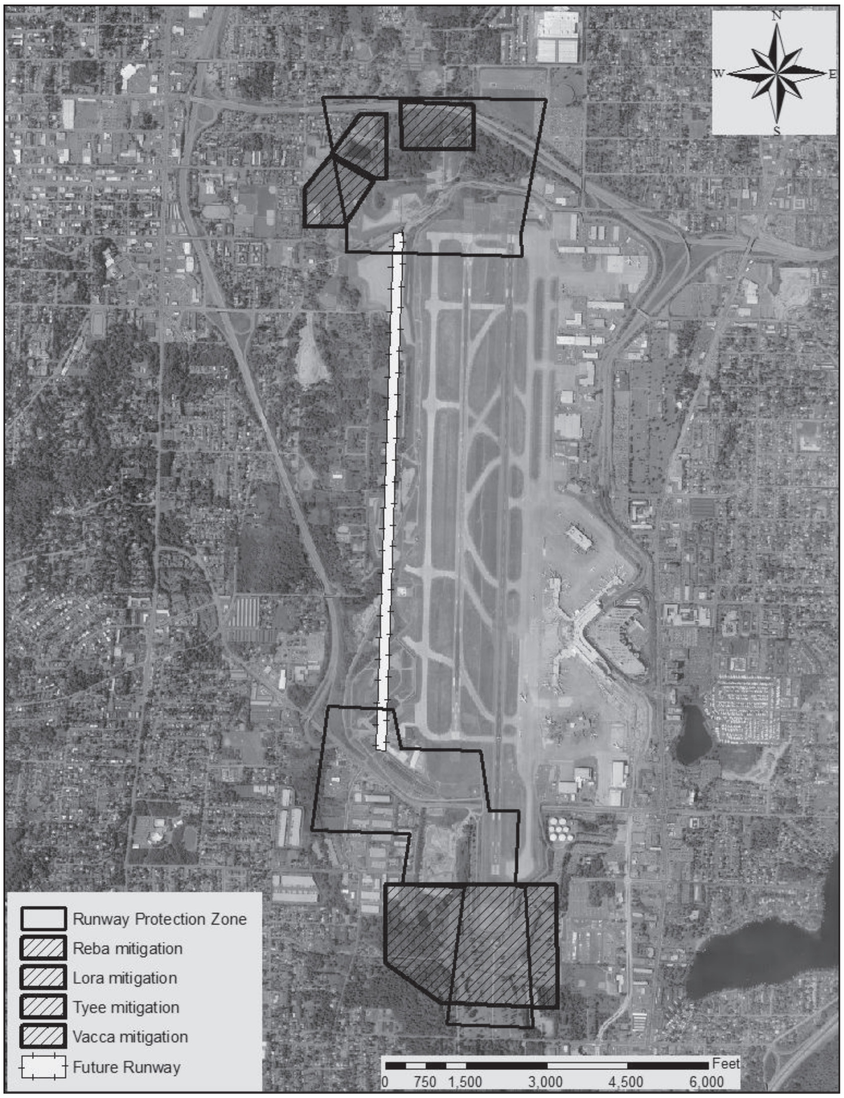



Figure 1. Seattle-Tacoma International Airport maintains two parallel runways approximately 2873 m and 3627 m in length, respectively, and 174 m apart. We conducted point-count and runway-protection zone surveys from four wetland mitigation areas (Lora, Reba, Vacca and Tyree) proximate to the runways.

## Study Area

Located in the southwest portion of King County, WA (47°26’29” North, 122°17’35” West), SEA is the 16th busiest passenger airport in the USA. The airport annually serves close to 29 million passengers, receives 359,000 flights, and moves 346000 metric tons of air cargo. Further, SEA covers approximately 853 ha and includes, in addition to structures, 339 ha of impervious surface, 205 ha of short vegetation (grasses), 15 ha of shrub/woodlots, 215 ha of water bodies, and 11 464 m of stream habitat. Also, SEA maintains two parallel runways, 2873 m and 3627 m in length, respectively, and 174 m apart (fig. 1). A third runway is under construction (Port of Seattle 2004: http://www.Portseattle.org/seatac/).

## Methods

Seattle-Tacoma International Airport has implemented an integrated wildlife management plan (e.g., see Cleary and Dolbeer 2005) to reduce the likelihood of wildlife-aircraft collisions (Port of Seattle 2000). Thus, we assumed that all birds observed during surveys conducted at SEA were, at some point, subject to the effects of the wildlife hazard-management methods (e.g., dispersal; see Port of Seattle 2000).

We referenced observational data collected by WS biologists at SEA. These observational data reflect point-count and RPZ surveys conducted from 4 wetland-mitigation areas proximate to SEA runways (fig. 1). The wetlands, though 3 sites were essentially adjacent (fig. 1), are each the subject of mitigation between the Port of Seattle and the state (Port of Seattle, unpublished data. The RPZ comprises approximately 32 ha and is 305 m wide proximate to the runway, 762 m long and extends beyond the runway terminus, 533 m wide at the end of the zone, and of unlimited altitude above ground level (fig. 1). Because of the proximity of each of the 2 active runways and a future third runway, the RPZs were merged into one zone. Also, due to concerns over potential wildlife hazards within the RPZs, officials with SEA included the 4 wetland-mitigation areas in the standard wildlife point-count survey conducted at the airport (see Port of Seattle 2000).

### Point Counts

Wildlife Services biologists at SEA conducted weekly surveys (across 50 weeks between 10 June 2003 and 11 June 2004) at the wetland sites noted above. Day, timing of the survey, and the sequence in site visits were not selected at random, but were functions of day-to-day work assignments for the airport biologists. Surveys by airport biologists are intended to identify wildlife hazards and attractants to wildlife, with subsequent mitigation the objective (see Cleary and Dolbeer 2005). The point-count survey differs from a standard scientific sampling protocol in which indices of species diversity, richness, or density might be objectives (e.g., Buckland et al. 1993). However, the biologists varied the times of day that each site was visited, and all sites were visited on the same day. All surveys were conducted during daylight hours and, when possible, 2 surveys were conducted per week. Three WS biologists conducted the surveys, but only 1 observer was present on any day.

Each observation at a site included a 3-min count of all avian species physically on the wetland or hunting over the wetland, as well as birds observed moving from cover or arriving during a 3-min period. No attempt was made to flush birds from cover, therefore, the data referenced are not reflective of more secretive avian wetland species (e.g., Gibbs and Melvin 1993). Further, because 3 of the wetlands were essentially adjacent, and the fourth was approximately 3700 m to the south (Fig. 1), birds counted at 1 site likely used the other sites as well. Thus, we did not consider the 4 wetlands as independent sites (see Analyses below).

### RPZ Surveys

Concurrent with the 3-min point count at each site and over an additional 17 min (i.e., a total of 20 min), the biologist recorded all species and flock sizes for birds entering the RPZ proximate to the wetland (fig. 1). In addition, the observer estimated the altitude (via comparison to an object of known height) of each species individual or flock within 4 elevation intervals (below runway grade [fig. 2]; 0–15.2 m; 15.3–30.5 m; and >30.5 m) and depicted the flight path of the individual or flock on an aerial photo of the site. For purposes of depicting the flight path, the flock was the focus of observation, not individuals within the flock.

Figure 2. Runways at Seattle-Tacoma International Airport, King County, Washington, are raised above surrounding grade.

## **Analyses**

We first assigned species observations (within survey and by day, time, and site) to groups that reflected American Ornithologist's Union classification or, in some cases, species of interest because of documented hazards to aircraft (Cleary et al. 2006; table 1). We summarized the point-count data relative to the maximum count per group by site and week.

For RPZ data, we used a geographic information system (ArcMAP, ESRI) to digitize the recorded flight paths and convert them to distance (m) traveled while in the RPZ. We included individuals or flocks in our analysis only if they were not flushed into the RPZ by the observer (noted by the biologist during each RPZ survey). In addition, because of the raised grade of the runways (fig. 2), we included only those individuals or flocks that were at grade or above (i.e., some birds entered the RPZ, but were flying below grade and therefore posed no immediate hazard to aircraft).

To estimate time (sec) in the RPZ, we divided the distance an individual or flock traveled in the RPZ by the average flight speeds (see Wege and Raveling 1984, Pennycuick 1997, Bird 2004) for those species composing our groups (table 1). We next converted each time estimate to flock seconds in the RPZ by multiplying the time estimate by flock size for each observation. Similar to the point-count data, we summarized the RPZ data relative to the maximum time in the RPZ, respectively, per group by site and week.

Table 1: Avian group classification and associated species observed between two bird surveysa made at four locations on the Seattle-Tacoma International Airport, Washington, USA: 3-min point counts and concurrent 20-min observations of birds flying through runway protection zones (RPZs). Flight speeds for each group are noted. Both surveys were conducted over 50 weeks from 11 June 2003 through 10 June 2004.

| | Counts | Surveys | Speed (m/sec)[b] |
|---|---|---|---|
| Wading birds: | | | |
| American bittern (*Botaurus lentiginosus*) | * | | |
| Great blue heron (*Ardea herodias*) | * | * | 9.4 |
| Shorebirds: | | | |
| Common snipe (*Gallinago gallinago*) | * | | |
| Greater yellowlegs (*Tringa melanoleuca*) | * | * | 13.0 |
| Killdeer (*Charadrius vociferous*) | * | * | 13.0 |
| Shorebirds: Least sandpiper (*Calidris minutilla*) | * | | |
| Spotted sandpiper (*Actitis macularia*) | * | | |
| Geese: | | | |
| Canada goose (*Branta canadensis*) | * | * | 18.0 |
| Other Waterfowl: | | | |
| American Green-winged teal (*Anas crecca*) | * | | |
| American coot (*Falica americana*) | * | | |
| American widgeon (*Anas americana*) | * | * | 18.0 |
| Barrow's goldeneye (*Bucephala islandica*) | * | | |
| Bufflehead (*Bucephala albeola*) | * | * | 18.0 |
| Blue-winged teal (*Anas discors*) | * | | |
| Canvasback (*Aythya valisineria*) | * | | |
| Common merganser (*Mergus merganser*) | * | | |
| Double-crested cormorant (*Phalacrocorax auritus*) | * | * | 13.2 |
| Gadwall (*Anas strepera*) | * | * | 18.0 |
| Greater scaup (*Aythya marila*) | * | | |
| Hooded merganser (*Lophodytes cucullatus*) | * | | |
| Mallard (*Anas platyrhynchos*) | * | * | 18.0 |
| Northern shoveler (*Anas clypeata*) | * | * | 18.0 |
| Pied-billed grebe (*Podilymbus podiceps*) | * | | |
| Ring-necked duck (*Aythya collaris*) | * | | |
| Wood duck (*Aix sponsa*) | * | | |
| Belted kingfisher (*Ceryle alcyon*) | * | * | 10.0[c] |
| Northern flicker (*Colaptes auratus*) | * | * | 10.0[c] |
| Swallows/swifts: | | | |
| Barn swallow (*Hirundo rustica*) | * | * | 10.0 |
| Tree swallow (*Tachycineta bicolor*) | * | * | 10.0 |
| Vaux's swift ( *Chaetura vauxi*) | * | * | 10.3 |

[a]Point counts entailed an instantaneous count of all avian species physically on the wetland or hunting over the wetland, as well as birds observed moving from cover or arriving during the initial 3 min. During the initial three min and the subsequent 17 min, the observer monitored avian use of the RPZ and recorded, by species, flock size,

## Calculation of Risk

We considered risk as the potential for damage to the aircraft that each group posed if struck. We defined risk as the product of the relative frequency of each group in total counts or total group time in the RPZ over the period of the study (i.e., the sum of the weekly maximum group counts and times, respectively) and the proportion of bird strikes involving the group that have resulted in damage to aircraft (across U.S. civil airports and civil aircraft). Importantly, risk does not equate to the probability of a future bird strike at SEA, but simply the relative potential for negative effects (i.e., damage to the aircraft) that might be incurred by bird strikes involving species at SAE. We used bird-strike related damage statistics from the FAA National Wildlife Strike Database for U.S. civil and joint-use airports (Cleary et al. 2006; http://wildlife-mitigation.tc.faa.gov/public_html/). In addition, we report the proportion of total risk within survey type associated with a bird strike involving a particular group, and the corresponding rank of the proportionate risk. Also, because the RPZ survey is considered supplemental to point counts, we refer only to the group rank within survey type and include no statistical comparison of proportionate risk between surveys.

## Strike Frequency

We ranked groups relative to strike frequency at SEA through the period in which the survey data were collected (2003-2004) and over the period represented by the FAA National Wildlife Strike Database (1990-2005; see Cleary et al. 2006). Strike data collected by the FAA are provided in voluntary reports by pilots and ground crews via standard form (5200–7) for wildlife strikes to civil aircraft in the USA.; strike reports are also made directly to the FAA National Wildlife Strike Database via the web address cited above. We note that a strike report might involve more than 1 bird, only about 20 percent of wildlife strikes are reported, not all bird strikes are identified to species, and bird-strike damage and down-time costs are underreported (Linnell et al. 1999, Cleary et al. 2006). Thus, species-specific losses and the associated costs to aviation due to those bird strikes are highly underrepresented by strike data within the FAA National Wildlife Strike Database. In addition, we emphasize that strike statistics represent past occurrences and do not necessarily reflect future hazards to aviation safety.

## Results

Wildlife Services biologists at SEA observed 51 avian species during point counts, 30 of which were also seen within the RPZ; we classified these species into 14 groups. Each group was represented in the RPZ survey as well as point-count data (table 1). Species categorized as other waterfowl, European starlings, swallows/swifts, corvids, and gulls were among the top 5 groups most frequently observed during point counts, composing 88.7 percent of observations (table 2). With the addition of raptors, the same groups represented 89.5 percent of the time recorded for species observed in the RPZ per week (table 2).

Table 2: Relationship between two bird surveys made at 4 locations on the Seattle-Tacoma International Airport, Washington, USA: 3-min point counts and concurrent 20-min observations of birds flying through runway protection zones (RPZs). Both surveys were conducted over 50 weeks from 11 June 2003 through 10 June 2004.

| Bird Group | Mean maximum birds/wk (SD) | Mean maximum sec in RPZ/wk (SD) |
|---|---|---|
| Blackbird | 0.29 (1.06) | 0.09 (1.24) |
| European starling | 2.62 (12.16) | 22.0 (108.94) |
| Other passerines | 0.87 (4.46) | 12.98 (76.78) |
| Corvids | 1.35 (7.48) | 54.10 (222.07) |
| Doves/pigeons | 0.07 (0.42) | 0.92 (6.80) |
| Raptors | 0.12 (0.32) | 21.11 (107.41) |
| Gulls | 0.82 (6.46) | 28.94 (131.39) |
| Shorebirds | 0.02 (0.22) | 0.26 (2.66) |
| Wading birds | 0.18 (0.40) | 1.30 (7.98) |
| Geese | 0.16 (0.94) | 3.71 (37.28) |
| Other waterfowl, including Double-crested cormorant | 7.73 (7.98) | 14.39 (57.14) |
| Belted kingfisher | 0.06 (0.27) | 0.10 (1.38) |
| Northern flicker | 0.04 (0.23) | 0.22 (3.12) |
| Swallows & swifts | 1.71 (8.08) | 39.51 (363.35) |

Between surveys, we found divergent proportionate risk values (i.e., the proportion of total risk within survey represented by a group) by factors ranging from 5.9 to >32 for 5 of the 14 groups (corvids, raptors, gulls, and other waterfowl; table 3). Overall, ranks for proportionate risk were similar between surveys for 9 of 14 avian groups. However, in both surveys, other waterfowl, corvids, gulls, and Canada geese were included in the top 5 groups for proportionate risk. Further, other waterfowl represented >85 percent of the proportionate risk based on proportionate risk in each survey (table 3). Notably, raptors ranked among the top 4 groups in proportionate risk (>16.0 percent of proportionate risk) based on the RPZ survey, but represented <1.0 percent of the proportionate risk based on point-count data. In contrast, European starlings represented similar proportionate risk between surveys, but ranked among the top 4 groups based on point-count data, versus the top 6 for the RPZ survey.

Actual strike statistics for SEA indicate that gulls, raptors, and European starlings were the groups most frequently struck (2003-2004). Gulls and other passerines tied for most frequent strikes/year (1990-2005), and were followed by ties among raptors, shorebirds, and swallows/swifts (table 4). Waterfowl (not including Canada geese) ranked 13 in groups most frequently struck (2003-2004) and 6 in strikes/yr (1990-2005).

## **Discussion**

We used risk analysis to contrast bird-strike hazards to aviation safety at SEA based on data collected during point-count surveys within habitats bordering active runways and concurrent surveys within the RPZ. For this study, risk comprised both a frequency component (based on the 2 surveys) and a damage metric, with damage associated with body mass and velocity at impact (Dolbeer et al. 2000; Cleary et al. 2006). Across 50 weeks of observations (between 10 June 2003 and 11 June 2004) biologists at SEA observed 51 species of birds, composing 14 groups in our analyses. Six of these groups appear in the FAA National Wildlife Strike Database and are associated with frequent (≥6 percent of reported bird strikes) and damaging strikes (see table 3; Cleary et al. 2006), and range ecologically from habitat specialists (e.g., shorebirds) to opportunistic generalists (e.g., European starlings).

Table 3: Relationship between risk[a] based on two bird surveys[b] made at four locations on the Seattle-Tacoma International Airport, Washington, USA (3-min point counts and concurrent 20-min observations of birds flying through runway protection zones [RPZs]) and bird-strike data from the U.S. Federal Aviation Administration FAA National Wildlife Strike Database for U.S. civil and joint-use airports (Cleary et al. 2006; http://wildlife-mitigation.tc.faa.gov/public_ html/). Both surveys were conducted over 50 weeks from 11 June 2003 through 10 June 2004.

| Bird Group | Proportionate risk based on point counts (rank)[c] | Proportionate risk based on RPZ surveys (rank)[c] |
|---|---|---|
| Blackbirds[d] | 0.004 (7) | 0.000 (12) |
| European starling[d] | 0.030 (3.5) | 0.043 (6) |
| Corvids | 0.034 (2) | 0.232 (2) |
| Other passerines | 0.006 (8) | 0.014 (8) |
| Doves/pigeons[d] | 0.001 (12.5) | 0.003 (12) |
| Raptors[d] | 0.005 (9) | 0.160 (4) |
| Gulls[d] | 0.033 (3.5) | 0.196 (3) |
| Shorebirds | 0.000 (12.5) | 0.000 (12) |
| Wading Birds | 0.006 (6) | 0.008 (9) |
| Canada goose[d] | 0.021 (5) | 0.079 (5) |
| Other waterfowl, including double-crested cormorant[d] | 0.853 (1) | 0.247 (1) |
| Belted kingfisher | 0.000 (12.5) | 0.000 (12) |
| Northern flicker | 0.001 (12.5) | 0.001 (12) |
| Swallows & swifts | 0.006 (9) | 0.016 (7) |
| Sum of proportionate risk | 1.000 | 1.000 |

[a]Risk is defined as the product of the relative frequency of each avian group in counts or group time in the RPZ over the period of the study and the proportion of bird strikes involving the group that have resulted in damage to aircraft. We used bird-strike data from the U.S. Federal Aviation Administration National Wildlife Strike Database for U. S. civil and joint-use airports (Cleary et al. 2005; http://wildlife-mitigation.tc.faa.gov/public_ html/).
[b]See footnote in Table 1.
[c]Rank of proportionate risk value = 1 > 2 > 3, etc.
[d]Group associated with frequent (?6percent of total reported strikes) bird strikes and strikes that result in damage to the aircraft (see Cleary et al. 2006).

We found that ranks for proportionate risk were similar between surveys for only 9 of 14 avian groups. However, other waterfowl (not including Canada geese, but including double-crested cormorants), corvids, gulls, and Canada geese were included in the top 5 groups in proportionate risk in both surveys. Most notable was that the rank based on proportionate risk for raptors differed by a factor >2 between surveys. Whereas raptors represented on average only 0.7 percent of observations during point counts, they composed 11.3 percent of total time recorded across groups during the RPZ survey. Clearly, the numbers of individuals observed during point counts diminished the risk value for raptors. In contrast, European starlings represented a similar proportionate risk between survey methods, yet overall rank within survey differed. Specifically, European starlings ranked 6 in proportionate risk for the RPZ survey, but fell among the top 4 for the point-count survey. The lower ranking of European starlings for the RPZ survey reflects the effect of the relative frequency of raptor sightings in the RPZ, which elevated the risk associated with raptors.

Table 4: Avian species group most frequently involved in bird strikes at the Seattle-Tacoma International Airport, Washington, USA. Bird-strike data were obtained from the U.S. Federal Aviation Administration FAA National Wildlife Strike Database for U.S. civil and joint-use airports (Cleary et al. 2006; http://wildlife-mitigation.tc.faa.gov/public_html/).

| Bird Group | Bird strikes/yr (1990–2005) | Total Bird Strikes (2003–2004) |
|---|---|---|
| Blackbirds | 0.5 | 2 |
| European starling | 1.8 | 5 |
| Corvids | 0.2 | 0 |
| Other passerines | 1.2 | 10 |
| Doves/pigeons | 0.6 | 0 |
| Raptors | 2.0 | 7 |
| Gulls | 2.2 | 10 |
| Shorebirds | 1.2 | 7 |
| Wading Birds | 0.1 | 0 |
| Rallids | 0.1 | 2 |
| Canada goose[d] | 0.2 | 0 |
| Other waterfowl, including double-crested cormorant | 1.1 | 0 |
| Swallows/swifts | 0.9 | 7 |

The FAA strike statistics for SEA, though not representing strike probability or effects of current management, underscore the risk assigned to European starlings, gulls, and, particularly, raptors based on the supplemental RPZ survey. For example, over 18 percent strikes involving raptors result in damage to the aircraft. Further, given that 10 percent of reported bird strikes involve waterfowl and 45 percent of those strikes result in damage to the aircraft, the level of risk associated with other waterfowl based on both survey methods is also warranted. However, the frequency of strikes (1990-2005) involving other passerines, shorebirds, and swallow/swifts versus the respective ranks in both surveys (ranging 7-12.5) is indicative that strike frequency alone does not necessarily connote a high level of hazard (i.e., damage to the aircraft, as per Dolbeer et al. 2000) or risk.

## Management Implications

Priorities given to management of wildlife hazards at airports stem not only from data collected during surveys across all airport habitats, but also airport-specific bird-strike records, and species representation in the FAA National Wildlife Strike Database. We suggest, however, that airport biologists evaluate the RPZ survey as a supplement to point counts. The addition of the RPZ survey at SEA revealed raptor use of the airspace over active runways (i.e., raptors posed a greater bird-strike risk), whereas raptors were rarely observed during point counts.

**Acknowledgements:** We thank officials with SEA for their support in wildlife management efforts at the airport and permission to use data collected at the airport. Salaries and logistical support for LMS and MAL were provided by WS, Washington, and SEA. The WS National Wildlife Research Center provided salary and logistical support for BFB. We thank Robert Beason, Richard Dolbeer, Patrick Kocovsky, and Thomas Seamans for their helpful reviews of early versions of this manuscript.

**Biographical Sketches:** Laurence M. Schafer began his career with USDA Wildlife Services after earning his BS in Wildlife Biology from the University of Montana in 1997. His first position was as a wildlife biology specialist at Atlantic City International Airport. In 1999, he became the Project Leader for the Wildlife Program at O'Hare International Airport, where he conducted his master's research on the efficacy of raptor translocation as a management tool. Though devastated to leave the soothing climate of Chicago, Laurence accepted a position as the Airport Coordinator/Staff Wildlife Biologist for USDA Wildlife Services in Washington and Alaska in 2002. While there, Laurence has assisted with the development of numerous Wildlife Hazard Assessments and Management Plans for WA and AK airports. His secondary interests are collaborating with the USDA Wildlife Services National Wildlife Research Center to develop additional operational management tools and Wildlife Hazard Assessment techniques.

Brad Blackwell received a B.S. in Animal Science and an M.S. in Zoology from North Carolina State University. He received a Ph.D. in Wildlife Ecology from the University of Maine and was selected as a National Oceanic and Atmospheric Administration, Cooperative Marine Education and Research Fellow through the Department of Forestry and Wildlife Management at the University of Massachusetts. Over the last 10 years, Brad has worked as a Research Wildlife Biologist with the USDA Wildlife Services, National Wildlife Research Center. His research has focused on the application of demographic models to wildlife management plans that include population reduction as a component, and avian behavioral ecology as related to response to visual, physical, and chemical repellents. Currently, Brad is involved in studies to quantify avian and mammalian avoidance response to a combination of vehicle approach and specific vehicle-mounted lighting treatments, as well developing design recommendations for airport stormwater-management facilities to reduce use by wildlife.

Mike Linnell is the Utah State Director for USDA Wildlife Services and has extensive experience conducting airport wildlife hazard assessments and developing wildlife hazard management plans.

## References

Bird, D. M. 2004. The bird almanac. A guide to essential facts and figures of the world's birds. Firefly Books, Inc., Buffalo, NY.

Blackwell, B. F., and S. E. Wright. 2006. Collisions of Red-tailed hawks (*Buteo jamaicensis*), Turkey (*Cathartes aura*), and Black vultures (*Coragyps atratus*) with aircraft: implications for bird strike reduction. Journal of Raptor Research 40:76-80.

Buckland, S. T., D. R. Anderson, K. P. Burnham, and J. L. Laake. 1993. Distance sampling: estimating abundance of biological populations. Chapman and Hall, London, UK.

Cleary, E. C. and R. A. Dolbeer. 2005. Wildlife hazard management at airports. 2nd Edition. Federal Aviation Administration, Office of Airport Safety and Standards, Airport Safety and Compliance Branch, Washington, DC U.S.A.

Cleary, E. C., R. A. Dolbeer, and S. E. Wright. 2006. Wildlife strikes to civil aircraft in the United States 1990–2005. U.S. Department of Transportation, Federal Aviation Administration, National Wildlife Strike Database Serial Report Number 12. Office of Airport Safety and Standards, Airport Safety and Certification. Washington, DC.

Dolbeer, R. A. 2006. Height distribution of birds as recorded by collisions with civil aircraft. Journal of Wildlife Management. In press.

Dolbeer, R. A. and P. Eschenfelder. 2003. Amplified bird-strike risks related to population increases of large birds in North America. International Bird Strike Committee 26:49–67.

Dolbeer, R. A., S. E. Wright, and E. C. Cleary. 2000. Ranking the hazard level of wildlife species to aviation. Wildlife Society Bulletin. 28:372–378.

Gibbs, J. P. and S. M. Melvin. 1993. Call-response surveys for monitoring breeding waterbirds. Journal of Wildlife Management 57: 27–34.

Linnell, M.A., M.R. Conover, and T.J. Ohashi. 1999. Biases in bird strike statistics based on pilot reports. Journal of Wildlife. Management 63: 997–1003.

Pennycuick, C. J. 1997. Actual and 'optimum' flight speeds: field data reassessed. Journal of Experimental Biology 200:2355–2361.

Port of Seattle. 2000. Wildlife hazard management plan. Seattle-Tacoma International Airport (SEA). Port of Seattle, Seattle-Tacoma International Airport in cooperation with U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, Olympia, WA.

Robbins, C. S., D. Bystrak, and P. H. Geissler. 1986. The breeding bird survey: its first fifteen years, 1965-1979. U.S. Fish and Wildlife Service Research Publication 157, Washington, D.C.

U.S. Federal Aviation Administration. 1989. Airport design. Advisory Circular No: 150/5200–13.

U.S. Federal Aviation Administration. 2004. Hazardous wildlife attractants on or near airports. Advisory Circular No: 150/5200–33A.

Wege, M. L., AND D. G. Raveling. 1984. Flight speed and directional responses to wind by migrating Canada geese. Auk 101:342–348.

# Trains, Grains, and Grizzly Bears: Reducing Wildlife Mortality on Railway Tracks in Banff National Park

**Jim Pissot** (403-678-0016, jpissot@defenders.org), Executive Director, Defenders of Wildlife Canada, P.O. Box 40001, Canmore, Alberta T1W 3H9 Canada

**Abstract:** Between 2000 and 2007, the Canadian Pacific Railway emerged as the leading human-related cause of grizzly bear mortality in Banff National Park. Seven grizzlies were struck by CPR trains, and none of the five cubs orphaned by these collisions survived within the park. Other wildlife also have been struck and killed. Spilled grain, track-side attractants, and preference of animals for open travel corridors are cited as contributing to these collisions. CPR's rail lines bisect the Canadian Rockies and, along with other factors, inhibit wildlife movement and genetic connectivity. Ecologists and conservations seek to implement measures to ensure continued ecological connectivity across these man-made barriers. Railways have adopted various methods to reduce wildlife mortality, including more efficient sealing of grain cars, vacuum cars to recover spilled grain, and warnings that alert wildlife of approaching trains. Fencing and crossing structures, such as those assisting wildlife to cross highways, also are being considered. We discuss the causes of train-wildlife collisions, steps taken to reduce the number of collisions, propose further opportunities to reduce the likelihood of collisions.

## Introduction

Connectivity, at a range of scales, is critical to the survival of wildlife populations. In Banff National Park in the Rocky Mountains of western Canada, Canada's main east-west highway, a principal rail line, and other natural and man-made barriers divide wildlife populations. Measures have been taken to mitigate the busy traffic on the Trans-Canada Highway, including fencing to increase motorist safety and reduce wildlife mortality, and under- and over-passes to promote safe wildlife movement. Speed limits and access are reduced on other roadways to conserve wildlife.

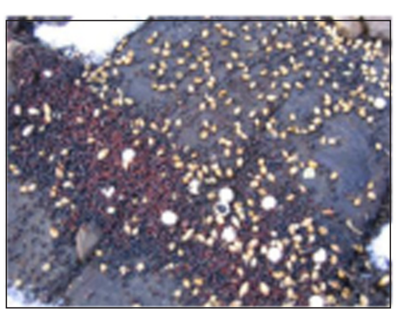
Since 2000, the Canadian Pacific Railway has emerged as "the number one known source of human-caused mortality" of grizzly bears in Banff National Park. Grizzlies and other animals are attracted to grain spilled from passing railway cars. Twelve grizzlies have been killed directly by trains or lost permanently to Banff National Park over the past seven years. This total includes four breeding age females and their seven cubs of the year. In 2006 alone, four black bears were killed. Necropsies by Parks Canada staff found grain in the stomachs of two of the black bears. More than a decade of efforts by the Railway has not meaningfully reduced the amount of grain on the tracks nor the number of animals struck and killed.

## Spilled Grain

Grain spilled by rail cars has been identified by Parks Canada staff as the principal attraction that draws bears to their deaths between the rails in Canada's mountain parks. There are four major sources of spilled grain:

1. Derailments and other significant events that spill large amounts of grain;
2. Faulty, leaking, or improperly closed grain car discharge gates that spill small amounts of grain along the tracks, particularly along sections of tracks where cars are shaken in any way;
3. The temporary siding, stopping, or parking of grain trains, allowing leaking cars to spill larger amounts of grain in a single spot between the rails; and
4. The spillage of excess grain that has fallen onto flat surfaces of grain cars at the loading terminals and subsequently falls to the ground as the train moves along.

The Railway and government agencies respond promptly to derailments and larger spills, and usually take measures to prohibit bears and other wildlife from feeding on the spilled grain. Fencing, 24-hour human presence, Karelian bear dogs and other deterrents have been used until all grain has been cleaned. Similarly, minor spills from stopped or sided cars generally receive prompt attention, although some reported spills have remained on the tracks for more than 36 hours.

Smaller spills—with potentially more negative impacts on wild animals within Banff National Park—occur when small amounts of grain trickle along the tracks as loaded trains move west. Grain falls from hopper car discharge gates at the bottom of grain cars that are defective, worn or not closed properly. Of course, these are the same gates that spill larger amounts of grain when the cars move more slowly or with more jerky motions, or when the train is stopped.

The second source of trickled grain originates at terminals where grain hopper cars are loaded. Careless loading causes grain to fall outside of the hopper cars and collect on virtually every flat surface, including the tops of the cars and flat decks on either end of the cars. In turn, grain falls off these surfaces as trains move along. More than 10 cm of sprouting grain, spilled grain and detritus has been observed on hopper car end decks.

In 1990, the Canadian Pacific Railway introduced a specially designed self-powered vacuum truck to remove grain spilled on the tracks. The vacuum has proven effective on larger spills, but nearly useless on the constant streams of grain that trickles from leaking discharge gates and flat surfaces.

The Canadian Pacific Railway reports increased shipments of grain each year. Tracks were recently modified to accommodate even longer trains—up to two miles in length. So, there is increasing potential for grain spillage. Parks Canada wardens noted in 2006, “this is one of the heaviest years we’ve seen [for grain on the tracks].” Supervisors reported to the media, “our wardens are saying they’re seeing more grain on the tracks.”

It has been said that some leaking grain cars arrive at the Vancouver terminal completely empty. Grain can be found scattered along the tracks, heavier in locations where cars move more slowly or are jostled along the way. In some sections, spilled grain sprouts to a thick green carpet. The Farmer Rail car coalition estimates that up to Cdn $10 million worth of grain and pulse are spilled annually from leaking hopper cars hauled by the Canadian Pacific Railway.

The Canadian Pacific Railway leases bout 6,300 grain hopper cars that are owned by the Canadian federal government. These cars have been in service for 30 to 40 years, and carry a variety of discharge gate designs. New loading and unloading equipment used at terminals is more powerful, likely stressing older discharge gates. Most cars owned by the Railway are of newer design, compatible with powerful and high-speed terminal equipment. Anecdotal evidence suggests that some of the older designs may be the most troublesome—worn or damaged, and failing to close securely.

### Grain and Dead Grizzlies

According to senior Parks Canada officials, “bears frequent the tracks because they get the reward of grain.” Dr. Stephen Herrero of the University of Calgary, one of Canada’s most respected grizzly bear experts, concluded that Canadian Pacific Railway trains “are the number one known source of human caused mortality” of grizzly bears in Banff National Park.

Between the spring of 2000 and mid-summer 2007, Canadian Pacific Railway trains struck and killed seven grizzly bears in Banff National Park alone. Four of these bears were breeding age females. None of the five orphaned cubs of the year survived in the park without their mothers. In 2006 alone, four black bears were struck and killed in Banff and Yoho national parks. Grain was found in the stomachs of two of the bears.

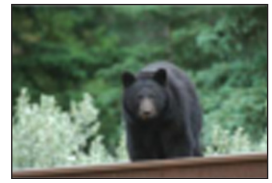
Bears and other wildlife are attracted to railway tracks for a variety of reasons—the promise of a meal between the rails, easy passage (particularly in the heavy snows of winter), and forage vegetation growing in open sunlight. In Canada’s Mountain Parks, grain has proven to be the most fatal attraction.

According to Edward Abbott, manager of resource conservation of Parks Canada’s Lake Louise, Yoho and Kootenay field unit, “bears frequent the tracks because they get the reward of grain. Over the years bears have a very good learning ability and they know where they get rewarded. And if they have been rewarded once, often they go back again just to check to make sure if there is anything there.”

We have observed and filmed a number of bears feeding between the rails and collected grain-filled bear scat along the tracks. More than a dozen bears have been seen in a single morning feeding at open railway tracks at Bath Creek Flats, near the border of Banff and Yoho national parks. When asked, some senior Parks Canada staff tell close friends and relatives that the best place to see grizzly bears in Banff National Park is along these tracks, as bears forage for grain. This is relatively open country, where the tracks offer no singular advantage of other forage or open travel. The bears are there because this is one of the very best dining areas along the “world’s longest bird feeder.”

Bears aren’t the only animals that seek grain and are killed between Canadian Pacific rails. According to Parks Canada figures, 564 elk, 9 moose, 51 deer were killed on CPR tracks between 1982 and 2001 in Banff and Yoho national parks. In turn, many of these carcasses attracted scavengers. During the same time period, 9 coyote and 9 wolves were killed by trains.

## Management Responses by The Canadian Pacific Railway



The Railway conducted a wildlife mortality study in 1997. In 1999, the Canadian Pacific Railway, Parks Canada and other parties contributed to a seminal paper on railways and wildlife mortalities (Wells, P. et al. 1999, Wildlife mortalities on railways: monitoring methods and mitigation strategies. 11 pp. Unpublished.). The paper identified seven promising mitigation strategies: 1) concentrate mitigation strategies on identified problem areas; 2) instruct train crews to report wildlife incidents; 3) remove carcasses from right-of-way to reduce scavenging; 4) remove spilled attractants (e.g., grain) in a timely manner; 5) reduce chronic grain spills through car maintenance and loading/handling procedures; 6) reduce attractant vegetation on right-of-way; and, 7) share data among jurisdictions.

In the year this study was completed, the Canadian Pacific Railway put the industry's first vacuum truck into service, marking a major and innovative investment. The truck was designed to respond to reported spills and to clean spilled grain from the tracks. At the same time, the Railway instituted a program to train and encourage grain handlers at loading terminals. The intent was to reduce the amount of grain spilled on hopper car tops and end plates, and to ensure that discharge gates were fully closed and operating properly.

Prior to train departure, faulty discharge gates are to be noted and reported as "bad order cars." These cars are to be pulled from service and repaired. To date, the Canadian Pacific Railway has refused to release "bad order car" reports or to conduct public tests to document the spillage of grain or the effectiveness of its vacuum operations. And the Railway has declined to release the results of any tests it may have conducted.

The Railway has an agreement with Parks Canada to report grain spills and collisions with wildlife. Most reports are timely and adequate, but the process falls short on occasion. Parks Canada also agreed to allow the Railway to remove struck carcasses from the right-of-way onto park lands, reducing the likelihood that predators would be struck.

In a presentation to the American Association of Railroads in Urbana-Champaign, Illinois, USA in 2000, a representative of the Canadian Pacific Railway indicated that the company would carry out a number of measures to investigate and reduce the number of wildlife collisions, including trials of lights and sounds to alert wildlife, observations of wildlife behaviour, limited fencing, and programs to educate train crews and grain terminal operators. In addition, the Railway pointed to possible "future directions" including aversive conditioning, "science-based decision-making," "integrated research and planning" and crossing structures. The Railway has not reported any progress on these possible directions.

Under Canadian law, contracts and other agreements between government and private parties are governed by legal principles which consider the agreements as "privileged" in favour of the private party. As a result, the terms of the grain car lease, reports filed and other communications between the parties, and other documents are not—or in some cases, not easily—available to the public.

## Media Responses by The Canadian Pacific Railway

Through most of this century, spokespersons for the Canadian Pacific Railway asserted the company was doing the best it could and that spilled grain was not a significant factor in the deaths of grizzly bears in the region. A sample of their responses, as recorded in local media, includes:

> "[The vacuum truck] does a good job of making the tracks as clean as possible so [the grain] is not evident. It has proven very effective." (August 5, 2004)
>
> "Look as a company at what we have tried to do to avoid contact with bears – we're trying our best." (Aug 25, 2005)
>
> "This is a bigger picture issue, not just a railway issue. It's the entire growth of human activity in that area. We're just one of the stakeholders. This is more of a community bear management issue." (Aug. 25, 2005)
>
> "But this is a bigger issue that just the railway..." (May 11, 2006)
>
> "I don't think grain is the issue here." (June 22, 2006 )
>
> "We aren't a major contributor to bear mortality." (June 27, 2006)
>
> "We do have stringent measures in terms of our hopper maintenance and repair process that has been enhanced over the past year or two." (June 27, 2006)

## The Big Breakthrough

On May 3, 2007, the Canadian Pacific Railway announced a new operating agreement with Canada's Ministry of Transport, Infrastructure and Community. The Railway's announcement read, in part (emphasis added):

> Under the agreement with Transport Canada, CP will, in addition to its normal maintenance practices, undertake over the next five years an extensive hopper car inspection and refurbishment program to ensure a quality fleet. **This will include the replacement of poor-performing discharge gates with technologically superior units as well as a general refurbishment program for the other gates on these cars.**

> "Canadian Pacific is pleased to have completed these extended negotiations with the federal government as it will ensure a secure hopper car supply for farmers and enhance operational fluidity," said Fred Green, President and CEO. **"This initiative will also strongly support our wildlife protection efforts by reducing grain and other wildlife attractants along our tracks."**

The refurbishment program on more than 6,300 hopper cars will take five years to complete at a cost of Cdn$20 million. The Railway expects to repair 70 percent of the cars by the end of 2010. The Canadian National Railway Company also agreed to invest Cdn$20 million in the 6,300 hopper cars it leases from the federal government.

## Next Steps

Repairing leaking grain cars is a necessary—but not sufficient—step to reduce wildlife mortality on railway tracks. Animals will stray onto the tracks, even if grain is not present. And Banff's wild animals are habituated to finding grain on the tracks. As many as three generations of grizzly bears in Banff and Yoho national parks are accustomed to finding meals between the rails. For 15 years after open dumps were closed at Yellowstone National Park, bears returned looking for a meal. Additional steps will need to be taken as defective cars are repaired and as trains continue to move through Canada's premier national parks.

We suggest these steps to reduce wildlife collisions on CP Railway tracks:

1. Characterize sites where animals are struck, killed or frequently seen. The first step in understanding and reducing vehicle-wildlife collisions is to investigate the situations where animals are seen and struck. Was the incident on a straight or curved section? Does vegetation—particularly edible forage—grow close to the tracks? Is escape blocked by steep slopes, rivers, or embankments? Is there a known wildlife movement corridor in the vicinity?
2. Document wildlife incidents. Train crews should record location, time of day, weather conditions and speed of train. How far ahead of the train was the animal when spotted; what was it doing? How did the train crew respond (whistle, horn, lights, other)? How did the animal react and what was the outcome?
3. Test the effectiveness of lights to alert and deter bears and other wildlife. Train crews have reported that flashing lights appear to scare bears from the tracks.
4. Proceed as quickly as possible with the car repairs. "Bad order cars" should be pulled from service immediately. Measure the amounts of grain spilled at various locations to document the effectiveness of the repairs. In addition, measure the effectiveness of the vacuum truck.
5. Convene a workshop of wildlife managers, animal behaviour specialists, railway experts and others to address the causes and solutions to train-wildlife collisions.

While collisions with animals can have serious consequences for wildlife populations, relatively few trains strike wildlife on the tracks. To gather sufficient data for analysis, a larger data set likely will be needed. We suggest that the Canadian National Railway Company and the Burlington Northern Santa Fe Railway be engaged to contribute to the incident site characterizations and the collision incident reports.

Chapter 3

# Ecological Mitigation Approaches and Performance

## Regulatory Compliance and Ecological Performance of Mitigation Wetlands in an Agricultural Landscape

**Terry J. VanDeWalle** (319-334-3755, tvandewalle@nrc-inc.net), Senior Environmental Scientist, Natural Resources Consulting, Inc., 2300 Swan Lake Blvd., Suite 200, Independence, IA 50644 USA

**Kelly E. Poole** (515-294-7467, kpoole@iastate.edu), Program Coordinator, Iowa Water Center at Iowa State University, 2218 Agronomy Hall, Iowa State University, Ames, IA 50011 USA

**Scott C. Marler** (515-239-1510, scott.marler@dot.iowa.gov), Water Resources Program Manager, Iowa Department of Transportation, 800 Lincoln Way, Ames, IA 50011 USA

**Craig A. Chumbley** (319-232-6531, craig.chumbley@earthtech.com), Environmental Scientist, Earth Tech, Inc., 501 Sycamore Street, Suite 222, Waterloo, IA 50703 USA

**Abstract:** The success of wetland mitigation projects nationwide is typically assessed by comparing the total number of wetland mitigation acres attained to the total number of mitigation acres required by Section 404 permits. In the absence of performance measurements on mitigation wetlands, the success of compensatory mitigation in replacing the ecological values of impacted wetlands is increasingly questioned by wetland scientists. This study focuses on evaluating regulatory compliance and ecological performance of mitigation wetlands in Iowa. Regulatory compliance was determined by comparing delineated wetland areas to permitted losses and by evaluating completeness of permit conditions at 24 randomly selected Iowa Department of Transportation wetland mitigation sites. In a separate study, intensive biological inventories were used to evaluate ecological performance at 12 mitigation and three reference wetlands. Species richness and abundance data were collected on algae, protozoa, aquatic invertebrates, butterflies, amphibians, reptiles, birds and mammals at each site. Species richness and diversity at mitigation sites and reference sites were compared to determine if mitigation wetlands are performing differently than reference wetlands in Iowa. The results are valuable for building and expanding the tools and knowledge necessary to effectively assess and manage the ecological performance of compensatory mitigation wetlands and improve the ecological effectiveness of wetland mitigation.

### Introduction

Section 404 of the Water Pollution Control Act or Clean Water Act (CWA) requires mitigation for unavoidable wetland losses resulting from transportation related impacts. Scrutiny of compensatory wetland mitigation programs across the country has taken place in recent years (National Research Council 2001; Storm and Stellini 1994). In the late 1990's, the National Research Council established the Committee on Mitigating Wetland Losses to evaluate how compensatory mitigation required under Section 404 of the CWA is contributing toward satisfying the overall objective of restoring and maintaining the quality of the nation's waters (National Research Council 2001). The committee concluded that the mitigation program fails to meet the goal of no net loss of wetlands for wetland functions. In addition, the committee found that permit conditions fail to clearly define performance expectations and that the mitigation program lacks a suitable mechanism to assure compliance. These conclusions have resulted in increased scrutiny and criticism of compensatory mitigation programs nationwide.

Several recent studies have attempted to evaluate the degree of success of compensatory wetland mitigation programs in other states. Brown and Veneman (2001) found over 50 percent of the mitigation sites sampled (n = 114) were not in compliance with wetland regulations. Sites failed to meet permit conditions largely due to acreage shortfall and out of kind mitigation (e.g., the mitigation wetland was not the type of wetland specified in the permit). Failure due to sites having less area than required by the permit is not uncommon. Nearly 75 percent of the mitigation sites reviewed in Tennessee failed to meet acreage requirements (Morgan and Roberts 2003) and in a similar study, researchers found 44 percent of the sites (n = 44) assessed failed to meet area requirements resulting in a net loss of wetlands (Robb 2002). With an increased awareness in wetland mitigation failure, regulatory agencies are initiating reviews of programs nationwide.

A steady increase in non-compliance inquiries in Iowa prompted the Iowa Department of Transportation to evaluate the compensatory mitigation program at two levels: regulatory compliance and ecological performance. The research objectives of these studies are to:

1. Determine the degree of regulatory compliance with requirements specified in the Clean Water Act Section 404 permits.
2. Quantify biological diversity of mitigation and reference wetlands.
3. Determine if mitigation and reference wetlands are functioning differently.

## Methods

### Data Collection

*Regulatory Compliance*

Wetland areas were delineated at 24 randomly selected Iowa Department of Transportation wetland mitigation sites (Figure 1 and Table 1). Wetlands at each study site were identified and their boundaries delineated using the Routine On-Site Determination Method as defined in the Corps of Engineers Wetlands Delineation Manual (Environmental Laboratory 1987). Wetland delineations were conducted in August and September 2003 and from May through August 2004. Wetlands were classified using the Cowardin et al. (1979) system.

Wetland boundaries were identified in the field and mapped using a Trimble GeoExplorer CE® Global Positioning System (GPS) receiver. Data from the receiver were post-processed using Trimble Pathfinder Office® version 3.00 software for an accuracy of <1 meter. The GPS data were then transferred to aerial photography. Because of the variability in mitigation sites, permit conditions, and mitigation objectives, additional data were collected to determine permit compliance (e.g., tree planting survival, waterfowl nesting islands) at specific sites as needed.

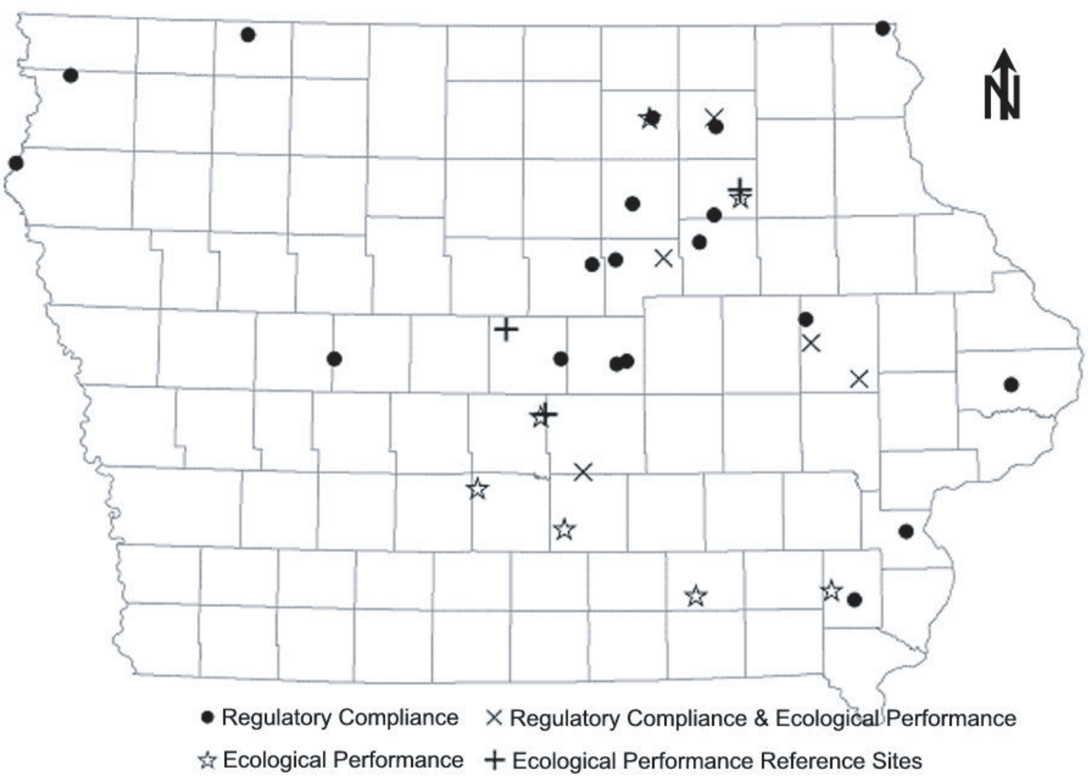



Figure 1. Location of mitigation and reference wetlands evaluated for regulatory compliance and ecological performance in Iowa, USA.

Table 1: Characteristics of mitigation and reference wetlands evaluated for regulatory compliance and ecological performance in Iowa, USA

| Site Name | Year Constructed | Mitigation Type |
|---|---|---|
| **Mitigation Sites** | | |
| 255th Street | 2000 | Creation |
| Abma Tract | 2001 | Creation |
| Akron Wetland Mitigation Site | 1999 | Restoration |
| Allbones Wetland Mitigation Site | 1997 | Restoration |
| Badger* | 2000 | Restoration |
| Boevers* | 2006 | Creation |
| Brush Creek* | 1998 | Restoration |
| Colo Bogs Cummings Tract | 1997 | Restoration |
| Denver Bypass 1 | 1994 | Restoration |
| Dike Mitigation Site B* | 1999 | Creation |
| Dunbar Slough | 2001 | Restoration |
| George Wyth State Park | 1994 | Creation |
| Grooms* | 2004 | Restoration |
| Hayes Lake | 1998 | Creation |
| Heartland Fen | 2000 | Creation |
| Indian Slough | 1998 | Restoration |
| Jarvis* | 2003 | Restoration |
| Lago Tract Welch WPA | 2001 | Restoration |
| Mink Creek* | 1998 | Creation |
| New Hampton Bypass Mitigation Site 1* | 2002 | Restoration |
| New Hampton Bypass Mitigation Site 2 | 2002 | Enhancement |
| Palisades Wetland Mitigation Site* | 2001 | Creation |
| Partridge Meadows | 1999 | Creation |
| Pleasantville* | 2002 | Restoration |
| Rainsbarger Wetland Mitigation Site | 2002 | Creation |
| Rice Grass B | 1995 | Creation |
| Rice Grass A | 1996 | Creation |
| South Beaver Creek Wellsburg | 2002 | Creation |
| South Point* | 2004 | Creation |
| Welton Borrow Site | 1995 | Creation |
| Wickiup Hill Linn CCB* | 2000 | Restoration |
| **Reference Sites** | | |
| Doolittle Prairie | - | - |
| Hay-Buhr | - | - |
| Engeldinger Marsh | - | - |

* Mitigation sites included in ecological performance study.

### Ecological Performance

Intensive biological inventories were used to evaluate the biological condition of 12 Iowa Department of Transportation mitigation wetlands and three reference wetlands in Iowa (figure 1 and table 1). Species richness and abundance data were collected at each site for eight species groups, including algae, protozoa, aquatic invertebrates, butterflies, amphibians, reptiles, birds and mammals.

*Algae, protozoa, and aquatic invertebrates*. Field collection of algae, protozoa, and aquatic invertebrates was done using benthic and surface grab sampling and net sampling for plankton (APHA 1998; US EPA 2002a). Each of the study sites was sampled over a period of three days during five sampling periods between April and November. An average of four samples was collected at each site on each sampling day and samples from similar habitats at any one site were pooled. Sample analysis included microscopic examination of fresh (or settled) samples and digestion and preservation of diatom samples (APHA 1998).

*Butterflies*. Butterfly data were collected on the species present at each study site every 10 days during the non-frost season. Methods included meander surveys of all habitats and counts of all individuals of each species encountered (Pollard 1991; Pollard and Yates 1993).

*Vertebrates*. Amphibians were surveyed from April through June to insure sampling of all species present (Heyer et al, 1994; US EPA 2002b). Salamanders were trapped April through June using wire screen funnel traps and hand collected during terrestrial and aquatic searches throughout the survey. Calling surveys and hand collecting of frogs and toads were conducted primarily from April through June during the time that each species is known to breed and continued throughout the survey.

Reptiles were surveyed from May through mid-July when they are most active. Snakes and lizards were documented through meander surveys of the study sites. Aquatic turtle trapping was conducted in all permanent bodies of water possessing suitable turtle habitat using modified fyke nets as described by Legler (1960).

The most intensive surveys for amphibians, reptiles and small mammals utilized drift fences as described by Christiansen and VanDeWalle (2000). Drift fence sampling took place from May through September. Sherman live traps were used in conjunction with the drift fence for small mammals.

Migratory birds were surveyed during March and November and breeding bird surveys took place from May through July (Fairbairn and Dinsmore 2001; US EPA 2002c).

*Voucher specimens*. Voucher specimens were taken for difficult identifications under current Iowa Department of Natural Resources Scientific Collecting Permits. Voucher specimens collected for this project were processed following standard methods for each species group (Heyer et. al. 1994; Wilson et. al. 1996; APHA 1998; Deblase and Martin, 2000; Winter 2000; Simmons 2002; US EPA 2002a).

**Data Analysis**

*Regulatory Compliance*

Regulatory compliance was determined by comparing the delineated wetland acreage at each study site to the total wetland acreage requirements specified in individual CWA Section 404 permits, regardless of how the acreage was obtained (creation, restoration, enhancement or preservation).

*Ecological Performance*

Diversity at mitigation and reference sites was quantified using Hill's N1 (Hill 1973) as a representative measure of species diversity. Hill's N1 is given by:

$$N1 = \exp(-\sum p_i \ln(p_i)$$

where $p_i$ is the proportion of a given species found at a site. N1 is one method of calculating the "effective number of species" (MacArthur 1965; Hill 1973). It is the exponential of the Shannon index; unlike Shannon's index, Hill's N1 represents a true diversity that behaves linearly and is therefore easier to interpret ecologically than the Shannon form (Peet 1974). Because it is derived from Shannon's index, it also has the advantage of not emphasizing either rare or common species (Jost 2006).

Species diversity of mitigation sites versus reference sites was compared using the Mann-Whitney two-sample rank-sum test (Mann and Whitney 1947) to determine if mitigation wetlands are performing differently than reference wetlands.

Because of the differing number of mitigation sites (n=12) and reference sites (n=3), species richness of mitigation sites versus natural sites was compared using expected species accumulation curves, i.e., sample-based rarefaction curves (Gotelli and Colwell 2001). The curves were calculated using EstimateS Version 8 (Colwell 2006). This program calculates the expected species accumulation and its associated 95 percent confidence intervals using the methods of Colwell et al. (2004).

For each of the major groups of organisms, observations of species abundance for all mitigation sites were amalgamated into one dataset, and data for reference sites were amalgamated into another. As recommended by Gotelli and Colwell (2001), the expected species accumulation curves and their 95 percent confidence interval curves by individuals were rescaled. By comparing the curves for each group of organisms, species richness between the two groups of sites could be compared based upon the actual number of individuals recovered.

## Results

**Regulatory Compliance**

Of the 24 sites evaluated for regulatory compliance, 58 percent (n=14) meet or exceed Section 404 permit requirements. Net gain (13 sites) ranged from 0.19 acre to 27.2 acres. Two sites, Abma Tract and Colo Bogs Cummings Tract, exceed the requirements by 929 percent and 631 percent, respectively. Forty –one percent (n=10) of the mitigation sites failed to meet Section 404 permit requirements. Net loss (10 sites) ranged from 0.2 acre to 14.6 acres. The Denver Bypass 1 site was the worst performer, having failed to establish any wetland mitigation acres and the Akron Wetland Mitigation Site was the best performer with slightly more than 27 wetland mitigation acres, over the permit requirement. A summary of Section 404 permit requirements, delineated wetland acreage and percent compliance for each of the study sites is shown in table 2.

A total of 338.02 acres of wetland were delineated at the 24 sites. This represents a total net increase of 43.91 acres over the Section 404 permit requirements for the projects. However, as shown in Table 2, the majority of the increase is due to just two sites, the Akron Wetland Mitigation Site and Colo Bogs Cummings Tract. If these two sites were removed from the analysis, it would result in a total net loss of 8.58 acres.

Table 2: Section 404 Permit Requirement, delineated wetland acreage and percent compliance for each study site evaluated for regulatory compliance

| Site Name | Section 404 Permit Requirement (Acres) | Delineated Wetland (Acres) | Net Gain/Loss (Acres) | Percent Compliance |
|---|---|---|---|---|
| 255th Street | 3.87 | 4.36 | 0.49 | 112.7 |
| Abma Tract | 1 | 9.29 | 8.29 | 929.0 |
| Akron Wetland Mitigation Site | 36 | 63.15 | 27.2 | 175.4 |
| Allbones Wetland Mitigation Site | 6 | 5.5 | -0.5 | 91.7 |
| Brush Creek | 16.6 | 14.11 | -2.49 | 85.0 |
| Colo Bogs Cummings Tract | 4.77 | 30.11 | 25.34 | 631.2 |
| Denver Bypass 1 | 14.6 | 0 | -14.6 | 0.0 |
| Dike Mitigation Site B | 10 | 14.11 | 4.11 | 141.1 |
| Dunbar Slough | 34 | 37.32 | 3.32 | 109.8 |
| George Wyth State Park | 23.3 | 15.3 | -8 | 65.7 |
| Hayes Lake | 0.6 | 0.4 | -0.2 | 66.7 |
| Heartland Fen | 2.5 | 3.36 | 0.86 | 134.4 |
| Indian Slough | 72.8 | 72.8 | 0 | 100.0 |
| Lago Tract Welch WPA | 5.1 | 7.85 | 2.75 | 153.9 |
| New Hampton Bypass Site 1 | 11 | 10.51 | -0.49 | 95.5 |
| New Hampton Bypass Site 2 | 1.3 | 2.24 | 0.94 | 172.3 |
| Palisades Wetland Mitigation Site | 3.2 | 5.08 | 1.88 | 158.8 |
| Partridge Meadows | 7.5 | 7.69 | 0.19 | 102.5 |
| Rainsbarger Wetland Mitigation Site | 4.5 | 5.08 | 0.58 | 112.9 |
| Rice Grass B | 2 | 1.06 | -0.94 | 53.0 |
| Rice Grass A | 11.9 | 9.16 | -2.74 | 77.0 |
| South Beaver Creek Wellsburg | 2 | 1.6 | -0.4 | 80.0 |
| Welton Borrow Site | 3.07 | 4.37 | 1.3 | 142.3 |
| Wickiup Hill Linn CCB | 16.5 | 13.57 | -2.93 | 82.24 |
| **Totals** | 294.11 | 338.02 | 43.91 | 114.9 |

The 10 under-performing sites are split equally between creation and restoration (five each) (table 1). Five of these (50 percent) are more than five years post construction, two (20 percent) are five years post construction, one (10 percent) is three years post construction and the remaining two (20 percent) are one year post construction. Of the sites that meet or exceed permit requirements, approximately 93 percent are five years or less post construction and approximately 43 percent are only one year old. Only one of the 14 successful sites is more than five years old.

Overall, mitigation at these 24 sites has resulted in a net gain of nearly 44 acres of wetland over the acreage required by the Section 404 permits. As previously indicated just two sites account for the majority of the excess acreage. Only one site completely failed to meet the definition of a jurisdictional wetland, the Denver Bypass site, which was constructed in 1994 (tables 2 and 3).

### Ecological Performance

A summary of species diversity by study site is shown in table 3 and figures 2 and 3. As a way of comparing diversity between the 15 sites, overall diversity was calculated using the effective number of species for each of the eight species groups to determine an average rank for each site. The sites were then given an overall ranking of 1–15 based on the average rank, with 15 representing the highest overall species diversity (table 3 and figure 4).

Table 3: Summary of species diversity as estimated by effective number of species at 15 wetland study sites (12 mitigation and 3 reference) located in Iowa, USA (2005-2006)

| | Effective Number of Species (Hills's N1 ) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Algae** | **Protozoa** | **Aquatic Invertebrates** | **Butterflies** | **Amphibians** | **Birds** | **Mammals** | **Reptiles** | **Overall Site Rank** |
| **Mitigation Sites** | | | | | | | | | |
| South Point | 49.60 | 13.67 | 18.15 | 13.99 | 4.96 | 11.28 | 4.66 | 4.46 | 15 |
| Pleasantville | 46.29 | 18.81 | 11.54 | 12.34 | 2.84 | 4.82 | 6.97 | 1.75 | 13 |
| Mink Creek | 39.57 | 25.20 | 11.44 | 12.93 | 1.99 | 12.28 | 6.01 | 1.00 | 12 |
| Badger Creek | 22.02 | 14.68 | 9.10 | 14.83 | 2.08 | 7.74 | 4.20 | 5.86 | 10 |
| Brush Creek | 18.79 | 20.43 | 10.00 | 9.97 | 1.13 | 15.97 | 4.12 | 2.05 | 9 |
| Wickiup Hill | 18.16 | 8.49 | 4.11 | 12.68 | 1.89 | 18.02 | 6.02 | 1.89 | 8 |
| Grooms | 14.62 | 3.77 | 2.55 | 11.62 | 5.59 | 16.61 | 4.48 | 2.83 | 7 |
| New Hampton | 37.84 | 10.62 | 14.63 | 6.17 | 1.15 | 15.01 | 2.47 | 2.00 | 6 |
| Palisades | 30.26 | 15.64 | 15.00 | 8.66 | 1.11 | 8.33 | 3.52 | 1.51 | 5 |
| Dike | 14.43 | 16.31 | 7.02 | 9.33 | 3.43 | 7.88 | 6.35 | 1.00 | 4 |
| Jarvis | 0.00 | 0.00 | 0.00 | 13.93 | 4.34 | 14.85 | 2.31 | 1.89 | 3 |
| Boevers | 15.53 | 4.21 | 4.22 | 8.39 | 3.94 | 10.92 | 6.25 | 1.00 | 2 |
| **Reference Sites** | | | | | | | | | |
| Hay-Buhr Area | 28.30 | 28.82 | 8.47 | 9.57 | 1.85 | 17.41 | 6.73 | 7.56 | 14 |
| Engeldinger Marsh | 25.77 | 14.53 | 10.42 | 14.95 | 4.31 | 10.86 | 5.25 | 1.00 | 11 |
| Doolittle Prairie | 15.31 | 8.87 | 4.55 | 7.43 | 1.00 | 8.19 | 4.06 | 1.75 | 1 |
| Mann-Whitney U | 19 | 14 | 20 | 19 | 24 | 18 | 15 | 24 | 16 |
| 2-Tailed P* | 0.95 | 0.63 | 0.84 | 0.95 | 0.45 | 1.00 | 0.73 | 0.45 | 0.84 |

*Not significant at α =0.05

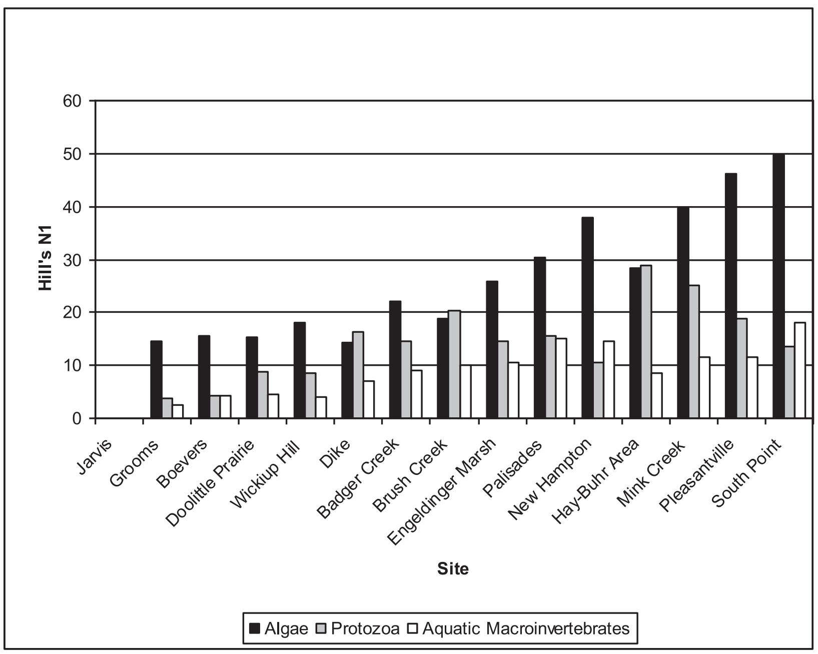



Figure 2. Biodiversity of aquatic organisms as estimated by effective number of species at 15 wetland study sites (12 mitigation and 3 reference) located in Iowa, USA (2005-2006).

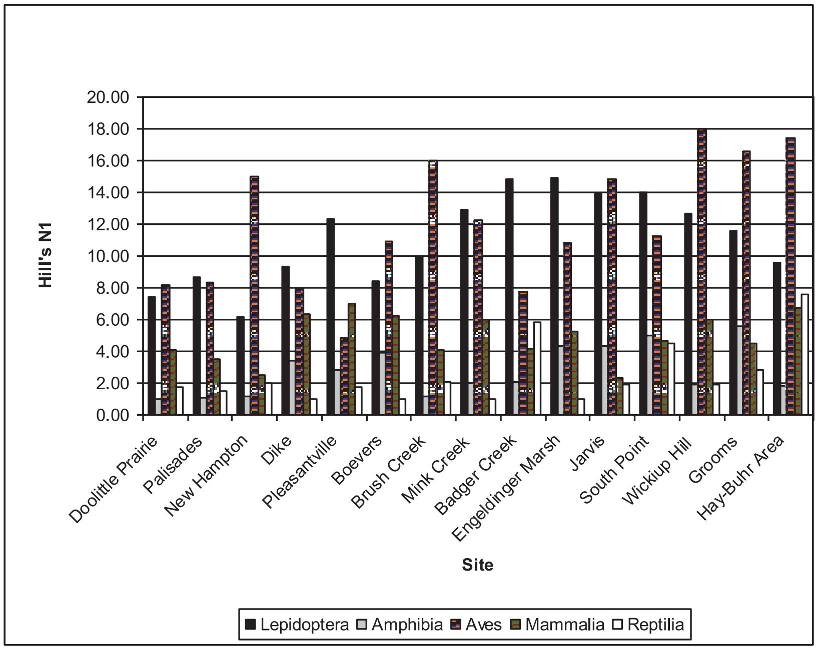



Figure 3. Biodiversity of terrestrial organisms as estimated by effective number of species at 15 wetland study sites (12 mitigation and 3 reference) located in Iowa, USA (2005-2006).

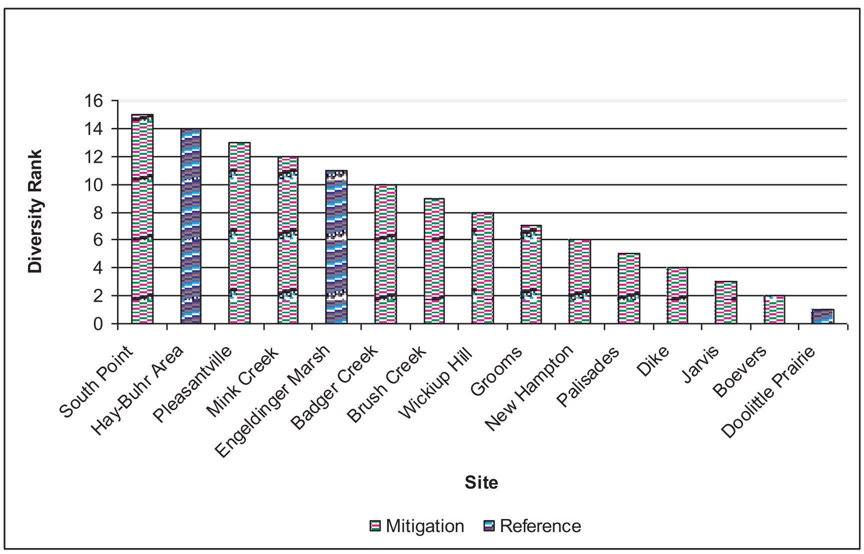



Figure 4. Overall species diversity found at 15 wetland study sites (12 mitigation and 3 reference) located in Iowa, USA (2005-2006).

The highest ranking site in terms of overall diversity is South Point, a large (40 acre), created mitigation site that was one year post construction at the time it was surveyed. South Point had the highest diversity of algae and aquatic invertebrates of any site (table 3 and figure 2), the second highest amphibian diversity and the third highest diversity of butterflies (table 3 and figure 3). Along with South Point, two of the reference sites (Hay-Buhr Area and Engeldinger Marsh) were in the top five in overall diversity.

The third reference site, Doolittle Prairie, ranked the lowest in overall diversity. Doolittle Prairie is a small (26 acre) native tallgrass prairie remnant with a series of small prairie potholes located across the site that was dedicated as one of Iowa's State Preserves in 1980. Portions of the site have never been plowed. Doolittle Prairie had the lowest amphibian diversity and the second lowest butterfly diversity (table 3 and figure 3). With respect to protozoa and aquatic invertebrates, the only sites with lower diversity than Doolittle Prairie were sites that were dry all, or a large portion, of the year in which they were sampled.

When the effective number of species (Hill's N1) by species group at mitigation sites is compared to that found at reference sites, no significant differences are found within any of the groups (table 3). Because the effective number of species is a measure of the number of common species at a site, this result suggests that the number of common species within each species group is approximately equal between mitigation and reference sites. In an effort to further explore the question of whether mitigation sites are performing differently than reference sites, the species richness of mitigation sites versus reference sites was compared using expected species accumulation curves (figures 5a–5h).

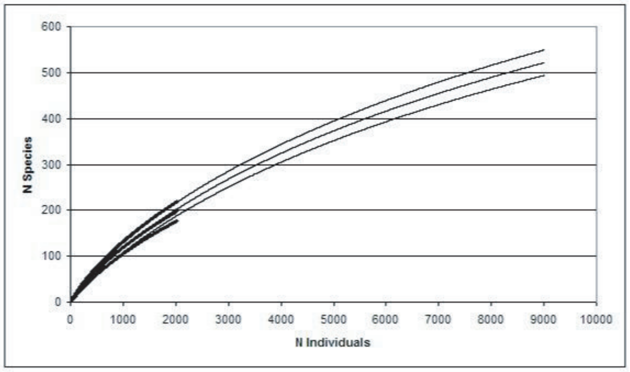
The species accumulation curves for algae, protozoa, and aquatic invertebrates all show similar patterns (figures 5a–5c). Based on the numbers of individuals recovered, the 95 percent confidence intervals for the mitigation sites overlap those of the reference sites for all three groups of organisms. This indicates that insufficient evidence exists to reject the null hypothesis of no significant difference in species richness between the two types of sites given comparable sample sizes. In addition, as more individuals are recovered, the number of species for both mitigation and reference sites do not appear to be converging to an asymptote, indicating that many additional species remain to be recovered. For algae, rarefaction of the mitigation site curve to a sample size of about 2000 individuals (the total for the pooled reference sites) suggests that when the number of individuals recovered is taken into account, "rarefied" species richness at the two types of sites is approximately equal at 200. For aquatic invertebrates at a sample size of about 110 individuals (the total for the pooled reference sites) it is approximately equal at 29 species. Based on a sample size of about 60 individuals (the total for the pooled reference sites), "rarefied" species richness for protozoa ranges from approximately 63 to 69 species at the two types of sites.

Among vertebrate taxa, the species accumulation curves for birds (figure 5d) exhibit patterns similar to those noted for algae, protozoa, and aquatic invertebrates. No significant difference in species richness was detected between the two types of sites given comparable sample sizes, and many additional species probably remain to be recovered. Rarefaction of the mitigation site curve to a sample size of about 575 individuals (the total for the pooled reference sites) suggests that "rarefied" avian species richness ranges from approximately 54 to 62 species between the two types of sites.

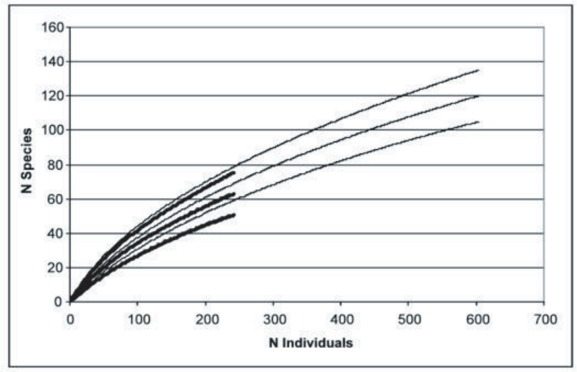
The species accumulation curves for mammals (figure 5e) exhibit a slightly different pattern than that noted for birds. No significant difference in species richness was detected between the two types of sites given comparable sample sizes, but the curve for mammals at the mitigation sites appears to be converging to an asymptote of about 25 species, thereby suggesting that all common and most rare species have been recovered. The curve for reference sites does not appear to converge to an asymptote, indicating that many additional species probably remain to be recovered. Rarefaction of the mitigation site curve to a sample size of about 330 individuals (the total for the pooled reference sites) suggests that "rarefied" mammalian species richness ranges from approximately 14 to 16 species between the two types of sites.

For reptiles, the species accumulation curves are somewhat similar to those for mammals (figure 5f). No significant difference in species richness was detected between the two types of sites given comparable sample sizes. The curve for reptiles at the mitigation sites appears to be converging to an asymptote, thereby suggesting that most species have been recovered. The curve for reference sites is not converging to an asymptote, indicating that most likely only the most common species have been found and that many additional species probably remain to be recovered. In addition, the 95 percent confidence intervals for the reference sites are very wide, ranging from five to 15 species at a sample size of 21 individuals (the total number recovered from all of the reference sites). This reflects both the small sample size and the high variability in observed reptilian species richness at the reference sites (one species at Engeldinger Marsh, nine at Hay-Buhr, and two at Doolittle Prairie). Rarefaction of the mitigation site curve to a sample size of 21 individuals (the total for the pooled reference sites) suggests that "rarefied" reptilian species richness ranges from approximately seven to 10 species between the two types of sites.

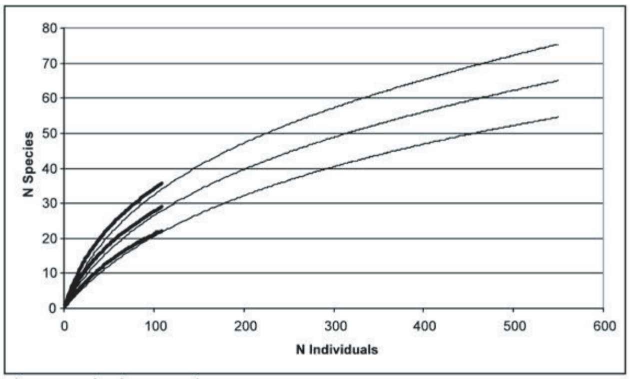
The species accumulation curve for amphibians (figure 5g) at mitigation sites is noteworthy because beginning at a sample size of about 1,000 individuals it converges to an asymptote of 13 species, suggesting that all available species have been found at this group of sites. The 95 percent confidence intervals for the mitigation sites overlap those of the reference sites, indicating that insufficient evidence exists to reject the null hypothesis of no significant difference in species richness between the two types of sites. However, at a sample size of about 190 individuals, the curve for reference sites shows signs of beginning to converge to an asymptote at an undefined level lower than that noted for the mitigation sites. This suggests that although additional species remain to be recovered at the reference sites, additional



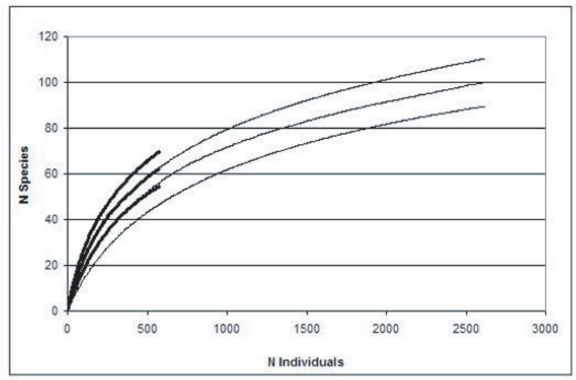

a) algae



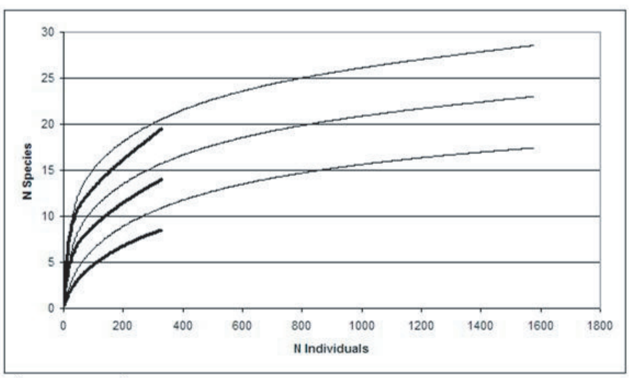

b) protozoa



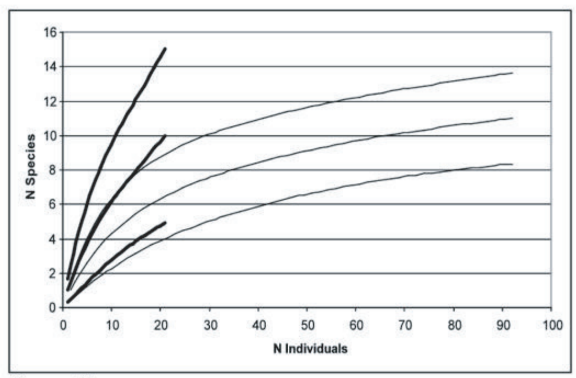

c) aquatic invertebrates



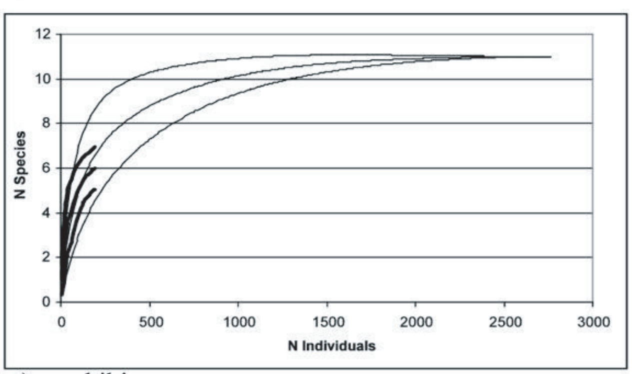

d) birds



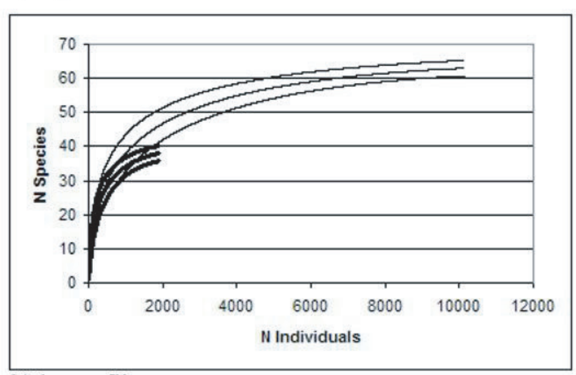

e) mammals




f) reptiles




g) amphibians




h) butterflies

Figure 5. Species accumulation curves. Thin line = mitigation site; thick line = reference site. The middle line in each curve represents the mean. The outer two lines represent the 95% confidence intervals. If the 95% confidence intervals for the two curves overlap, this indicates there is no significant difference in species richness between the two groups.

sampling at the reference sites could cause the curves to diverge, with the reference sites possibly being less diverse than the mitigation sites. Rarefaction of the mitigation site curve to a sample size of about 190 individuals (the total for the pooled reference sites) suggests that "rarefied" amphibian species richness ranges from approximately six to seven species between the two types of sites.

The species accumulation curves for butterflies (figure 5h) indicate that "rarefied" species richness is significantly higher at the mitigation sites than it is at the reference sites. The 95 percent confidence intervals for the two groups of sites diverge at about 1,800 individuals, providing evidence sufficient to reject the null hypothesis of no significant difference in species richness between the two types of sites. The curves for both groups of sites appear to converge to asymptotes (approximately 65 species at mitigation sites and approximately 40 species at reference sites, a difference of 63 percent). Rarefaction of the mitigation site curve to a sample size of about 1,900 individuals (the total for the pooled reference sites) suggests that "rarefied" butterfly species richness ranges from approximately 38 species at reference sites to approximately 46 species at mitigation sites, a difference of 21 percent. This result, in combination with the finding of no difference in the effective number of species between the two groups of sites, suggests that the difference in species diversity is due to the presence of significantly more rare species at the mitigation sites.

## Discussion

Using Section 404 permit acreage requirements as the criteria for measuring success, 58 percent of the wetland mitigation sites evaluated for regulatory compliance are successful. Using net gain/loss as the measure of success, wetland mitigation has resulted in a net increase of nearly 44 acres of wetland over what was required by permits. While the program as whole has been marginally successful at meeting permit requirements, individual sites have done exceptionally well, which has resulted in the large overall net increase.

These results are in contrast to those of previous studies in Massachusetts, where over 50 percent of the study sites failed to meet regulatory requirements (Brown and Veneman 2001), and Tennessee where 75 percent of the study sites failed to meet acreage requirements (Morgan and Roberts 2003). Percent success in meeting acreage requirements in this study was similar to the 56 percent found by Robb (2002) in Indiana. However, in the Indiana study, the 44 percent of the sites that did not meet the acreage requirements resulted in a net loss of wetlands, as opposed to this study which found an overall net gain in wetland acreage.

When the age of the sites is taken into consideration, the data suggest that sites that have been constructed in the last five years are more successful than sites constructed five or more years ago. Of the sites constructed in the last five years, 75 percent meet or exceed permit requirements. Only 33 percent of the sites constructed five or more years ago meet or exceed permit requirements, suggesting that the Iowa Department of Transportation's Compensatory Wetland Mitigation Program has been improving with time. In all likelihood, this is due to improved site selection criteria and better site design.

This improvement in the success of meeting regulatory requirements may reflect the development and growth of wetland programs within Departments of Transportation in many states. In the past, wetland mitigation design was often done as an afterthought by civil engineers with little or no ecological training. Wetland mitigation was commonly located in borrow sites with that hope that some cattails would grow satisfying the wetland requirement. Many of these sites resulted in nothing more than sterile ponds.

Within the last 15 years or so, many Departments of Transportation have begun staffing their wetland and water resources departments with individuals trained in ecology or wetland science. In addition, outside environmental consultants with expertise in wetland science and design are often brought in as part of the design team. The result has been the development of mitigation sites that are designed to function as wetlands.

Not only are these better designed sites more successful at meeting Section 404 permit requirements, they no doubt function ecologically better as well. Data from this study suggest that ecologically, mitigation sites in Iowa are functioning similarly to reference sites. However, the lack of convergence to an asymptote in many of the species accumulation curves suggests that for the most part sampling for many of the sites/species groups (particularly the reference sites) is effectively incomplete, which may explain the inability to demonstrate differences in the effective number of species (Hill's N1) at mitigation versus reference sites. A true difference in species diversity may exist between the two groups of sites; however, due to small sample size and/or a lack of a sufficiently powerful statistical test, a true difference may have gone undetected.

Even though an overall difference in species diversity between mitigation and reference sites was not detected, differences between individual mitigation and reference sites are apparent from the data. The starkest contrast is between the newly constructed South Point with the highest overall species diversity and Doolittle Prairie State Preserve, which had the lowest overall species diversity. One possible explanation for the difference in diversity between the newly constructed South Point and the remnant wet prairie at Doolittle is the connectivity of each site to other suitable habitat. South Point has a direct connection to a 6,500 acre wildlife area located along the Skunk River, which is home to a diverse collection of woodland, wetland and prairie wildlife. In contrast, Doolittle Prairie is located in a highly agricultural part of the state and is surrounded by intensively cropped agricultural land. The fencerows that formerly bordered the site have been removed and the adjacent fields are plowed right to the edge of the prairie. No direct connection to any large area of natural habitat exists.

Within species groups, a significant difference in species richness between mitigation and reference sites was found only with the butterflies (figure 5h). No significant difference in the number of effective butterfly species between the mitigation and reference sites was found (table 3), indicating that both groups contain approximately equal numbers of common species. The 21 percent difference seen in “rarefied” butterfly species richness between mitigation and reference sites therefore suggests that the difference in species diversity is the result of more rare species being found at the mitigation sites. The underlying reason(s) for why mitigation sites may be able to harbor a larger assemblage of butterfly species is beyond the scope of this study, but may be related to such factors as plant species diversity, plant community types, connectivity to other suitable habitat and management.

Many factors can influence whether a site is successful at meeting its regulatory requirements, including site selection, site design and construction. Even with the best site location and design, an improperly constructed site may result in an acreage shortfall. Although a site may be unsuccessful from a regulatory standpoint, it still may be successful from an ecological standpoint and therefore may still be replacing the functional values lost with the impacted wetland.

The Brush Creek mitigation site in this study is an example of a site that is unsuccessful in meeting its Section 404 requirements, but is performing well ecologically. The Brush Creek site is only 85 percent compliant with its permit requirements, resulting in a net loss of 2.49 acres of wetland (table 2). Ecologically, it ranks ninth out of 15 in overall species diversity (figure 4), had the fourth highest diversity of birds and a higher diversity of protozoa, aquatic invertebrates, butterflies, reptiles and birds than two of the three reference sites (table 3; figures 2 and 3).

Likewise, a site can be successful in meeting its regulatory obligations, but perform poorly ecologically, such as the Dike mitigation site, which is 141 percent compliant with its permit requirements, resulting in a net increase of 4.11 acres of wetland (table 2). However, the site ranks fourth out of 15 in overall species diversity and on the low end of the diversity for many of the species groups (table 3; figures 2 and 3). These examples serve to illustrate that the success/performance of a wetland mitigation site should be evaluated on both regulatory compliance and ecological performance.

**Biographical Sketches:** Terry J. VanDeWalle is the Senior Environmental Scientist for Natural Resources Consulting, Inc in Independence, Iowa. He has 20 years of natural resource experience related to wetland delineation, wetland mitigation design and monitoring, coordination of environmental impact statements and assessments, animal and natural areas surveys, and threatened and endangered species surveys. He has specialized experience in wetland permitting and mitigation for Section 404 of the Clean Water Act and ESA Section 7 consultation.

Kelly E. Poole is the Program Coordinator for the Iowa Water Center at Iowa State University, Ames, Iowa. She has over 11 years of natural resource experience related to aquatic ecology, biological sampling and habitat evaluation, conservation planning for protected species, restoration ecology, and wetland biology. She has specialized experience in wetland permitting and mitigation for Section 404 of the Clean Water Act and threatened and endangered species surveys.

Scott C. Marler is the Water Resources Program Manager for the Iowa Department of Transportation, Ames, Iowa. He has over 13 years of natural resource experience related to wetland assessment, wetland delineation, wetland mitigation, wetland biology, plant identification, plant ecology, vegetation analysis, and habitat management. He has specialized experience in wetland permitting and mitigation for Section 404 of the Clean Water Act and works directly with the U.S. Army Corps of Engineers, the Iowa Department of Natural Resources, the US Fish and Wildlife Service, the US EPA and other public and private entities

Craig A. Chumbley is an Environmental Scientist for Earth Tech, Inc in Waterloo, Iowa. He has over 15 years of natural resource experience related to paleoecology, coordination of environmental impact statements, and data analysis. He has specialized experience in geographic information systems and statistical analysis and works frequently with the Iowa Department of Natural Resources and other public and private entities.

## References

APHA (American Public Health Association, American Water Works Association, and Water Environmental Federation). 1998. Standard methods for the examination of water and wastewater. 20th edition. American Public Health Association, Washington, DC.

Brown, S.C. and P.L.M. Veneman. 2001. Effectiveness of compensatory wetland mitigation in Massachusetts, USA, Wetlands, 21(4): 508-518.

Christiansen, J. L. and T. J. VanDeWalle. 2000. Effectiveness of three trap types in drift fence surveys. Herpetol. Rev. 31(3):158-160.

Colwell, R. K., C. X. Mao, & J. Chang. 2004. Interpolating, extrapolating, and comparing incidence-based species accumulation curves. Ecology 85, 2717-2727.

Colwell, R.K. 2006. *Estimate* S: Statistical estimation of species richness and shared species from samples. Version 8. Persistent URL <purl.oclc.org/estimates>.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. “Classification of Wetlands and Deepwater Habitats of the United States,” FWS/OBS-79/31, U.S, Fish and Wildlife Service, Office of Biological Services, Washington, DC.

DeBlase, A.F. and R.E. Martin, 2000. A Manual of Mammology with keys to families of the world, 3rd ed.

Environmental Laboratory. 1997. “Corps of Engineers Delineation Manual,” Technical Report YR-87_1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Fairbairn, S. E., and J. J. Dinsmore. 2001. Local and landscape-level influences on wetland bird communities of the prairie pothole region of Iowa, USA. Wetlands 21:41-47.

Gotelli, N., and R. K. Colwell. 2001. Quantifying biodiversity: Procedures and pitfalls in the measurement and comparison of species richness. Ecology Letters 4, 379-391.

Heyer, W.R., M.A. Donnelly, R.W. McDiarmid, L.C. Hayek, M.S. Foster (Eds.). 1994. Measuring and monitoring biological diversity: Standard methods for amphibians. Smithsonian Institution Press, Washington, D.C.

Hill, M.O. (1973). Diversity and evenness: a unifying notation and its consequences. Ecology 54:427-431.

Legler, J. M. 1960b. A simple and inexpensive device for trapping aquatic turtles. Utah Acad. Proc. 37:63-66.

Jost, L. 2006. Entropy and diversity. Oikos 113:2, 363-375.

MacArthur, R.H. 1965. Patterns of species diversity. Cambridge Philosophical Society Biological Review 40: 510-533.

Mann, H. B. and D.R. Whitney. 1947. On a test of whether one of two random variables is stochastically larger than the other. Annals of Mathematical Statistics 18, 50-60.

Morgan, K.L. and T.H. Roberts. 2003. Characterization of wetland mitigation projects in Tennessee, USA, Wetlands, 23(1): 66-69.

National Research Council. 2001. Compensating for Wetland Losses Under the Clean Water Act, National Academy Press, Washington, DC, USA.

Peet, R.K. 1974. The measurement of species diversity. Annual Review of Ecology and Systematics 5:285-307.

Pollard, Ernest. 1991. Monitoring Butterfly Numbers, Monitoring for Conservation and Ecology, Barrie Goldsmith Ed., Chapman and Hall, London.

Pollard, E. and T.J. Yates. 1993. Monitoring Butterflies for Ecology and Conservation. Chapman & Hall, London.

Robb, J.T. 2002. Assessing wetland compensatory mitigation sites to aid in establishing mitigation ratios. Wetlands. 22(2): 435-440.

Simmons, J.E. 2002. Herpetological Collecting and Collections Management. Society for the Study of Amphibians and Reptiles Herpetological Circular No. 31. pp. vi + 1-153.

Storm, L. and J. Stellini. 1994. Interagency follow-through investigation of compensatory wetland mitigation sites. Joint Agency Staff Report, U.S. Environmental Protection Agency, Region 10, Water Division, Wetlands Section, Seattle, WA, USA and U.S. Fish and Wildlife Service, Ecological Services. Washington, DC, USA. EPA 910-R-94-013.

U.S. EPA. 2002a. Methods for Evaluating Wetland Condition: Using Algae to Assess Environmental Conditions in Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA/822-R-02-021.

--------2002b. Methods for Evaluating Wetland Condition: Using Amphibians in Bioassessments of Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA/822-R-02-022.

--------2002c. Methods for Evaluating Wetland Condition: Biological Assessment Methods for Birds. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA/822-R-02-023.

Wilson, D.E., F.R. Cole, J.D., Nichols, R. Rudran, M.S. Foster (Eds.). 1996. Measuring and monitoring biological diversity: Standard methods for mammals. Smithsonian Institution Press, Washington, D.C.

Winter, William D. Jr. 2000. Basic Techniques for Observing and Studying Moths and Butterflies, The Lepidopterists Society, Natural History Museum, 900 Exposition Blvd., Los Angeles, CA.

**Acknowledgements:** We thank the Iowa Highway Research Board, USEPA Region 7 and the Iowa Department of Transportation for funding the study. We thank the following individuals for collection of species data used in this project, Neil Bernstein (vertebrates), Steve Main (algae, protozoa, aquatic invertebrates), David McCullough (vertebrates), Frank Olsen (butterflies), Jeff Parmelee (vertebrates), Dennis Schlict, (butterflies) and Wendy VanDeWalle (vertebrates). We thank Lou Jost for several useful discussions regarding data analysis.

# Effective Wetland Mitigation Site Management: Plant Establishment to Closeout

**Cyndie Prehmus** (360-570-6644, prehmuc@wsdot.wa.gov),
**Bob Thomas** (360-705-7405, thomasbo@wsdot.wa.gov), and
**Paul Wagner** (360-705-7406, wagnerp@wsdot.wa.gov), Biology Branch, Environmental Services Office, Washington State Department of Transportation, P. O. Box 47331, Olympia, WA 98504-7732 USA

**Abstract:** Wetland mitigation projects in Washington State are developed using well-defined and documented guidance in the design, permitting and construction phases. Traditionally, there has been little guidance for post construction management of these sites. Post-construction management has largely been left to the discretion of the permit holder. There were no methods in place to effectively determine when regulatory requirements were achieved, or a standard to certify that the site was considered complete. Over the last decade, the Washington State Department of Transportation (WSDOT) has developed standardized mechanisms and processes for site management, reporting, and closeout procedures. These include establishment of site management crews, predictable funding sources for management activities, monitoring and reporting methods, and inter-disciplinary adaptive management teams that develop strategies for short and long-term site management. Recently, WSDOT partnered with local U. S. Army Corps of Engineers staff to develop a process for closing out mitigation sites with fulfilled permit requirements. These process improvements provide predictability for our mitigation efforts and long-term budget requirements to support site management activities. They also increase our credibility with the resource agencies by demonstrating the effectiveness of our adaptive management. These overall improvements also benefit future mitigation project proposals. We intend to use our monitoring data to increase the scientific knowledge about mitigation site development and management practices, and to continue the process of fine-tuning ecologically meaningful performance measures for future mitigation projects.

## Introduction

Creating, restoring, and enhancing wetland functions to compensate for impacts are a major component of the Washington State Department of Transportation's (WSDOT) environmental efforts. More than twenty years of minimizing the loss of wetlands while maintaining and improving state highway infrastructures has provided significant experience in successful wetland mitigation site establishment.

When a WSDOT project may impact a wetland area, our planning process seeks ways to avoid or minimize how the wetland is affected. As responsible environmental stewards, and as required by federal law, state law, and WSDOT policy, we mitigate for lost wetland acreage and function when unavoidable impacts occur. The resulting mitigation sites are a long-term environmental commitment for the agency.

## Elements of a Successful Mitigation Program

Our wetland mitigation approach includes three distinct phases. To start, WSDOT has strong organizational commitment to environmental stewardship, and providing appropriate funding to support environmental efforts. Our headquarters office provides guidance and policy support to region staff with the intent of improving our mitigation performance on an ongoing basis. During mitigation site establishment, we use an adaptive management paradigm that includes a statewide monitoring program, rapid feedback and coordination with site managers, several types of site management work crews, and a strategy for dealing with problematic sites. And finally, when a mitigation site is well established and we have met our commitments, we progress through a closeout process into long-term management.

## Organizational Support

Our monitoring capabilities are a reflection of the agency's high level of environmental commitment. Executives and managers support mitigation efforts and receive an annual update on the status of our mitigation sites. This information is shared with the public and agency executives in The Gray Notebook, WSDOT's quarterly performance report. This executive level scrutiny of our mitigation helps in securing the resources needed to monitor and manage our mitigation sites.

### Funding

While strong organization support is necessary to successfully design and construct effective sites, sufficient financial resources are necessary to sustain them. After WSDOT mitigation sites are built, they are managed by a contractor under a one-year plant establishment contract as part of the project construction budget. When the one-year contract is completed, management funds are provided from the agency general operating budget. As part of the biennial budgeting process, each region and mode requests an allocation for mitigation site management funds. Generally, regional site managers anticipate routine weed control, and low levels of replacement plantings. Those requests are reviewed by a Headquarters wetland biologist, and are ultimately submitted to the state legislature as part of the agency biennial budget request. Recently, our budget for normal site management for mitigation, roadside and riparian sites has been about $1 million per year.

WSDOT is organized into seven geographic regions and two modes that operate autonomously. State headquarters provides general oversight, policy and guidance development, and direct project support as needed. One unique service provided by headquarters is the Wetland Assessment and Monitoring Program. This program operates with its own budget, which reduces demand on regional budgets, and helps to maintain objectivity in our monitoring efforts. Typical resource allocation to provide monitoring services is slightly more than $0.5 million per year.

**Feedback to policy and guidance**

There are internal and external feedback mechanisms throughout the WSDOT mitigation process. WSDOT biologists from each region and mode meet quarterly to discuss emerging issues, current problems and potential solutions. Another venue, the Wetland Mitigation Technical Group, provides a more focused discussion on technical issues. These groups provide a forum to disseminate information on ideas that are not working, new ideas that may improve mitigation success, and contributes to WSDOT guidance and policy development. These groups provide a broader viewpoint to reflect on the longer-term consequences of implementing our ideas. By providing agency resources for WSDOT wetland staff to develop dependable methods for producing mitigation proposals, we make ongoing contributions to the knowledge of the mitigation community in Washington.

**Partnerships with resource agencies**

One key to our efforts has been our ability to create proactive partnerships with resource agencies to improve mitigation results. As proponents of development, Departments of Transportation may find themselves in an adversarial relationship with those agencies charged with protecting natural resources. By sharing our knowledge of site development, including resource agency staff in our training activities, proactively participating in regional guidance and policy development, we have provided appropriate leadership as a state agency.

As an example, WSDOT recently provided information and data for resource agencies to use in preparing model performance standards and permit requirements for individual mitigation sites. We provided direct input to the Army Corps of Engineers (Corps), the Environmental Protection Agency, and the Washington State Department of Ecology in drafting *Wetland Mitigation in Washington State* (Washington State Department of Ecology 2006). This document provides written guidance for how mitigation proposals and permit conditions should reflect all six required elements of a complete performance measure.

After several years of using statistically valid monitoring methods, we now have a substantial data set that includes hundreds of monitoring events. This gives us solid information on how the vegetative characteristics of mitigation sites develop over time. We provided this information to the resource agencies so they better understand how sites develop, and have empirical data to inform discussions about achievable performance measures. For example, it used to be common for permits to require 80% aerial cover by woody species in a wetland within five years of planting. We now know that 50% aerial cover is a reasonable goal after 5 years (figure 1), and that 80% woody cover is attainable in 8 to 10 years after planting (Celedonia 2002).

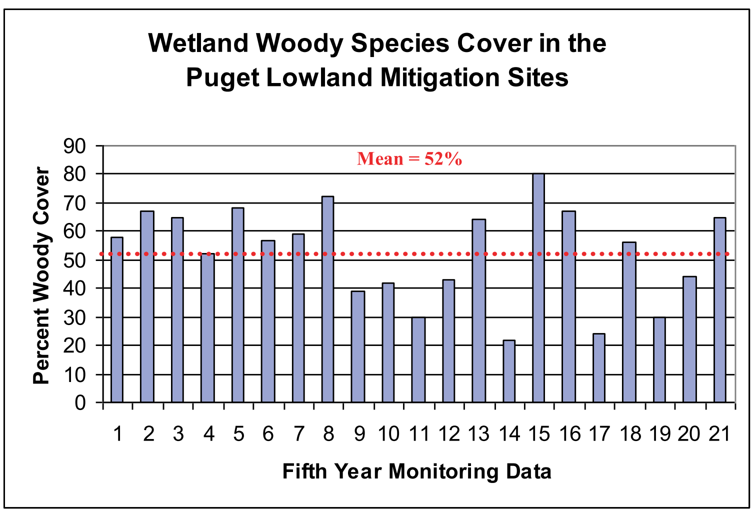



Figure 1. Fifth year estimated cover values for wetland trees and shrubs for 21 mitigation sites in the Puget Lowlands (data source: WSDOT Environmental Services Office).

The combination of our rigorous monitoring program, objective reporting of mitigation site conditions, and consistent site management activities, helps establish the credibility of our environmental commitment.

**Mitigation Site Establishment**

Prior to construction of mitigation sites, we determine impacts, develop site plans, and coordinate permits. Then the mitigation sites are constructed, and after initial plant acceptance, we monitor them throughout the establishment period. WSDOT utilizes the concepts of adaptive management to increase the likelihood of mitigation site establishment.

### Adaptive Management

In our model of adaptive management, there are four steps (modified from Elzinga et al. 1998):

1. *Describe the desired condition* - this is provided by the appropriate mitigation plan, permit condition, or performance measure.
2. *Monitor the resource* - we use statistically valid methods of data collection that allow use of confidence intervals.
3. *Determine if the desired condition has been achieved* - have we met our goals, or is the site developing as intended?
4. *Adjust desired condition, or change management to achieve desired condition*- in this step, we may decide that the desired condition is unachievable, such as an unrealistic target for a plant species, or that the planned management action is not effective.

### Monitoring Program

The foundation of our adaptive management process is our statewide monitoring program. A part of the Wetlands Assessment and Monitoring Program, the monitoring group completes a variety of activities, including vegetation assessment, hydrology monitoring, soil assessments, bird point-count and amphibian surveys. This information is used on two critical pathways for successful site establishment. One pathway is to document site conditions and track site development. This helps us to understand how sites develop over time, and can lead to early identification of poor mitigation performance. The other important pathway is to provide statistically valid monitoring data to guide site management decisions.

### Performance Measures

We have learned the importance of clearly written performance measures. There are six elements of a complete management objective or performance measure: species, location, attribute, action, quantity/status, and time frame (Elzinga et al. 1998). When one or more of these required elements are missing, the intent of the performance measure may be ambiguous. As a result, monitoring data may be inconclusive for the purposes of guiding management activities, or not relevant to determining compliance with permit conditions.

### Summer Internship for Wetland Monitoring

An integral part of WSDOT's Monitoring effort is our internship program. This internship program, a partnership between WSDOT and The Evergreen State College, began in 1997. Every summer we select 12 to 16 interns to work as monitoring field staff, while they also earn college credits. After a week of training, the interns assist our staff in collecting field data on our mitigation sites. These data are used to determine how the sites are developing, if they are on a satisfactory trajectory to meet success criteria, and if undesirable species are out-competing desirable plant species. Most data are collected using statistically valid methods that allow values to be reported with a confidence interval. This provides reliable information to guide site management decisions, and adds credibility to our annual reports on how individual sites are meeting permit conditions. Table 1 is an example of final year monitoring results summarized in an annual monitoring report for one mitigation site. Estimated cover values are presented with their corresponding statistical confidence interval.

Table 1: Example of final year monitoring results in an annual monitoring report

| Final Year Success Standards | 2006 Results | Management Activities |
|---|---|---|
| At least 60% cover of woody vegetation in the wetland | 66% ($CI_{90\%}$ = 59-74% cover) | |
| At least 30% cover of woody vegetation in the buffer | 16% ($CI_{80\%}$ = 12-20% cover) | Replanting and supplemental watering |
| Less than 20% cover of reed canarygrass or other invasive species in the wetland | 6% ($CI_{80\%}$ = 1-11% cover) | Weed control |
| Less than 20% cover of reed canarygrass or other invasive species in the buffer | 2% ($CI_{90\%}$ = 1-3% cover) | Weed control |
| Hydrology (within 12 inches of the soil surface) must be present for at least 12.5% of the growing season | Present | |

### Feedback to Site Managers

Another important element of our mitigation effort is the feedback loop between monitoring staff and regional site managers. Management activities are often time sensitive, such as removing invasive plants before they go to seed. Others require lead time for planning purposes, such as ordering planting stock from a nursery.

To address both long and short term planning needs, we have three mechanisms for communicating site conditions to managers. First, if monitoring staff determine that a site needs an unanticipated management action, they notify the site manager of the issue within one week of the visit, usually by email. This timeframe generally accommodates required scheduling actions. Second, monitoring staff holds yearly meetings with each region and mode, where the present conditions at each mitigation site in the region is discussed, and appropriate management activities are identified. Third, an annual monitoring report is written and distributed for each mitigation site. This report is used to communicate site conditions to regional staff, and to document permit compliance to resource agencies.

Numerous studies have indicated that mitigation frequently is unsuccessful, and does not result in the desired outcome (National Research Council 2001). WSDOT makes a concerted effort to learn from the work of others. While many factors may contribute to poor mitigation, it is recognized that sites that are actively managed tend to perform better (Johnson et al. 2002). Recognizing the validity of this observation, we report to senior staff and the public on how many recommended management activities are completed by regional site managers (table 2). WSDOT devotes significant resources to ensuring that our mitigation sites are actively managed to meet their objectives.

Table 2: WSDOT's Site Management Activities by Region, 2006

| Region | Sites | Recommendations | Completed | Scheduled |
|---|---|---|---|---|
| NW | 8 | 9 | 9 | 0 |
| SW | 8 | 13 | 11 | 2 |
| Olympic | 5 | 8 | 8 | 0 |
| Eastern | 0 | 0 | 0 | 0 |
| SC | 3 | 4 | 4 | 0 |
| NC | 3 | 6 | 6 | 0 |
| Source: WSDOT Environmental Services Office, Gray Notebook | | | | |

**Regional Coordination and Site Management**
With over 150 sites in our system, the decentralized relationship between monitoring and multiple site managers requires coordination to be effective. Experience has shown us that we need to coordinate monitoring activities with planned management activities. Our solution to this problem is the use of electronic calendars that are commonly available in computer network systems. This enables interested parties to see potential schedule conflicts that can contribute to lost field time and re-scheduling headaches. Another advantage with this system is that the activities can be scheduled electronically using meeting invitations. This automatically updates individual staff's schedule, and identifies other resources that will be required. This increases the efficiency of resource planning and simplifies staff oversight.

We use two main strategies to complete the management activities on our mitigation sites. The most common method is to contract specified work out to private firms specializing in plant establishment. This works well for anticipated activities, like routine plantings, weed control, and irrigation. WSDOT has established a Small Works Roster, comprised of contractors who are pre-qualified to submit bids on specific types of contracts. The other method is use of regional restoration crews, staffed by WSDOT employees. This work best for unanticipated management activities, or small projects that are uneconomical for private contractors to complete.

WSDOT presently manages 749 acres of wetlands at 137 mitigation sites (figure 2). These sites include those that are in the monitoring process and those that are no longer monitored.

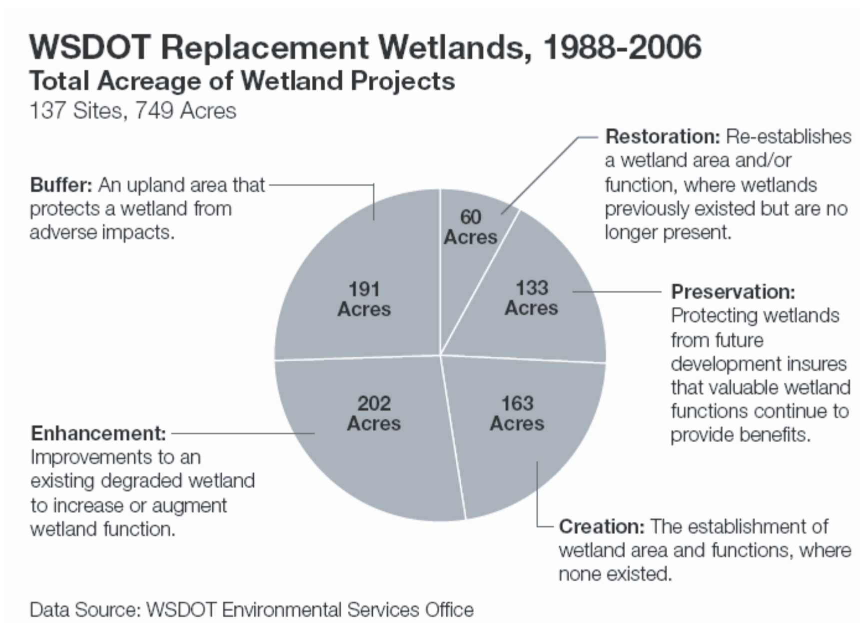



Figure 2. Acreage by type of WSDOT wetland mitigation.

**Effective Mitigation**

WSDOT has been very successful at establishing functioning wetlands at mitigation sites. At the end of the monitoring period we delineate wetlands, conduct a functions assessment and score the wetland using the Washington State Wetlands Rating System (Hruby 2004). Based on a broad suite of attributes, we provide replacement wetlands that function at equal or higher levels than those that we impacted. In a recent study, we found that our mitigation efforts often minimize impacts to higher value wetlands and replace the required wetland area (Bergdolt et al. 2005).

We typically conduct an interim delineation at each wetland mitigation site about three years into the monitoring period. If a problem is noted, there is time to develop and implement remedial activities before the end of the initial monitoring period. If needed, we extend the monitoring period to ensure that the desired conditions are being closely approached.

**Non-conforming Sites**

Sometimes, regardless of thorough planning, painstaking design, and timely management, a mitigation site can fail to develop into an acceptable condition. These sites generally exhibit different hydrology than anticipated, or develop into significantly different plant communities than intended. Finding solutions for "big misses" can be technically challenging, often requiring extensive new data collection and planning processes. This can cause undue stress on regional resources and staff that are already fully committed to meeting ambitious project schedules. At the same time, correcting these deficiencies is crucial to meeting agency environmental commitments and maintaining credibility with resource agencies.

WSDOT's response to this challenge is to assemble a multidisciplinary team of technical experts from regional and headquarters staff to provide a detailed review of the site, and recommendations for appropriate remedial actions. This approach provides a high level of technical expertise to support regional staff, and can generate remediation options that may be otherwise overlooked. If the selected corrective action results in a significant deviation from the original proposal, resource agency staff is consulted prior to implementation.

**Close-out Process**

In 2005, the General Accountability Office (GAO) issued a report criticizing the Corps for having poor oversight on mitigation activities resulting from CWA section 404 permits. Incomplete files were cited as the main cause of the deficiency. In response to this need, WSDOT and Corps staff worked together to identify what information was typically missing from their files, and to develop a systematic process for providing this required information.

**Agency Coordination**

Through this effort, we identified three things that were consistently missing from Corps files: a deed restriction or surrogate, an as-built drawing of the mitigation site, and monitoring reports or other documentation of current site conditions. Two of those, monitoring reports and a right-of-way plan to serve as a deed restriction, were readily provided from our files. An as-built drawing for each site was more problematic, and has required some discussion with contract specialists, construction staff, and environmental offices. Long-term solutions are still being considered to meet this need.

Finding solutions to this file maintenance problem led to a solution for another problem; how to close out established mitigation sites. After some consideration between WSDOT and Corps staff, we agreed to identify a small list of sites that WSDOT staff felt were good candidates for close-out, and conduct a trial on how to reach agreement on acceptable condition for these sites.

**Closeout Reports**

As a result of this effort, we have developed a systematic process for closing out mitigation sites with CWA section 404 permits issued by the Corps. In this process, we consider three parameters in determining if our mitigation effort has been successful. They are: wetland acreage provided, functions provided by the mitigation site, and achievement of success standards.

*Wetland acreage*. The area of wetlands provided is a relatively simple and accurate measure of mitigation success. WSDOT staff performs delineations on wetland mitigation sites in year three of the monitoring period, and at the completion of the monitoring period. The wetland boundaries are recorded as GPS data, which are used to determine the acreage provided. Provided acreage is compared to intended acreage as recorded in the mitigation plan or permit. The GPS data are loaded into our GIS system, enabling us to overlay the wetland boundary onto an aerial photograph of the site. This presents a powerful communication tool for demonstrating an important aspect of site establishment.

WSDOT has performed 45 delineations on mitigation sites that have completed their monitoring period. For these sites, 93 wetland acres were intended, and 100 wetland acres have been provided, an excess of 7% (Figure 3). As noted in the Corps Regulatory Guidance Letter 02-02 (USACE 2002), no-net-loss of wetland acreage is intended to be considered on a program scale, rather than a site-by-site scale. With this program-level information on the performance of our mitigation sites in preventing the loss of wetland area, resource agency staff have been able to determine individual mitigation site success even when the provided acreage is less than intended acreage.

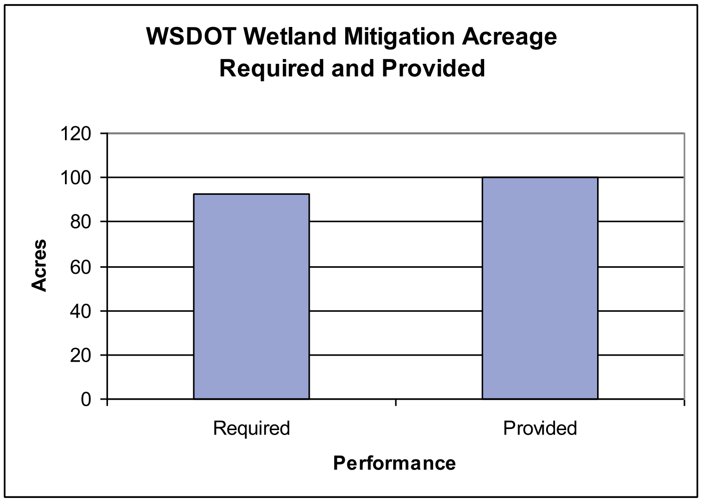



Figure 3. WSDOT wetland mitigation acreage required and provided (data source: WSDOT Environmental Services Office).

*Functions provided*. Evaluating the functions provided by a mitigation site, and comparing those to the lost functions or intended functions, provides information required for the second key consideration of the no-net-loss policy; no net loss of wetland function. Our experience has been that for some older sites, there is poor documentation of what functions were provided by wetland that have been lost. When possible, we prepare a clear comparison of functions lost (or intended) to functions provided. In most cases, we have been able to show that our sites provide lost functions, or an improvement in function. In one WSDOT study of our established mitigation sites, we demonstrated an overall increase in score using the Western Washington Rating System (Washington State Department of Ecology 1993) comparing mitigation sites to pre-impact sites (Bergdolt et al. 2005).

*Achieving success standards*. The final parameter we consider for potential closeout sites is a review of how success standards have been achieved. As wetland scientists and mitigation specialists are aware, there has been a steady paradigm shift in how success standards have been written over the last 20 years. What were once routinely accepted as realistic success criteria, such as zero presence of invasive plant species, or developing 80% woody cover in 5 years, are now recognized as ecologically irrelevant or unachievable. By providing resource agencies with an objective explanation of how the site has developed, and by considering practical expectations for mitigation site development, we have been able to reach agreement of reasonable ecological success, despite antiquated success standards.

The level of effort expended to achieve the desired site condition is an important consideration for some sites with aggressive performance measures. For example, in an effort to establish native herbaceous vegetation, it is common for our permits to require low levels of reed canarygrass (*Phalaris arundinacea*), a common invasive grass species in western Washington. In some landscape settings, the adjacent plant community is 100% reed canarygrass. On those sites, aggressive weed control allows the establishment of a desirable woody plant community, but reed canarygrass is generally a dominant plant in the herbaceous layer. When the woody species become established further management would only incrementally change the overall site condition.

**Long-term Management**

Once WSDOT mitigation sites have been closed-out, we plan for long-term site management. For some sites, transfer of ownership to another agency or non-profit group, such as The Nature Conservancy, is a viable option. We feel this is a particularly attractive alternative consider when the initial mitigation effort was a partnership, or based on watershed needs identified by area stakeholders. However, sites without any connection to natural areas, especially where the mitigation was located in the right-of-way, are unlikely to be attractive to other groups. For these sites, WSDOT provides long-term management of established mitigation sites through our Maintenance Program. This management includes control of noxious weeds, fence repair, removal of dumped material, and other actions to protect the public safety.

**Feedback to the Design Process**

Experience gained at the site level and program level through the monitoring, site management and close out activities provides insight into what is needed for mitigation site success. The information gained is applied back to the mitigation development process for future projects. This can have applications in site selection, development of performance measures, planting plans, and site management activities, so that our knowledge and success with mitigation improves over time.

The combination of a rigorous monitoring program, objective reporting of mitigation site conditions, consistent implementation of site management activities and feedback from practical experience has also helped establish the credibility of our environmental commitment with resource agencies.

## Conclusion

The ultimate objective of compensatory wetland mitigation is to produce a site that functions appropriately to offset the losses of impacted wetlands. While there are challenges in putting this into practice, wetland mitigation can be successful. As much as good site selection and planning, this success also relies on post construction follow-through with monitoring and site management. The efficient establishment of wetland mitigation sites requires high level of organizational commitment. Executive leadership and resource allocation are needed, as well as proactive in partnering with the resource agencies to improve the knowledge and products of the mitigation community. A robust monitoring program focuses resource use, and establishes credibility with resource agencies. Monitoring information provides the basis for guiding site management activities and for evaluating the effectiveness of those management activities. With proper attention to site design as well as the follow through of monitoring and site management, mitigation sites can demonstrate success, fulfill regulatory requirements and perform as functional wetlands over the long term.

## References


Bergdolt, F.S., C.A. Prehmus, and J.B. Barham. 2005. An Evaluation of Wetland Mitigation Site Compliance at the Washington State Department of Transportation. Washington State Department of Transportation, Olympia, WA.

Celedonia, M. T. 2002. Establishing appropriate benchmarks for site development by documenting successional characteristics, Phase 2. Washington State Department of Transportation, Roadside and Site Development Unit, Olympia, WA.

Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 1998. Measuring and Monitoring Plant Populations. Bureau of Land Management Technical Reference 1730-1, BLM/RS/ST-98/005+1730.

Hruby, T. 2004. Washington State wetland rating system for western Washington — Revised. Washington State Department of Ecology Publication #04-06-025.

Johnson, P. A., D. L. Mock, A. McMillan L. Driscoll, and T. Hruby. 2002. Washington State wetland mitigation evaluation study phase 2: Evaluating success. Washington State Department of Ecology, Lacey, WA.

National Research Council (NRC). 2001. Compensating for wetland losses under the Clean Water Act. National Academy Press, Washington, D.C.

United States Army Corps of Engineers (USACE). 2002. Regulatory Guidance Letter No. 02-2, December 24, 2002, Washington, D.C.

Washington State Department of Ecology, U.S. Army Corps of Engineers Seattle District, and U.S. Environmental Protection Agency Region 10. March 2006. Wetland Mitigation in Washington State - Part 2: Developing Mitigation Plans (Version 1). Washington State Department of Ecology, Publication #06-06-011b. Olympia, WA.

Washington State Department of Ecology. 1993. Washington State Wetlands Rating System for Western Washington, second edition. Publication No. 93-74, Olympia, WA.


## Links to Resources

http://www.wsdot.wa.gov/Environment/Biology/Wetlands/reports.htm
http://www.wsdot.wa.gov/Environment/Biology/Wetlands/wetlands.htm
http://www.wsdot.wa.gov/accountability/default.htm
http://www.wsdot.wa.gov/eesc/design/roadside/pdf/mitigationbenchmark.pdf
http://www.ecy.wa.gov/biblio/0406025.html

## A Multi-Scale and Context Sensitive State-Wide Environmental Mitigation Planning Tool for Transportation Projects in California

**James H. Thorne** (530-752-0225, jhthorne@ucdavis.edu),
**Evan H. Girvetz** (530-219-8442, ehgirvetz@ucdavis.edu), and
**Mike C. McMcoy** (mcmcoy@ucdavis.edu), Information Center for the Environment, University of California at Davis, 107 Huerta Place, Davis, CA 95616 USA

**Abstract:** The University of California Information Center for the Environment (ICE) and the California Department of Transportation (Caltrans) are developing a GIS-based analytical framework to improve the effectiveness of biological mitigation throughout California. Goals include incorporating the best available sets of mapped natural resource data into the early project planning and preliminary environmental assessments for single and multiple projects. Incorporation of these data will facilitate early and more strategic identification of mitigation requirements and opportunities, for both single-project and regional mitigation efforts.

The cost of delays and over-runs due to late and fragmented project-by-project environmental planning and mitigation in California is estimated at $75 million per year. Developing systematic GIS-based decision-support tools to identify important species and habitats, both those impacted directly by Caltrans activities and those that might contribute to effective mitigation in the same locale or watershed will permit Caltrans, counties, and environmental regulators to incorporate the results of biological impact assessments earlier in the planning process, and identify opportunities mitigating the combined biological impacts of many projects in a given area. By building upon previous efforts and using tools known to be effective for integrated analyses, this project will help Caltrans improve planning results, decrease costs, improve project delivery schedules and provide greater environmental protection in the long-term.

To accomplish these goals, Geographic Information Systems (GIS) analysis and conservation planning principles are being applied to develop multi-scale long-range (10-year) mitigation need forecasts for each Caltrans district, county, and watershed in the State of California. These will be used to determine the cumulative mitigation needs for early biological mitigation planning of multiple projects in a given area. Available statewide biological data have been integrated into a database that can be queried by Caltrans district, county, or any of six levels of watershed classification. For a queried geographic area, the database returns the biological resources expected to exist in the area based on the available data, as well as the potential impacts to these resources from Caltrans projects that are currently funded to be constructed in the area over the next 10 years. The type of project programmed to occur was then used to estimate the impact zone of each project (e.g. road repaving, road widening, new road, etc.). Then, by querying the database for a given geographic region, the area, habitats and species potentially affected by cumulative biological impacts from all programmed highway projects in that region can be estimated. From this, estimates of area and types of lands that would need to be acquired for mitigation can be determined.

This project provides a framework for analyzing and estimating biological mitigation needs that could be generalized for use in transportation planning in other geographic areas, as well as for other types of planning. The database schema developed here could easily be adapted to analyze the potential impacts and mitigation needs for urban growth planning efforts, and other development projects with biological impacts that require biological mitigation planning. Overall, by integrating available data into a useful database format, this project has developed a system for assessing long-term biological mitigation needs that will assist in the implementation of early biological mitigation planning

### Introduction

Late incorporation of environmental assessment into road development projects is inefficient and can lead to costly delays. The primary problem is that considerable resources have already been committed to a road design by the time the environmental review occurs. California, like many other States, does not review potentially significant environmental impacts of a proposed project until the project receives funding authority, at which point, for the purposes of the National Environmental Policy Act and most State acts, it is then a potential "project" subject to environmental review. However, in order to have reached the stage of program funding, a project must be fairly well developed in terms of its engineering requirements. This means significant investment has been made in siting and design and the flexibility to avoid or minimize environmental impacts is substantially reduced. Mitigation becomes the tool of choice and is often a costly and time consuming procedure. Besides foregoing the flexibility to practice avoidance and minimization of impacts at the early planning stage the current practice is prone to rush environmental scoping in the haste to produce projects once their funding is programmed. It is estimated that errors in environmental mitigation scoping costs the State of California $75 million per year in direct costs not including the time cost of delays.

In addition, biological solutions for effective mitigation derived under these planning conditions do not necessarily represent the optimum, in part due to the fact that solutions must be identified late in the life time of the project. Much mitigation is done on a project-by-project basis, which ignores the cumulative impacts of multiple projects in a region. Regional mitigation analysis and planning has been recognized by the Environmental Protection Agency (EPA) and Federal Highway Administration (FHWA) as an objective in the regulatory and transportation planning sectors, as a way to attempt to deal with the problems of cumulative impacts. Regional assessments that quantify impacts from multiple projects are one way to address such problems, and are starting to be incorporated into the planning practices of transportation departments. Some state-wide examples of mitigation assessments include projects in Florida (Florida Department of Transportation 2001, Hoctor et al 2000) and initiatives listed in Brown (2006); while regional examples include Thorne et al. (2006a) who modeled the distribution of 12 species of concern along a 100 km stretch of highway in the San Joaquin Valley and looked at the expected impact from future urban growth along that transportation corridor.

Some of the issues that arise when considering multiple-site assessments include determining the pros and cons of on-site versus off-site mitigation, identifying the appropriate scale of analysis, and quantifying the expected impacts before they occur. Timing also becomes an issue because the long time required for major capital projects means that off-site mitigation locations available at the beginning of a project may either no longer exist or be affordable by the end of a project. Because single projects may affect only one watershed, but multiple projects in a county or district may impact the same habitat types in several watersheds, the scale of analysis needs to be flexible. Watershed-level analyses present an ecologically meaningful way to look at regions in a scaled manner due their nested capacity. Watershed-level analyses are also becoming the standard used by regulatory agencies, such as the EPA which has adopted Total Maximum Daily Load (TMDL). The FHWA has also adopted a watershed-based operational paradigm through its 'Eco-logical' program (Brown 2006), which identifies integrated planning as the first step towards an ecosystem-based approach. Other groups moving to watershed-based approaches include the United States Forest Service and National Parks Service.

However, much planning is done through human-defined areas such as counties or transportation districts. So, a multi-scale framework needs to be able to report cumulative impacts for both watershed units and administrative units (e.g., transportation planning districts and municipal counties). This multi-scale watershed and administrative boundary framework will to permit transparent cross-tabulation of potential biological impacts due to multiple project planning blueprints.

The California Department of Transportation (Caltrans) has recognized these limitations and called for the development of early mitigation assessment capacity. This capacity would need to be able to address mitigation assessments for any location in the state, for a minimum of a 10-year planning horizon, and would permit the earlier incorporation of estimates of the level mitigation needs that could be associated with any given project. In particular, Caltrans needs the capacity to assess the overall mitigation needs of its transportation planning districts. There is a desire to know if impacted habitat types are rare or not, both locally and state-wide. Finally, the resulting tool needs to be flexible enough that it can be used by a wide variety of users, who do not necessarily have enough GIS training to conduct the spatial analyses themselves.

### Potential Solutions

We developed a database tool that permits multi-scale advanced assessment capacity of mitigation needs for single or multiple highway improvements. The database consists of eight spatial scales that cover the entire 410,000 km2 of California in a spatial framework consisting of: Caltrans districts, county boundaries, and six nested views of watershed boundaries. Into each of these spatial templates, we intersected the best available state-wide landcover data, outlines of species ranges, and human impacts including road and population density. Finally, programmed highway projects were also incorporated in to the database to allow for the assessment of biological impact due to these projects. The resulting database permits non-GIS users to query by project or spatial region and determine the potential impacts to habitat types, the known presence and the potential presence of federally or State listed threatened and endangered plants and animals.

This paper presents four summary analyses to demonstrate the capacities of this approach. First, we report the projected impacts of a single project; second, the projected cumulative impacts from four planned projects along California State Highway 132; third, we report the projected impacts for all 94 programmed projects in Caltrans District 5; and fourth  we report the project impacts of 21 projects occurring in an intermediate-size watershed within District 5, the Elkhorn Slough watershed.

## Methods

### Overview

We developed a relational spatial database framework which permitted the integration of biological, cultural, and infrastructure data. The database was developed using spatial overlays in a geographic information system (GIS, ESRI 2006), that were subsequently output to a Microsoft Access relational database (Microsoft 2006).  The spatial framework for the database consists of a combination of two nested administrative boundary delineations and six nested levels of watershed boundary delineations for the entire state of California (figure 1). The administrative boundaries used are Caltrans districts (12 units), and counties (58 units). The six nested levels of watersheds, listed from largest to smallest size are: river basins (RB, 9 units), hydrologic units (HU, 189 units), hydrologic areas (HA, 578 units), hydrologic sub-area (HAS, 1040 units), super planning watersheds (SPWS, 2309 units), and planning watersheds (PWS, 6998 units). All of these boundary delineations were intersected together to create a combined planning unit map layer that contains 8058 unique combinations of district, county, and watersheds.

Highways and proposed projects buffered on each side of their centerline by 500 meters were intersected with these combined planning units in order to allow for watershed specific analyses of the biological resources potentially impacted by highways and proposed future highway projects. This combined planning unit layer was used to summarize available biological, physical, and cultural information that was input into a relational database for assessing the biological mitigation needs of Caltrans districts, counties, and watersheds in the State of California.

**Biological Database**

The biological components of the state-wide database currently comprise four main elements: landcover derived from aerial imagery, point locations of known occurrences, listed plant species range maps, and vertebrate animal range maps.

We included a landcover map to be able to assess the extent of impact of proposed projects on different habitat types. The landcover map used for this exercise was the California Department of Fish and Game's Fire and Resource Assessment Program (FRAP, 2003) digital multi-source landcover of California map, which is a composite map is based on the best available landcover information. It identifies approximately 50 different landcover types, termed Wildlife Habitat Relationship (WHR) classes, for the state of California.

We incorporated two sets of information about species: known occurrences and potential occurrences as measured by range maps. The known occurrences were derived from the state's California Natural Diversity Database (CNDDB, California Department Fish and Game, Wildlife & Habitat Data Analysis Branch 2006), a current collection of the reported locations of listed species. The terrestrial vertebrate range maps used are the same as those used by California Department of Fish and Game (CWHR 2005). Each species range map was intersected with each of the spatial configurations mentioned above. Vascular plant range maps were derived from the CalJep database (Viers et al 2006). Plant ranges in this database are defined as a plant's presence or absence in each of 228 mapping units in California. We took the definitions for each listed plant, and intersected that range map with the estimated elevational distribution as listed in the most recent flora of California (Hickman 1993), resulting in a more conservative estimate of the distribution of each species.

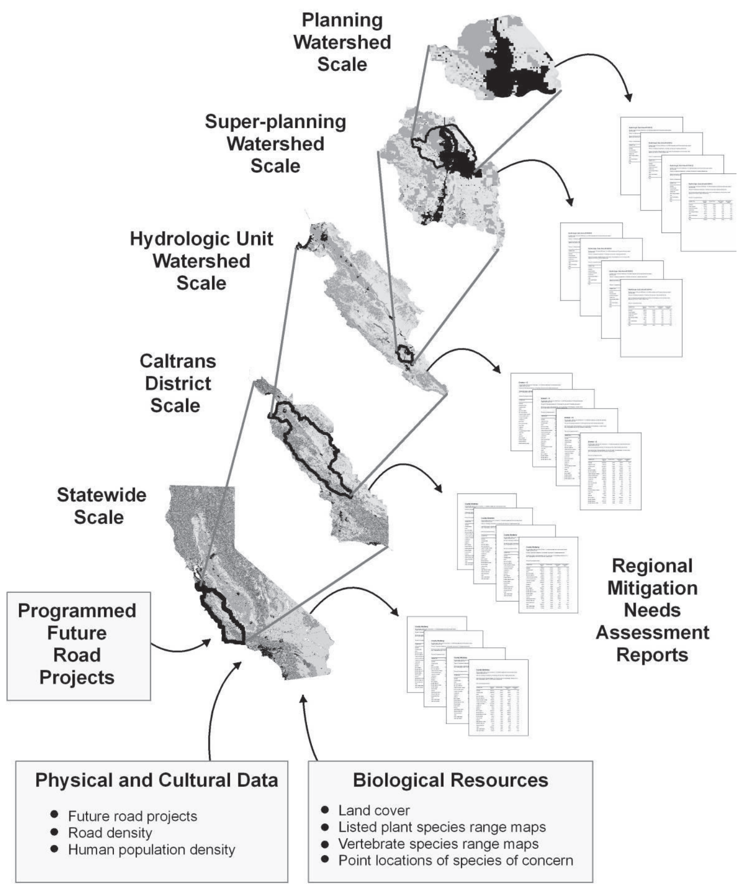



Figure 1. The state of California was cut into 8 spatial frameworks. Each spatial framework was contained the same data- four datasets representing biological data, and four representing human activities.

**Impacts Database**

*Cultural Impacts*

For each unique combination of Caltrans district, county, and watershed, a set of summary statistics were calculated that indicate the level of human impact already present on the landscape, including road and population density in that planning unit. The roads layer (from Geographic Data Technologies, GDT, 2006) was intersected with the combined planning unit layer to calculate the road density in each spatial unit. Similarly, block level population density was broken into each spatial unit.

*Future Transportation Project Impacts*

A GIS of future programmed transportation projects was obtained from the California Transportation Investment System (CTIS) and used to estimate the potential biological impacts due to each project within each county, district, and watershed (figure 2). The CTIS GIS database shows the stretches of roads along which projects have been identified and funded, and has a description of each project. Based on the project description and consultation with Caltrans, we estimated the linear distance from the center of the road that would be impacted by different types of projects (table 1). The distance impacted ranged from 500 feet for a highway being build on an new alignment to 5 feet for median replacement or traffic operation systems. Then to estimate the types of habitat impacted by the programmed projects, we buffered each project 500 meters out from the road on either side and intersected it with the land cover map. This analysis provided a relative estimate of the amount of each habitat type that might be impacted by that particular project. Then to estimate the actual area that would need to be mitigated for, the total area of each habitat type within the buffered area was divided by 500 and multiplied by the distance out from the center of the road estimated to be impacted (table 1).

The CTIS projects buffered by 500 m within the combined planning units were also intersected with the point and polygon observations of rare and endangered species from the CNDDB database. For each CTIS project, the vertebrate and listed plant species ranges were identified that intersected with any of the planning watersheds the project touches.

*Database Assembly*

Once the spatial processing was completed, the tables representing the results were imported into a relational Microsoft Access database. All of the biological data were linked to each highway and programmed project within each of the combined planning units. A graphical user interface (GUI) was developed to allow for queries to be run easily, and a report generating function was created to output standardized reports from the custom queries (figure 3). Using the GUI, any combination of district, county, watershed, highway, and project can be queried and potential biological impacts due to future transportation projects will be returned in a standardized report format. The four types of standardized reports available for any given queried area are: (1) area of different land cover types and estimated area impacted by all programmed future transportation projects based on the project type in the given queried area; (2) a list of the known species occurrences including listing status (from the CNDDB database) that are located in the queried area, as well as those that are located within 500 meters of a programmed project; (3) a list of the vertebrate species range maps, including listing status, that overlap with the queried area (from the CWHR database); and (4) a list of the state and federally listed plant range maps that overlap with the queried area (from CalJep database). All the reports include a header proving background summary information about queried area that includes the density of the different types of roads, human population density, and the number of programmed projects.

Table 1: Estimated footprint width of highway project types in California

| Project Type | Estimated Footprint Width (feet) |
|---|---|
| New alignment | 500 |
| Reconstruct interchange and access ramps | 200 |
| Construct expressway | 200 |
| Construct new bridge | 150 |
| Widen roadway | 100 |
| Remove rail trestle | 100 |
| Realign curve | 100 |
| Grade separation improvements | 100 |
| Construct expressway existing alignment | 100 |
| Truck climbing lanes | 50 |
| Slow vehicles lane | 50 |
| Passing lanes | 50 |
| construct lane | 50 |
| High occupancy lanes | 40 |
| Stabilize slope | 30 |
| Rehabilitate roadway | 30 |
| Construct noise barrier | 30 |
| Slope erosion control | 30 |
| Construct left turn lane | 30 |
| Construct bike path | 30 |
| Construct retaining wall | 20 |
| Rehabilitate other | 20 |
| Other project | 20 |
| Install median barrier | 20 |
| Repair landslide | 20 |
| Roadside rest areas | 10 |
| Rehabilitate pavement | 10 |
| Install warning devices | 5 |
| Install message signs/traffic operation systems | 5 |
| Install ramp metering | 5 |
| Operational improvements | 5 |

## Results

There are many ways to query the database presented here. The following results present four examples of how the database may be useful for assessing biological mitigation needs for future transportation projects: (1) by a single project, (2) by all the projects along a specific highway, (3) by a specific transportation district, and (4) by a specific watershed.

### Mitigation Needs Reports

*Single Project*

Selecting a single CTIS programmed project at random, ID #0A4000, is a roadway rehabilitation (see inset of figure 3 for location). The work is along 5 miles of highway and is estimated to traverse 54.6 acres; with 52% of that going through Agriculture and 34.6% through annual grasslands, both types that are extensive within the state and for which mitigation requirements are generally low. The project may cross blue oak woodland (0.25 acres), a valuable type for the wildlife that uses it, and might impact 0.8 acres of critical coastal Scrub habitat, which houses several endangered species and is a recognized conservation concern.

There are 13 listed vertebrate species whose range maps intersect the watershed that the project occurs in. These species are therefore possibly present within the footprint of the project, and the list serves to alert the biologists who would do the field survey to their potential presence. Similarly, there are nine listed plant species whose range maps intersect the watershed the project occurs in. The actual geographic location of sightings of five listed species are recorded for the watershed the project occurs in, and of those four are found within the footprint of the programmed project: *Caulanthus californicus* (California jewel-flower), *Dipodomys ingens* (giant kangaroo rat), *Gambelia sila* (blunt-nosed leopard lizard) , and *Vulpes macrotis mutica* (San Joaquin kit fox). It took approximately three minutes to retrieve this information from the database.

*Specific Highway*

Highway 132 is an east-west highway running between Modesto and Freemont in California's San Joaquin Valley (figure 3 inset). There are four highway improvements projects programmed to occur along the highway over the next 10 years. The habitat map identifies 16 landcover types, covering 30,030 acres, of which 168.9 acres that would be impacted (table 2), along a highway that measures 76 miles. The type that will be most impacted is agriculture, at 40.8 acres. Three natural vegetation types would be impacted, including 2.2 acres of Annual Grasslands. Sensitive habitats, including Valley foothill riparian and Freshwater emergent wetlands are projected to be impacted by 1.6 and 0.3 acres, respectively. The database also includes the overall extent of each landcover type in the state- e.g. freshwater emergent wetlands cover 456,952 acres, of which 79,422 acres are currently protected. Three of the four projects programmed on this highway are along the edges of urban regions, leading to the high level of urban impacts.

There are 14 listed terrestrial vertebrates and 21 listed vascular plants whose species ranges fall in watersheds that intersect this highway. Sixteen listed species have georeferenced sightings within the project's watersheds, and of those and one is already known to be within the footprint of the programmed projects along the highway.

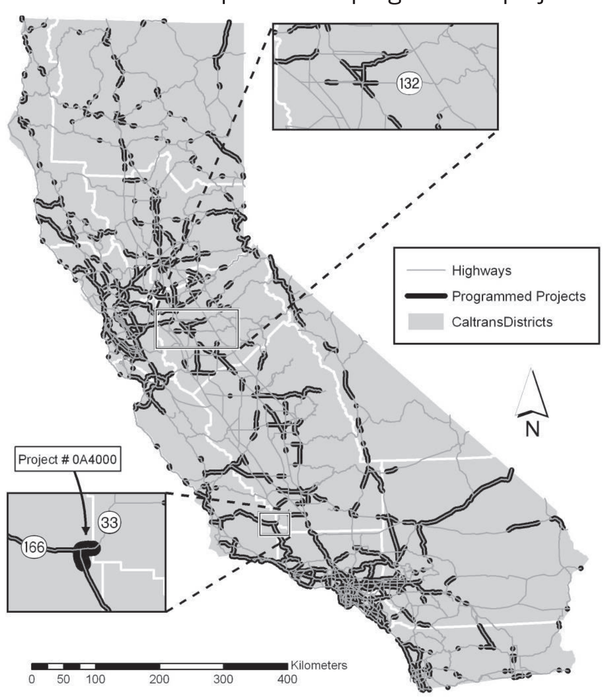



Figure 2. The 967 programmed projects in California, as derived from the CTIS database. The impacts of each of these were assessed separately and the data complied for report generation from a number of perspectives.

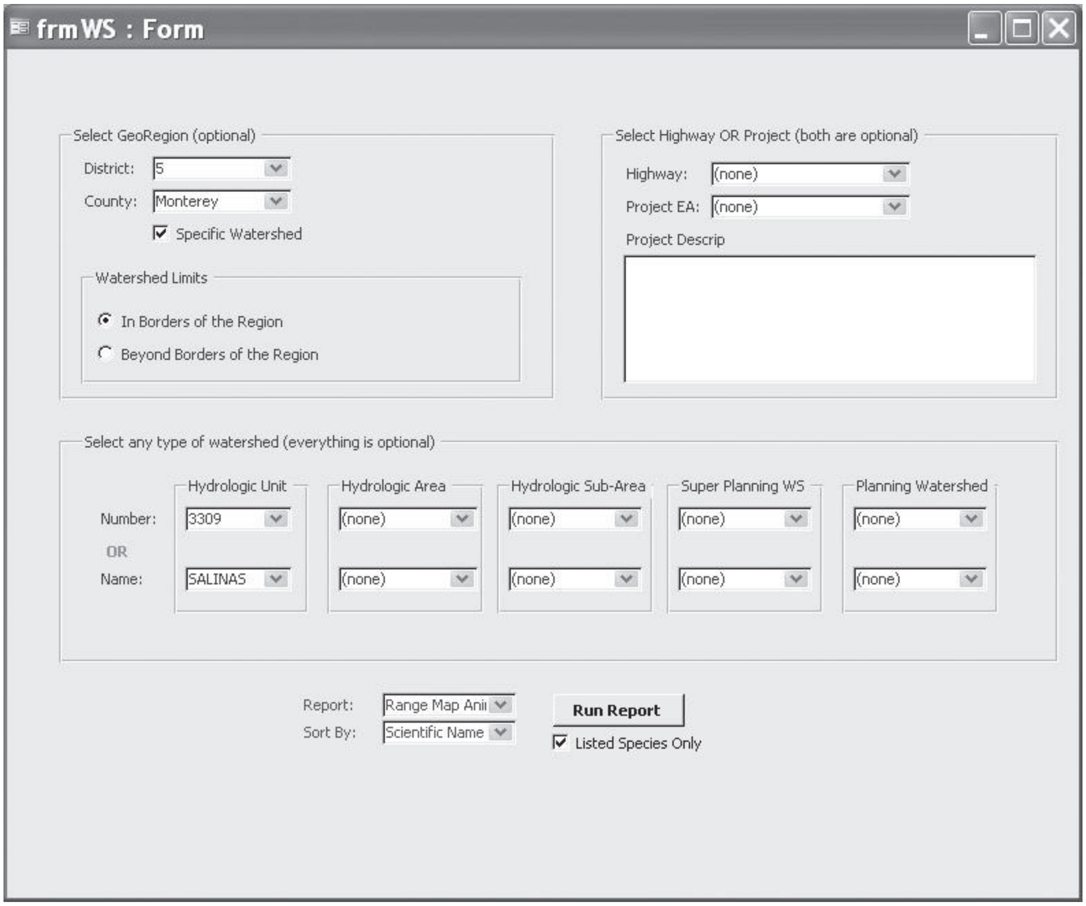



Figure 3. The interface of the California state biomitigation needs database. The coarsest scale watershed units (Hydrologic Region) are not shown.

*Single Transportation District*

Caltrans district five is located along the central coast of California, shown as in figure 1 termed ‘Caltrans district’. By querying the district, the following summary information is developed. The total area of the district covers 7,054,287 acres. As of 2000 the population was 1.34 million and the area contained 480,427 housing units. The district contains 0 miles of interstate highways, 275 miles of federal highways, and 903 miles of state highways. There are 94 programmed projects in the district. Examples of the first page of outputs from each of the categories available are shown in appendix 1.

Range maps of 132 listed plant species and 73 listed vertebrates intersected the footprint of the programmed projects in district 5, and therefore should be the focus of field surveys to confirm presence or absence as projects move forward. Actual occurrence data is available for 371 species in the district, of which 98 are state or federally listed. Within the programmed area footprints, there are 157 recorded occurrences of plants and animals, of which 49 are listed. These represent recorded populations of state or federally listed species that are in locations that are currently planned for highway improvements. There are 38 landcover types recorded for the region, of which Annual grasslands will be the most impacted by programmed projects, and 1174 acres. Coastal Scrub, a critical habitat for several endangered species is projected to lose 64 acres, and extremely rare saline and fresh water emergent wetlands to lose 6.6 acres and 0.03 acres, respectively. For each landcover type, the amount impacted, the amount of the type in the state, and the percentage of the impacted over the state, and the amount protected as of January 2007 was listed.

Table 2: The extent of landcover types along Highway 132, California, and the extent of each type projected to be impacted by the four programmed projects on the highway

| Landcover Type | Total Acres Along Highway of Type | Acres of Type Affected |
|---|---|---|
| **Agriculture** | 12,295.7 | 40.8 |
| **Annual Grassland** | 7,153.6 | 2.2 |
| **Barren** | 101.3 | 0.0 |
| **Blue Oak Woodland** | 2,248.6 | 0.0 |
| **Blue Oak-Foothill Pine** | 180.4 | 0.0 |
| **Chamise-Redshank Chaparral** | 736.4 | 0.0 |
| **Douglas-Fir** | 12.4 | 0.0 |
| **Freshwater Emergent Wetland** | 158.1 | 0.3 |
| **Mixed Chaparral** | 175.4 | 0.0 |
| **Montane Hardwood** | 988.4 | 0.0 |
| **Montane Hardwood-Conifer** | 625.2 | 0.0 |
| **Unknown Conifer Type** | 143.3 | 0.0 |
| **Unknown Shrub Type** | 395.4 | 0.0 |
| **Urban** | 4,089.5 | 123.9 |
| **Valley Foothill Riparian** | 573.3 | 1.6 |
| **Water** | 153.2 | 0.1 |
| **Total** | 30,030.1 | 168.9 |

*Specific Watershed*

The Salinas River occupies one of the largest watersheds in district five. Of the 94 programmed projects in district five, 21 of them occur in the Salinas watershed. An estimated 402 acres will be impacted, including 2.5 acres of coastal scrub, 20.4 acres of coast live oak woodland, and 0.15 acres of Saline emergent wetland. Over 350 acres of the total is in urban areas, on agricultural lands or on annual grasslands. There are 59 federally or state-listed threatened, endangered, sensitive or candidate vertebrate species whose range maps intersect the watershed (out of 368 vertebrates in the region). There are 74 plant species of concern (64 listed as state or federally rare, threatened or endangered) whose range maps intersect the valley. There were 176 recorded sighting of species (plants and vertebrates) of concern in the watershed, of which 72 are state or federally listed. Of those recorded sightings, 45 are in the footprint of the programmed projects, and of those 13 are federally listed.

## Discussion

The objective of this effort was to provide a variety of transportation planners and transportation agency biologists a simple tool that allowed mitigation forecasting. We specifically wanted the end user to not have to be a GIS expert to extract the information they needed from what we compiled. Therefore, we pre-calculated the spatial relationships between natural resources defined in four ways and four measures of human activity in a geographic framework, which permitted their integration in multiple arrangements. Once all the data were integrated into the 8 spatial frameworks used to represent the state, a database could be developed that allowed the cross-querying of these items. The resulting reports permit a rough estimate of the mitigation needs that will be encountered for any or all of the 967 programmed projects that were registered to the database.

The multi-scale framework permits assessments at different scales, depending on the questions being asked. Therefore, a district biologist can use the database as a way to preview what species might be encountered when heading out to the field for a survey of a potential site. It could also be used by an environmental planner trying to assess what the overall magnitude of mitigation requirements for a transportation district might be. This type of forecasting capacity will make it easier to justify the acquisition of important habitat types at the early phase of the planning process, when acquisition of the property will be more economic. In some cases early acquisition will be the only option, because waiting could lead to no habitat remaining available for acquisition.

One of the advantages of using a defined set of spatial domains is that as other important data are developed for a region, they can be incorporated into the overall analyses. Effective mesh size (Girvetz et al. these proceedings), or wildlife connectivity models (e.g., Penrod et al. 2000, Thorne et al. 2006, Shilling et al 2002, Noss et al. 1999) could be spatially integrated into the California database presented here, so that planners would know when terrestrial connectivity was an issue in a particular watershed. Air quality and stream condition data could also be assembled, which would permit an entry into the aquatic side of mitigation planning, and an assessment of the contribution to current air pollution that new planned roads might have.

We developed an expandable database framework as a first step for mitigation forecasting in California. If this data framework proves useful, additional work will make it possible to update the database, and modifications could eventually be possible by the user, such as defining a new project area by drawing new polygons that would get incorporated into a central server where the updated GIS processing would be done to update the database. The geodatabase should at that point be able to return the updated impacts report for the user. This arrangement would mean that new biological, cultural and physical data would have to be updated at a central location, but that projects could essentially be loaded and queried remotely. Until that time arrives, the advantage to the database to date is that it can be run on a desktop computer without a GIS.

**Biographical Sketches:** James Thorne is a research scientist at the Information Center for the Environment, UC Davis. He received his PhD in Ecology at UC Davis in 2003, and has a masters in Geography from the UC Santa Barbara. His research interests include the integration of ecological data into planning, development and deployment of large datasets, and estimating the impacts of climate change.

Evan Girvetz is a doctoral student in the Graduate Group in Ecology at the University of California UC Davis (degree expected December 2007). His research focuses on using geographic information systems (GIS) integrated with quantitative analysis techniques to provide decision-support for answering real-world questions faced by land use planners and decision makers. He is currently a graduate student research fellow with the Road Ecology Center (UC Davis), and with the Information Center for the Environment (UC Davis).

Michael C. McCoy serves as academic administrator and principal investigator for the Information Center for the Environment. He specializes in the development, aggregation and dissemination of environmental information. In this capacity he works with a variety of agencies, committees and funding sources and works to achieve consensus on the best strategies for integrating data and implementing strategy. Projects include studies of regional environmental planning methodologies, land use and infrastructure planning policy, and the development of rule based and microeconomic land use models.

## References

Brown, J. W. 2006. Eco-logical: An Ecosystem Approach to Developing Infrastructure Projects. Office of Project Development and Environmental Review, Federal Highway Administration. Washington, DC.

California Dept. of Fish and Game, California Interagency Wildlife Task Group, 2005. California Wildlife Habitat Relationships model, version 8.0. Personal computer program.

California Department of Fish and Game, Wildlife & Habitat Data Analysis Branch, 2006. California Natural Diversity Database. Sacramento, Ca.

California Department of Fish and Game, Fire Resource and Assessment Program, 2003. FRAP multi-source vegetation map. Sacramento, CA.

ESRI. 2006. ArcGis software. Redlands, CA.

Geographic Data Technologies (GDT). 2006. Boston, MA.

Hickman, J.C., Ed. 1993. *The Jepson manual: higher plants of California*. University of California Press, Berkeley.

Microsoft. 2006. Access database software. Seattle, WA.

Noss, R.F., Strittholt J.R., Vance-Borland, K., Carroll, C. and P. Frost. 1999. A conservation plan for the Klamath Siskiyou Ecoregion. Natural Areas Journal 19:392-411.

Penrod, K., R. Hunter, and M. Merrifield. 2000. Missing Linkages: restoring connectivity to the California landscape. California Wilderness Coalition, Davis, CA.

Shilling, F.M., E.H. Girvetz, C. Erichsen, and B. Johnson. 2002. A Guide to Wildlands Conservation in the Greater Sierra Nevada Bioregion. California Wilderness Coalition, Davis, CA, USA.

Thorne, J.H., S. Gao, A.D. Hollander, J.A. Kennedy, M. McCoy, R.A. Johnston, and J.F. Quinn. 2006. Modeling potential species richness and urban buildout to identify mitigation sites along a California highway. Transportation Research Part D, 11: 277-291.

Thorne, J.H., D. Cameron, and J.F. Quinn. 2006. A conservation design for the Central Coast of California and the evaluation of mountain lion as an umbrella species. Natural Areas Journal 26: 137-148.

Viers J.H., Thorne, J.H. and Quinn, J.F. 2006. CalJep: A spatial distribution database of CalFlora and Jepson plant species. San Francisco Estuary and Watershed Science 4: online at http://repositories.cdlib.org/jmie/sfews/vol4/iss1/art1.

**Appendix 1**

Output tables produced by querying the mitigation needs database for all programmed projects within Caltrans district 5 located on the central coast of California. The Headers and first several rows from each files are presented, as well as the total landcover assessment.

For range maps of listed plant species that intersect with watersheds that programmed projects occur in:

# District # 5 Plant Range Distributions

The Area occupies 28547.69 sq.km (7054287 acres). As of 2000 the population was 1327400 people and the area contained 480427 house units.

There are 25 hydrologic unit watersheds, 70 hydrologic Sub-Areas and 870 planning watershed units.

There are 0 km (0 miles) of Interstate Highways, 443.1 km (275.33 miles) of Federal Highways, 1454.58 km (903.84 miles) of State Highways, and 125.57 km (78.03 miles) of Unknown Type

There are 94 of programmed projects.

| Scientific Name | Common Name | Federal List | State List |
|---|---|---|---|
| Acanthomintha ilicifolia | San Diego thorn-mint | Threatened | Endangered |
| Acanthomintha obovata ssp. | San Mateo thorn-mint | Endangered | Endangered |
| Ambrosia pumila | San Diego ambrosia | Endangered | None |
| Amsinckia grandiflora | large-flowered fiddleneck | Endangered | Endangered |
| Arctostaphylos edmundsii var. | Hanging Gardens manzanita | | Rare |
| Arctostaphylos glandulosa ssp. | Del Mar manzanita | Endangered | None |
| Arctostaphylos hookeri var. | Hearst's manzanita | | Rare |

For range maps of listed terrestrial vertebrates that intersect with watersheds in which programmed projects occur:

# District # 5 Animal Range Distribtutions

The Area occupies 28547.69 sq.km (7054287 acres). As of 2000 the population was 1327400 people and the area contained 480427 house units.

There are 25 hydrologic unit watersheds, 70 hydrologic Sub-Areas and 870 planning watershed units.

There are 0 km (0 miles) of Interstate Highways, 443.1 km (275.33 miles) of Federal Highways, 1454.58 km (903.84 miles) of State Highways, and 125.57 km (78.03 miles) of Unknown Type

There are 94 of programmed projects.

| Scientific Name | Common Name | Federal List | State List |
|---|---|---|---|
| Accipiter gentilis | Northern Goshawk | BLM/FS | None |
| Agelaius tricolor | Tricolored Blackbird | BLM/FS | None |
| Ambystoma californiense | California tiger salamander | Threatened | None |
| Ambystoma macrodactylum | Long-toed Salamander | Endangered | Endangered…. |

For actual occurrences of listed terrestrial plants and animals that are in the Caltrans district five:

## District # 5 Species Occurrences by Planning Watershed

The Area occupies 28547.69 sq.km (7054287 acres). As of 2000 the population was 1327400 people and the area contained 480427 house units.

There are 25 hydrologic unit watersheds, 70 hydrologic Sub-Areas and 870 planning watershed units.

There are 0 km (0 miles) of Interstate Highways, 443.1 km (275.33 miles) of Federal Highways, 1454.58 km (903.84 miles) of State Highways, and 125.57 km (78.03 miles) of Unknown Type

There are 94 of programmed projects.

| Scientific Name | Common Name | Federal List | State List |
|---|---|---|---|
| Agelaius tricolor | Tricolored Blackbird | BLM/FS | None |
| Ambystoma californiense | California tiger salamander | Threatened | None |
| Ambystoma macrodactylum | Santa Cruz long-toed salamander | Endangered | Endangered |
| Antrozous pallidus | Pallid Bat | BLM/FS | None |
| Aquila chrysaetos | Golden Eagle | BLM/FS | None…. |

For actual occurrences of listed terrestrial plants and animals that recorded in the footprint of programmed projects:

## District # 5 Species Occurrences by Programmed Project

The Area occupies 28547.69 sq.km (7054287 acres). As of 2000 the population was 1327400 people and the area contained 480427 house units.

There are 25 hydrologic unit watersheds, 70 hydrologic Sub-Areas and 870 planning watershed units.

There are 0 km (0 miles) of Interstate Highways, 443.1 km (275.33 miles) of Federal Highways, 1454.58 km (903.84 miles) of State Highways, and 125.57 km (78.03 miles) of Unknown Type

There are 94 of programmed projects.

| Scientific Name | Common Name | Federal List | State List |
|---|---|---|---|
| Agelaius tricolor | Tricolored Blackbird | BLM/FS | None |
| Ambystoma californiense | California tiger salamander | Threatened | None |
| Ambystoma macrodactylum | Santa Cruz long-toed salamander | Endangered | Endangered |
| Ammospermophilus nelsoni | Nelson's antelope squirrel | None | Threatened |
| Antrozous pallidus | Pallid Bat | BLM/FS | None…. |

For the habitat types found in Caltrans district five. This table is presented in its entirety.

# Habitat Impact Report District # 5

The Area occupies 28547.69 sq.km (7054287 acres). As of 2000 the population was 1327400 people and the area contained 480427 house units.

There are 25 hydrologic unit watersheds, 70 hydrologic Sub-Areas and 870 planning watershed units.

There are 0 km (0 miles) Interstate Highways, 443.1 km (275.33 miles) Federal Highways, 1454.58 km (903.84 miles) State Highways, and 125.57 km (78.03 miles) Unknown Type

There are 94 programmed projects.

| Vegetation Type: | Total Area of state | Selected Percent (acres): | Area Protected (acres) | Area Impacted (acres): |
|---|---|---|---|---|
| Agriculture | 1320435.68 | 15.30% | 2693.39 | 651.79 |
| Alkali Desert Scrub | 32612.26 | 0.38% | 1200.91 | 3.71 |
| Annual Grassland | 2747008.23 | 31.82% | 47364.13 | 1174.74 |
| Barren | 30724.41 | 0.36% | 7106.60 | 20.21 |
| Blue Oak Woodland | 582807.59 | 6.75% | 20630.38 | 99.11 |
| Blue Oak-Foothill Pine | 160859.63 | 1.86% | 1929.85 | 1.44 |
| Chamise-Redshank Chaparral | 303073.09 | 3.51% | 55612.33 | 0.75 |
| Closed-Cone Pine-Cypress | 12930.74 | 0.15% | 3595.31 | 3.65 |
| Coastal Oak Woodland | 710086.33 | 8.23% | 81750.56 | 79.45 |
| Coastal Scrub | 608370.08 | 7.05% | 62049.28 | 63.91 |
| Desert Scrub | 882.15 | 0.01% | 0.00 | 0.56 |
| Desert Succulent Shrub | 286.64 | 0.00% | 0.00 | 1.58 |
| Desert Wash | 953.81 | 0.01% | 0.00 | 10.28 |
| Douglas-Fir | 2673.62 | 0.03% | 397.83 | 0.00 |
| Eucalyptus | 1947.15 | 0.02% | 0.00 | 0.88 |
| Freshwater Emergent | 242.16 | 0.00% | 210.04 | 0.03 |
| Jeffrey Pine | 439.84 | 0.01% | 410.19 | 0.00 |
| Juniper | 14262.61 | 0.17% | 1000.76 | 0.17 |
| Lacustrine | 59.30 | 0.00% | 0.00 | 0.08 |
| Mixed Chaparral | 950702.42 | 11.01% | 298464.68 | 17.94 |
| Montane Chaparral | 1771.71 | 0.02% | 1321.99 | 0.00 |
| Montane Hardwood | 100124.92 | 1.16% | 41922.99 | 2.04 |
| Montane Hardwood-Conifer | 73230.56 | 0.85% | 32849.47 | 2.41 |
| Montane Riparian | 13847.48 | 0.16% | 657.29 | 2.56 |
| Pasture | 2456.17 | 0.03% | 0.00 | 0.00 |
| Pinyon-Juniper | 30039.95 | 0.35% | 3852.29 | 0.00 |
| Ponderosa Pine | 4428.03 | 0.05% | 1485.07 | 0.00 |
| Redwood | 139166.72 | 1.61% | 34972.06 | 11.10 |

| Vegetation Type: | Total Area (acres): | Percent of | Area Protected (acres): | Area Impacted (acres) |
|---|---|---|---|---|
| Sagebrush | 9377.45 | 0.11% | 390.42 | 3.16 |
| Saline Emergent Wetland | 3135.70 | 0.04% | 1672.87 | 6.63 |
| Sierran Mixed Conifer | 2616.79 | 0.03% | 2327.68 | 0.00 |
| Unknown Conifer Type | 24334.41 | 0.28% | 1848.31 | 0.20 |
| Unknown Shrub Type | 119670.53 | 1.39% | 5181.69 | 45.10 |
| Urban | 550983.58 | 6.38% | 3281.49 | 731.63 |
| Valley Foothill Riparian | 17739.31 | 0.21% | 746.24 | 3.20 |
| Valley Oak Woodland | 25893.61 | 0.30% | 1018.05 | 3.49 |
| Water | 31507.72 | 0.37% | 822.84 | 10.92 |
| Wet Meadow | 17.30 | 0.00% | 0.00 | 0.00 |
| **Total:** | **8631699.67** | **100%** | **718766.95** | **2952.73** |

# Under the Boardwalk – Case History – St. John's Sideroad at the McKenzie Wetland, Aurora, Ontario, Canada

**Ian D. Buchanan** (905-830-4444, ian.buchanan@york.ca), Manager, Natural Heritage and Forestry Services, and Dino Basso, P.E., Regional Municipality of York, 17250 Yonge Street, Newmarket, Ontario L3Y 7E2, Fax: 905-895-7735 Canada

**Abstract:** St. John's Sideroad, is a major east-west arterial under the jurisdiction of the Regional Municipality of York (York Region). It is located in the Town of Aurora, Ontario, Canada and lies within the watershed of the East Holland, Lake Simcoe basin. This unique project involved the widening and reconstruction of a two-kilometre section of St. John's Sideroad between Yonge Street and Bayview Avenue.

As a result of increased traffic volumes due to highly active residential development in the area, the existing two-lane rural road section could not meet the needs of the growing population (figure 1). In response to the proposed development growth in the Town, the Class Environmental Assessment study undertaken for the project identified that additional roadway capacity was needed, and recommended that this section of roadway be widened to a four-lane urban cross-section.

Figure 1. St. John's Sideroad prior to construction looking west across the McKenzie Wetland.

This project presented significant environmental challenges as St. John's Sideroad runs through the McKenzie Wetland (also known as Aurora Wetland or McKenzie Marsh), an area designated as a Provincially Significant Wetland and an important environmental feature to the local community. The McKenzie Wetland is a permanent home to numerous fish and wildlife species. Recognizing a significant opportunity to both protect and enhance the wetland and its functions along with the roadway, York Region implemented a number of key design elements to limit intrusion in the marsh and restore many of the impaired functions of the wetland.

While achieving the transportation objectives, project design emphasized improvements to:

- Wetland area, function and attributes
- Fish and wildlife habitat and function
- Water quality and circulation

Other technical innovations associated with the project included:

- Timber boardwalks, viewing areas, education and interpretive signage.
- Unique streetscaping elements including landscaping and decorative lighting.
- Bike paths throughout the length of the project, which linked the Town's existing bicycle trail network to the McKenzie Wetland and its boardwalk.
- Widening the roadway to a fully illuminated four lane urban cross-section with curb and gutter, storm sewers, sidewalks on both sides and traffic signals at major intersections.
- Railway safety improvements that included profile revisions and new gates and signals at an existing at-grade commuter railway crossing.
- Extension of the East Holland River Culvert, a triple-cell culvert, with construction being staged to maintain stream flows without using dam-and-pump or flow bypass methods.
- Tunnel construction of the East Holland Sanitary Trunk Sewer using a tunnel boring machine with a connection to the Aurora Pumping Station.

This $20 million project presented several challenges that in turn provided opportunities to develop unique design approaches. This project complimented the surroundings by being sensitive to both the natural environment, while enhancing the communities enjoyment of the area (figure 2).

Figure 2. Aerial view of the St. John's Sideroad project post construction, looking eastward.

## Environmental Considerations

In 1973, as part of a habitat improvement program, the McKenzie family, in conjunction with Environment Canada, created the McKenzie Wetland by installing a simple stop-log dam structure on a small tributary of Tannery Creek. The resulting flooded area quickly became a permanent and highly productive wetland habitat teeming with wildlife.

St. John's Sideroad had already been in place long before the wetland was created. Today the McKenzie Wetland is a 10 ha wetland complex that has been designated as a Provincially Significant Wetland by the Ministry of Natural Resources (MNR). It is recognized as a significant ecological feature due to its diverse wildlife habitat functions and high aesthetic social and cultural value to the local community (figure 3).

Throughout the Class EA process, the potential effects of the road widening on the McKenzie Wetland were a key concern to York Region, the Town, the MNR, the Department of Fisheries and Oceans (DFO), the LSRCA and the general public. In light of this, one of the primary goals of the Class EA was to:

> *Ensure that any recommended road design incorporates natural environmental design features to avoid or mitigate the effects of the undertaking and, to the extent feasible, to make recommendations to enhance important wetland functions and attributes.*

To achieve this overall goal, the key attributes and functions of the wetland were described, and the existing and potential future loss of environmental function associated with the proposed road widening was identified. Design recommendations to mitigate these concerns were aimed at minimizing the loss of wetland, reducing the loss of wildlife (i.e. roadkills), managing stormwater runoff quality, and accommodating a pedestrian boardwalk within the right-of-way, which in turn minimizes the overall "footprint" of the road.

The ecological and hydrological functions of the McKenzie Wetland have been enhanced and the plants and animals it supports have been protected through this project. The wetland was protected by minimizing the width of the road through the marsh while re-connecting the north and south portions of the wetland through the provision of both wet and dry culverts under the road. A variety of other enhancements implemented through the project provided net benefits to the wetland and its inhabitants.

Figure 3. The McKenzie Wetland looking north from St. John's Sideroad.

## Environmental Issues

### Wetland Loss

The original profile of the section of St. John's Sideroad that bisected the wetland was only about 0.5m above the water level in the wetland. The road profile did not meet road design standards and therefore had to be raised 2.5m above the original profile. Using conventional embankments to raise the road by 2.5m and to widen it from 2 to 4 lanes would have significantly increased the road footprint with corresponding wetland loss. In order to reduce the footprint of the road, thereby reducing the loss of wetland and fish habitat, sheet pile vertical retaining walls were constructed (instead of conventional sloping embankments) for a distance of 300 m through the wetland. This resulted in a loss of wetland of only 0.22 ha, or just over 2% of the total area of the McKenzie Wetland.

Construction was carried out during the fall and winter to protect nesting and migrating wildlife and spawning fish during critical seasons. The use of sheet piles helped minimize the degree of disturbance to the natural environment by clearly separating the construction zone from the adjacent wetland.

### Wildlife and Fish Habitat Loss

Two years of pre-construction monitoring provided irrefutable evidence that slow-moving animals inhabiting McKenzie Wetland such as turtles, frogs, aquatic mammals (e.g. muskrats) and fledgling waterfowl were susceptible to roadkill at certain times of the year. Of the greatest concern was the number of turtles that were being killed, a condition that had been reported by local residents for many years. Both Snapping Turtles and Painted Turtles are present and historically, the female turtles laid their eggs around the Wetland, as well as in nests excavated from the soft gravel that lined both shoulders of St. John's Sideroad.

Not surprising, this made adult females particularly susceptible to roadkill, as they crossed the road to lay eggs in the Spring. Turtles were again at risk during September and October, when the young hatched and the adults returned to favoured winter hibernation locations in the marsh. Frogs and toads often crossed the road in large numbers on warm wet nights in Spring and again in Fall. Ducks and geese that nest near the wetland would traverse the road when moving their broods from one side to the other which could also result in significant roadkill.

In order to reduce the incidence of roadkill, which was an almost daily occurrence during the non-winter months, the design team recognized the need to eliminate the ability for wildlife to gain access to the surface of the road. This could be achieved in two ways: by eliminating the habitat adjacent to the road or by maintaining (and in some locations even enhancing) the habitat but preventing access to the road surface. Accordingly, the decision was made to design the road cross-section through the wetland with vertical retaining walls on both sides in order to prevent animals that use crawling, hopping or walking as their means of locomotion from gaining access to the roadway.

This project provided for the protection of both wetland and upland habitats, while increasing the opportunity for the unobstructed movement of fish and wildlife through the variety of culverts placed under the road bed. These culverts provide and alternative means for animals to gain safe passage from one side of the road to the other while reducing the incidence of wildlife loss from roadkill. Three culverts (two wet and one dry) were incorporated into the design of the road through the marsh. The dry culvert, having a diameter of 1.2 m was installed with drift fencing at both ends and strategically situated on higher ground just east of the wetland (figure 4).

Figure 4. Dry culvert at McKenzie Wetland with drift fencing to direct wildlife movement.

The largest wet culvert is a 4 m-wide concrete box culvert, which replaced a 0.6 m diameter culvert that was too small and often plugged with sediment and debris. The larger culvert allowed fish and other wildlife to move back and forth from one side of the marsh to the other (figure 5). The new structure was deliberately oversized (i.e. it is considerably larger than required for hydrological purposes) so that it would facilitate improved fish and aquatic wildlife passage under the road. The design also included the installation of fish habitat friendly structures called 'root wads' which were placed in the open marsh to provide important cover for resident fish. Water quality improvements associated with the project also provided benefits to the fisheries resource.

Figure 5. Wet culvert at McKenzie Wetland for fish, waterfowl, reptile and amphibian passage.

In addition, special consideration was also given to the design of several culverts that accommodate the flow from significant tributaries of the East Holland River under St. John's Sideroad to the east of the wetland. These culverts incorporated the installation of extensive aquatic habitat restoration and enhancement measures both upstream and downstream.

**Water Quality and Quantity**

Prior to its widening the existing surface of St. John's Sideroad was graded directly into the wetland and all road runoff was directed to the marsh with little opportunity for infiltration and no treatment. As a result, oil, grease and other contaminants that are commonly associated with roads entered directly into the wetland ecosystem. Prior to the improvements, the small diameter pipe culverts crossing the road were predominantly plugged, which prevented any circulation of water between the two water bodies.

Improvements to water quality and quantity were achieved through the installation of storm water management structures which included an integrated system of curbs and gutters, an oil grit separator and the use of infiltration swales (figure 6). Each of these storm water management components improves the quality of water before it enters the wetland. The system of culverts underneath the road not only improve wildlife and fish passage, but serve to re-connect the water flow from the north and south sides of the wetland and balance water levels. These improvements in water quality and connectivity are vital to sustaining a thriving wetland and its inhabitants.

Figure 6. Storm water outfall retrofit to promote infiltration.

**Recreational Use**

Wildlife viewing and walking in the non-winter months, and ice-skating in the winter have historically been the primary human activities associated with the McKenzie Wetland. The southern basin has been subjected to increasing human pressure from the adjacent residential development and Atkinson Park. The creation of a series of informal trails has resulted in trampling of the upland vegetation that fringes the wetland.

To accommodate these highly valued and traditional human uses of the area, while avoiding direct intrusion into the sensitive wetland ecosystem, a 3.6 m wide timber boardwalk has been constructed along the north side of the road through the wetland (figure 7). The boardwalk is used by both pedestrians and cyclists and has viewing outlooks that provide excellent vistas of the wetland. Interpretive signage mounted on pedestals has been placed in strategic locations along the length of the boardwalk to provide visitors with information about the features and functions of the wetland, its ecological significance, and how protection and enhancement of the McKenzie Marsh ecosystem has been incorporated into the design of the road. This boardwalk prevents human access to the wetland itself, provides a safe environment for walking and cycling away from vehicular traffic and has established a key east-west link in the Nokiida Trail System, linking it to the regional Holland River Trail System.

Decorative lighting has been installed to provide safe lighting levels along the boardwalk and incorporates special distribution to prevent light spillage into the wetland which could impact nocturnal wildlife.

Figure 7. Boardwalk, lighting and viewing platform at the McKenzie Wetland looking west.

**Monitoring**

Monitoring (prior to, during and post-construction) was an essential component of the environmental approvals process, with the following goals:

- To help ensure that public confidence in the process is maintained;
- To ensure that best management practices were implemented and enforced during construction;
- To direct post-construction changes that may need to be made to the project; and
- To provide information regarding the efficacy of mitigation so that lessons can be learned and wisely applied to future projects.

*Pre-Construction Monitoring* - Surveys to quantify the level of roadkills prior to construction of the road were carried out and those data are being compared to the results of post-construction surveys (which commenced in 2006) to measure the effectiveness of the design measures intended to prevent wildlife from gaining access to the roadway.

*Construction Monitoring* - To minimize the disturbance to the wetland and its inhabitants, construction of the four-lane road through the wetland commenced after July 1, effectively avoiding the sensitive fish spawning and bird nesting seasons.

*Post-Construction Wildlife Monitoring* - To complement the pre-construction field inventory and assessment, and further test the validity of the wildlife mitigation and enhancement aspects of the project, post construction wildlife monitoring was implemented. The following suite of field investigations were undertaken in 2006:

- Amphibian calling counts
- Breeding bird surveys
- Road kill surveys
- Wildlife passage at the dry culvert

The results of these surveys were compared to pre-construction data and will be compared with results of monitoring studies which will be repeated in 2007.

*Amphibian calling counts*

Monitoring was conducted using the Provincial Marsh Monitoring Program protocol. This targeted an early (mid April) and late (late May) survey by walking transects at dusk and recording calls of male amphibians. The survey recorded Gray Treefrogs (*Hyla versicolor*) and numerous Green Frogs (*Rana clamitans*). Unfortunately, the early monitoring did not occur in 2006. It is anticipated that species recorded in pre-construction assessments including Leopard Frogs (*Rana pipiens*) and American Toads (*Bufo americanus*) will be recorded in 2007.

*Breeding bird surveys*

Breeding bird surveys included walking through the wetland and also recording territiorial responses to pre-recorded calls played in the field. These survey consisted of two days of field work in June (early and late). The survey results indicate that the marsh continues to support a relatively low species richness, with most species recorded being habitat generalists and highly resilient species. These generalists include Red-winged Blackbirds, Song Sparrows, Yellow Warblers, Warbling Vireos and waterfowl such as the Canada goose and Mallard ducks.

Pre-construction inventory includes a variety of information from observations dating back to the 1970's, and including works done in the 1990's. Two factors have likely contributed to the general decline in the presence of more sensitive species including Pied-billed Grebes, the American Coot, Wood duck, Sora etc.. These factors include the overall increase in disturbance associated with urbanization in the area. Increased urbanization has resulted in higher direct and indirect stresses on the marsh and its community, associated with increased predation (pets and urban wildlife e.g. racoons) and higher public activity and traffic in the area. The second factor relates to water level management. The current water level management has maintained a large area of open water marsh. This limits the amount of emergent, wet meadow and upland habitat areas. This influence on habitat diversity may affect the variety of nesting and brooding habitat available to a wider variety of species. In subsequent years water level management may be regulated to help enhance certain habitat values associated with more sensitive species use of the marsh.

*Road kill surveys*

One of the major ecological concerns raised by the public during the consultation phase of the project was road kill of reptiles and amphibians. Pre-construction roadkill surveys were conducted in 2002 and 2003. In 2006 16 post construction field visits were made between May and October. Road killed species recorded in pre-construction monitoring included the Common Snapping Turtle (*Chelydra serpentine*) and Midland Painted Turtles (*Chrysemys picta*). Both adults, when searching for nesting sites in the Spring and migrating in the Fall, and young turtles emerging from nests in the Spring and early summer. Mortality of turtles declined from 20 (over 2 years) pre-construction to one specimen recovered in 2006.

The frequency of amphibian mortality was also significantly reduced following the project. Muskrat (*Ondatra zibethicus*) mortality declined from 13 pre-construction to zero recorded in 2006. Overall the reduction in the occurrence of road kill of all wildlife through the wetland area was significantly reduced.

*Wildlife passage at the dry culvert*

The project included the installation of a 1.2 m CSP culvert in a terrestrial location. The culvert was installed with permanent drift fencing at both ends. It was noted that the drift fencing was not functioning at 100% efficiency due to a gap in the fencing at the culvert interface. This situation was corrected following the 2006 survey. A Digital Game Camera (Model IR-3BU) was obtained from Leaf River Outdoor Products. The camera works with an infra-red sensor and motion detector, and set up to take pictures day or night and store them on a Compact Flash Card (512MB). At night an infra-red flash, invisible to animals, is used to illuminate the image while not disturbing the animals. The camera was in place from August 11th until October 10th, 2006 (60 days).

Figure 8. Rabbit at north entrance to dry culvert.

Images captured of animals using the culvert included primarily racoons (10 records), Eastern Cottontail rabbits (3 records), and a singled record of a Red fox. Animals recorded at the entrance to the culvert included groundhogs, Eastern Gray squirrels, domestic cats, American Robin and one inquisitive young boy who appeared to be inspecting the culvert.

Certainly the dry culvert is working for wildlife passage as indicated by a well worn trail leading to and from the culvert.. In 2007 it is hoped to deploy the camera earlier in the Spring to hopefully capture reptile and amphibian migration. In addition, it is suggested that vegetation be planted and or woody debris be placed along the drift fence at the culvert to provide cover for moving wildlife and deter predation.

**Summary of Environmental Impacts**

Table 1: Summary of environmental impacts, mitigation and net effects.

| ISSUES | MITIGATION | NET EFFECTS |
|---|---|---|
| **WETLAND AREA AND FUNCTION** | road designed to minimize encroachment | - loss of 0.2 ha (0.5 acres) of wetland (2% of total area) |
| | plantings around south wetland | + provide additional habitat for wildlife (nesting birds) |
| | manage water levels | + more "natural" hydrologic cycles<br>+ increased wetland productivity |
| **FISH HABITAT** | road designed to minimize encroachment | - minor loss of 0.03 ha (0.1 acres) of open water |
| | oversized culvert | + replaced habitat under road |
| | manage water levels in wetland | + more wetland vegetation, more productive fish habitat |
| **WILDLIFE** | vertical retaining wall | + reduced roadkills |
| | wet and dry culverts | + improved wildlife movement |
| | alternative turtle nesting habitat | + no turtle nesting habitat at roadside |
| **SURFACE WATER RUNOFF** | removal of gravel shoulders | + reduction in direct discharge of road debris and contaminants |
| | urban road design (curb and gutter, catchbasins, oil grit separator and grassed swales) | + water to be treated in oil grit separator and grassed swales |
| | retrofit of storm water pond to south | + reduced sediment loading<br>+ overall improvement in water quality |
| **HUMAN USE** | boardwalk and trail (part of Nokiida Trail) | + reduces uncontrolled access |
| | focus pedestrian access with plantings, controlled observation points | + provides passive recreational opportunities |
| **CONSTRUCTION AND POST-CONSTRUCTION MONITORING** | minimum 2 year monitoring program | + test impact predictions, identify corrective measures<br>+ contribute to understanding of road/wetland dynamics |

+ = positive net effect - = negative net effect

## Effective Community Relations

Context sensitive design and effective constructive engagement with stakeholders is vital to any successful project but is especially important when a project description includes a provincially significant wetland, high animal mortality rates, a substandard road, unsafe pedestrian conditions, development pressures for widening roadways and a community demanding active involvement. With this view, York Region undertook the project with a Context Sensitive Solution (CSS) approach as a guiding principle to build a functional infrastructure facility that fits with the adjacent social and environmental surroundings.

CSS is a collaborative, interdisciplinary approach that involves all stakeholders to develop a transportation facility that fits its physical setting and preserves scenic, aesthetic, historic and environmental resources, while maintaining safety and mobility. CSS is an approach that considers the total context within which a transportation improvement project will exist. CSS principles include the employment of early, continuous and meaningful involvement of the public and all stakeholders throughout the project development process.

### Public Consultation

There was a conscious decision by York Region on this project to do more than just the minimum level of public consultation. In addition to the two mandatory Public Consultation Centres (PCCs) required for Class Environmental Assessment (EA) studies, three additional PCCs were held during the EA study for this project. The PCCs were facilitated by an independent facilitator in order to present the project to the public and solicit feedback. Two more PCCs were held during detailed design. These were not a compulsory public contact requirement, but it was advantageous to obtain the public's comments. Once the preliminary design for the McKenzie Wetland area was completed. A pre-construction public consultation centre was also not compulsory but was arranged after the construction contract was awarded, so that the project could be presented to the public one last time, with specific emphasis on the construction schedule and phasing, anticipated environmental issues and proposed mitigation measures, and the upcoming temporary road closure. The owner, consultant and contractor all participated in the PCC.

### Meetings with Individual Stakeholders

The project team was aware of concerns of some members of the public, so proactive one-on-one consultation was arranged throughout the project, utilizing on-site meetings with politicians and local ratepayer groups. During one meeting, the proposed footprint was actually staked-out in the field so that the stakeholders could visualize the extent of the widening into the wetland. Kitchen-table forums were also useful in resolving those concerns in advance of the public meetings. In this way the public consultation centres were not 'bogged down' by the concerns of a few, and resulted in meetings being successfully managed and objectives met.

Through the constructive engagement approach, York Region was able to change public opinion from resistance to one of acceptance, praise and community pride at the outcome.

### Graphical Renderings

Sometimes it is difficult for members of the community to visualize how the end result of the project might appear and this can lead to unintentional misconceptions by the public. Therefore photo imagery using computer generated renderings was useful in presenting how the proposed work would appear before construction occurred. Figure 9 presents a rendering that was created for the public consultation centres to present the project. The renderings were very useful in easing the concerns of the public towards this project. Also, design input by the community resulted in the project team modifying the cladding/facing of the sheet pile wall with wood planks instead of steel. This was done on the south side of the road that faces the adjacent residential development. Figure 10 is a post construction photograph, demonstrating the accuracy of the computer rendering.

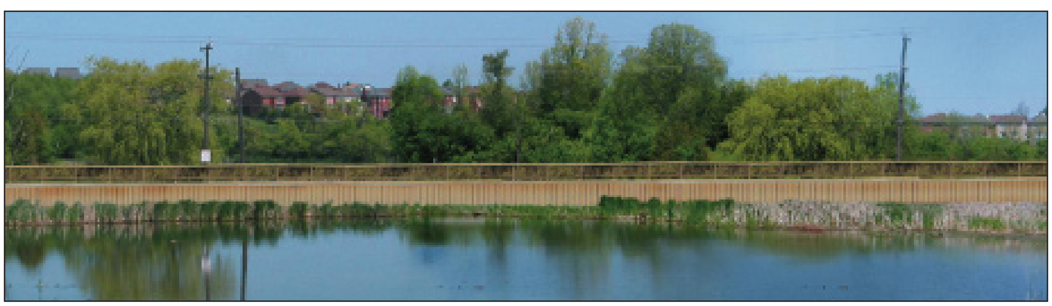


Figure 9. Computer rendering of the proposed road improvements through the McKenzie Wetland.

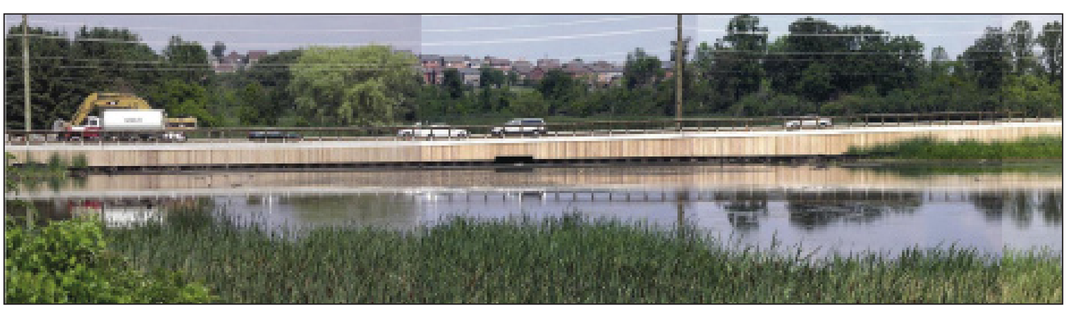


Figure 10. Photograph looking northwards across the McKenzie Wetland to St. John's Sideroad.

**Consultation with Town of Aurora**

The Town of Aurora was a significant stakeholder for this project, since the project was located within the Town. The landscaping and streetscaping improvements would not have been done without a funding partnership with the Town. The Town contributed to the construction of the watermain, timber boardwalk, sidewalks, bike paths and streetlighting. Several meetings were arranged with the Town staff to obtain their input into the design alternatives and agreement to the final design. York Region used innovative ideas such as design workshops where questions such as "Imagine if money was no object, what would you like to see built?" were posed in order to 'brainstorm' solutions. This helped develop ideas that normally may not have been considered if funding was the only factor. The project team considered cost only after all ideas had been developed. Through those meetings, agreement was reached on various components of the project and the designs were developed in order to present to Town Council for approval. Examples include the selection of timber materials for the handrails and the idea to incorporate a cedar veneer to the face of the south sheet-pile wall to enhance the look when viewed from the residential development on the south side of the McKenzie Wetland area.

**Consultation with Department of Fisheries and Oceans, Ministry of Natural Resources and Conservation Authority**

Extensive consultation was undertaken with the federal Department of Fisheries and Oceans (DFO) and provincial Ministry of Natural Resources (MNR) throughout the project. Several meetings were also instrumental in creating open dialogue and achieving approval from the Lake Simcoe Region Conservation Authority (LSRCA). Early in the design, a site meeting was arranged to present the design concept, summarize the environmental issues, and obtain their initial agency comments. LSRCA's agreement in principle to the proposed design was obtained during this initial meeting, and laid out the foundation for the subsequent development of the road design.

**Design Charette Workshop**

In keeping with the Context Sensitive Solution approach, towards the end of the design phase there was discussion as to how a good project could be made even better. A design charette workshop was arranged that included the Town of Aurora, the project team and a landscape architect, where ideas that would enhance the design further at the McKenzie Wetland area could be brain-stormed. Out of that session came an agreement to contribute the additional funding necessary to improve the project further with the following features:

- Various renderings were produced to enable staff and the public to visualize the project goals and as an aid to help present it to council for approval.
- Eliminate guiderail on each side of the road and replace with armour-stone planter walls and metal bollards.
- Extensive plantings, which consisted of trees, shrubs and ground cover with irrigation system.
- Revise the boardwalk layout so that it is meandering, with lookout features for the enjoyment of the public.
- Use of decorative street furniture such as benches, metal bollards, trash receptacles, signage and special pavements such as impressed concrete.
- Incorporate ornamental lighting rather than traditional roadway lighting.

**Ongoing Commitment to Education**

York Region has an ongoing commitment to educate the public on how the region is managing and directing growth, transforming urban landscapes and protecting-/enhancing the natural environment and heritage features. Education is imparted through mobile workshops or guided tours and presentations at conferences such as the 2006 APWA Congress and Exposition in Kansas City, Kansas.City, Kansas.

## Challenges and Technical Accomplishments

The St. John's Sideroad project presented various technical, environmental and financial challenges that had to be effectively managed for this project to achieve success. These challenges include unusual subsurface conditions and their effect on the retaining wall design, environmental constraints and opportunities, impacts to utilities and their relocation, project financing, and most importantly, how the project could be implemented to the satisfaction of the public and other stakeholders.

In the McKenzie wetland area, these challenges had to be implemented within a very limited area bounded by water on each side of the existing narrow road platform.

**Soil Consolidation and Settlement Monitoring Prior to Permanent Works**

Geotechnical investigations determined the presence of a deep underlying zone of sensitive silty clays and clayey silt materials. Under the existing road platform, this material was already pre-consolidated, but additional settlement was expected due to the raising of the road profile by 2.5m. For the proposed road widening, the amount of settlement under the proposed fills would be greater than under the existing road platform, since it had not been pre-consolidated. On this basis, the project team recommended that temporary asphalt be placed and that the settlement be monitored over a period of time before construction of the permanent works. Regular measurements were taken during construction to record the rate of settlement and establish when the majority of consolidation of the sensitive clay materials would be completed.

**Wetland Constraints and Mitigation**

The proposed design recommended vertical retaining walls at the McKenzie wetland in order to reduce the roadway footprint and prevent wildlife from accessing the roadway.

Sheet-pile retaining walls were selected over other retaining wall systems such as gravity or cantilever retaining walls for several reasons. First, due to the consolidation of the sensitive material underlying the road platform, it was necessary to select the lightest structure possible. Second, sheet-pile walls could be driven by equipment positioned on the existing road platform, and therefore disturbance to the wetland by equipment or by workers was avoided. Third, once the sheet-pile walls were driven, they immediately formed a barrier between the construction work zone and the wetland environment for the remainder of the project.

**Subsurface Excavation 'In the Wet'**

Within the wetland area itself, a surficial zone of peat material was sub-excavated after the pile-driving operation and replaced with clear stone backfill material wrapped in geotextile filter material. This excavation 'in the wet' avoided pumping large volumes of water out from behind the retaining wall, and eventually back into the wetland.

Figure 11. Road platform and the sheet-pile retaining wall under construction.

**Utility Relocations**

The project team expected the increase of road profile over the poor subsurface conditions to cause additional consolidation and corresponding significant settlement problems which could cause damage to existing and newly placed utilities and services.

**Sanitary Trunk Sewer**

An existing 1050 mm diameter sanitary trunk sewer was replaced with concrete pressure pipe having extra deep joints that could tolerate the anticipated joint movement as the pipe settled during the consolidation of the underlying materials. The replacement and the construction of connection chambers around the existing sewer at each end were carefully staged to avoid interruption of sewer flows.

**Watermain**

A new 500 mm diameter watermain was proposed within the McKenzie Wetland area, and it was also important that the watermain have the flexibility to tolerate the anticipated consolidation of the underlying material. High-density polyethylene pipe (HDPE) was selected, since it can be butt-fused together to eliminate joints. The watermain was also installed successfully by horizontal direction drilling (HDD) to avoid impacting the wetland.

**Gas Main Relocation**

A 300 mm diameter gas main on the north side of the road was in conflict with the proposed retaining wall. It was also considered that the vibrations caused by pile driving may also endanger the gas main at its original location. Therefore, prior to construction, the gas main was relocated further north - under the bed of the wetland using directional boring to avoid impacts to the wetland itself. During the construction of St. John's Sideroad, survey crews monitored vibrations on the gas main and took settlement readings throughout the pile-driving activities to ensure that the gas main was protected.

### Hydro Pole and Bell Canada Relocations

Although Hydro power and Bell telephone relocations were arranged in advance of construction in most areas within the contract limits, it was not possible to do so at the McKenzie Wetland area, due to the future road fills and open water beyond the existing shoulders. This required that the relocations be included within the overall construction staging. To resolve this issue, the retaining walls on the south side were constructed, but not immediately backfilled to the design elevations. The construction contract was structured to accommodate a six week construction hiatus in order to allow Aurora Hydro to install poles. The poles had unique foundation details, designed to be temporarily supported within the existing peat material, and extra-deep embedment to account for the placement of future road fills. Once the overhead lines were transferred to the new poles on the south side, the poles on the north side were removed to permit pile driving for the north retaining wall. Bell relocations were scheduled during the settlement monitoring period, after the walls were backfilled to design grades.

### Financial Considerations

Securing funding for infrastructure to support our growing communities is achieved annually through Council approval. This funding process for key infrastructure is not unusual in other municipalities. What is unusual and sometimes difficult, however, is securing funding for those little extras that often times are deemed not necessary, or too expensive in light of fiscal constraints that many public agencies face. However, these little extras very often transform routine projects into "WOW" projects. York Region was able to work cooperatively with the Town of Aurora staff and council to secure funding for several project features that could easily be considered as not required or extra to the project. Through the context sensitive solution approach, a number of features were added to the original scope of the project to make it better. These features included the meandering timber boardwalk/bicycle path, timber railings, interpretive signs, decorative lighting, landscaping and street furniture (metal bollards, flags, trash receptacles and benches).

### Public Resistance - Transformed to Acceptance

This project initially received much public resistance over concerns that the road improvements would have a detrimental impact to the McKenzie Wetland. However, through the Context Sensitive Solution approach and sound construction management, York Region was able to change public opinion from resistance to that of acceptance, praise and pride for the community (figure 12).


Figure 12. Articles taken from local newspapers, demonstrating a shift in public opinion.

## Conclusion

The St. John's Sideroad/McKenzie Wetland Project is characterized as being unique and not typical of most road construction projects. This project implemented a wide variety of different environmental mitigation and restoration techniques, and utilized a combination of different construction specialties.

The $20 million project completed in June 2006, included a variety of environmental restoration and enhancement techniques concurrent with roadworks, sewers, watermain, streetlighting and traffic signals, with the construction of sheet-pile retaining walls, horizontal directional drilling, tunneling, railway crossing improvements, timber boardwalks, bicycle trails, and landscaping.

In particular, the McKenzie Wetland posed several operational constraints that required the design improvements to be carefully planned to address the complex construction staging requirements and to achieve the project's interim and final completion dates. Up-front planning and preparation of detailed construction schedules during design was vital to properly coordinate the critical activities that had to be completed within the available road closure time window. The construction of this project was completed on time, on budget and with no accidents or time lost through work related injuries.

York Region was able to overcome initial resistance to the project from a concerned community through a context sensitive solutions approach and constructive engagement. This project was an opportunity for the design team, in consultation with stakeholders, to include environmental enhancements which recognized the unique setting of the McKenzie Wetland, and to make this project much more than a typical road widening project. As a result of this project, York Region was able to not only protect the sensitive natural environment but enhance it by designing and constructing the infrastructure to address natural environment and social concerns. Overall the road widening and habitat enhancement have served to create an area where local residents and wildlife can safely co-exist side by side (figure 13).

York Region received the Ontario Public Works Association's Project of the Year Award for this project in 2006, and was honoured to present a paper at the 2006 APWA Congress and Exposition in Kansas City, Kansas.


Figure 13. Before and after pictures of the St. John's McKenzie Wetland project.

# Watershed Approaches to Compensatory Mitigation: Using Comprehensive Mitigation Planning to Achieve More Effective Mitigation for Transportation Projects

**Jan Cassin, Ph.D.** (425-458-6204, jcassin@parametrix.com), Senior Scientist, Parametrix, Inc., 411 108th Avenue NE, Suite 1800, Bellevue, WA 98004, Fax: 425-458-6363 USA

**Abstract**

This research project deals with development of tools and approaches for implementing more effective environmental mitigation for transportation projects.

In this presentation we evaluate the availability of tools, methods, and data necessary for implementing comprehensive, watershed-based planning for mitigation for transportation projects, and we present lessons learned from innovative approaches being implemented in the Pacific Northwest. It has long been recognized that project-specific, on-site mitigation projects have high rates of failure, frequently do not achieve the desired environmental benefits, and are very expensive. The emphasis for on-site and in-kind compensatory wetland mitigation makes it difficult to design wetland mitigation projects that are not small, isolated, of limited functional value, and difficult and/or costly to maintain in the long-term. Designing and planning mitigation projects within a watershed or landscape context has long been recognized as necessary for ensuring sustainable, successful mitigation. Transportation projects epitomize these challenges, but also provide some of the best opportunities to create better mitigation alternatives through implementation of watershed approaches. In addition, regulatory agencies are recognizing the importance of watershed approaches. The proposed EPA/COE joint rules for compensatory mitigation explicitly incorporate the need for watershed approaches. How prepared are we, however, to implement watershed approaches in mitigation planning and design? States in the Pacific Northwest have been conducting watershed and basin planning for at least the past 10 years under a number of state and local mandates. This region arguably possesses some of the most complete watershed information available in the United States. To determine the availability of the data necessary for implementing a watershed approach we: (1) evaluated more than 50 watershed and/or basin plans to determine how many plans incorporate key elements of a watershed or landscape approach: spatially explicit, process and function based, both biotic and abiotic processes, multi-species focus; and (2) determined the overlap between locations of transportation projects and watershed data. The majority of watershed plans lack one or more of these key elements. We assess the feasibility of implementing watershed approaches for transportation projects using existing information. Using this analysis, we then discuss the development of innovative tools and databases that are being used for planning for watershed-based mitigation at regional restoration sites. For local, state and federal transportation planning purposes, this allows systematic evaluation of the type and amount of mitigation that is or will be needed in the future for the region or a particular watershed, the existing functional condition of the watershed, and where in the watershed restoration is most needed and will have the greatest benefit.

Chapter 4

# Fisheries, Aquatic Ecosystems and Water Quality

## Assessment of Freshwater Mussel Relocation as a Conservation Strategy

**Andrew J. Peck** (870-680-8472, andrew.peck@smail.astate.edu), Arkansas State University, P.O. Box 599, State University, AR 72467 USA

**John L. Harris** (501-569-2285, john.harris@arkansashighways.com), Arkansas Highway and Transportation Department, Environmental Division, 10324 Interstate 30, P.O. Box 2261, Little Rock, AR 72203 USA

**Jerry L. Farris** (870-972-3079, jlfarris@astate.edu), Arkansas State University, College of Sciences and Mathematics, P.O. Box 1030 State University, AR 72467 USA

**Alan D. Christian** (870-972-3296, achristian@astate.edu), Arkansas State University, P.O. Box 599, State University, AR 72467 USA

**Abstract:** Over the last 30 years, relocation of freshwater mussels has been used as a conservation strategy for potential impacts from bridge construction and dredging operations. Improved methods have effectively increased relocated mussel survivorship rates of target species from ~ 50% to ~ 90% under ideal circumstances. Success to date is largely based upon survivorship rates without consideration of relocation activity effects upon fitness and behavioral traits of mussels.

In 2003, the Federal Highway Administration (FHWA) and Arkansas Highway and Transportation Department (AHTD) funded research to: 1) determine the success of mussel relocation efforts associated with highway construction projects by investigating survivorship, movements, mortality, fitness (as indicated by condition factor), and fecundity of relocated and non-relocated adults and sub-adults, 2) determine success of mussel propagation efforts by investigating survivorship of juveniles returned to identified habitats and used for population enhancement (recruitment), and 3) determine impacts at highway construction sites by comparing pre- and post-construction mussel assemblage abundance and composition, sediment deposition downstream of the construction, and individual mussel fitness.

This project seeks, in part, to use the data acquired in the formulation of a programmatic biological assessment/biological opinion streamlining initiative for P. capax that will be proposed to the U. S. Fish and Wildlife Service by the ATHD and FHWA. Biochemical composition (i.e. condition factor) and movement (i.e. displacement) were monitored for two species of freshwater mussels subjected to relocation activity, the federally endangered P. capax and a species with a different life history, *Quadrula quadrula* and compared with control (i.e. non relocated) populations. Trends were identified in condition factor, through repeated measures ANOVA, associated with short (glycogen), moderate (lipid), and long term energy stores (proteins, RNA:DNA ratios) sampled pre- and post-relocation. Behavioral trends (i.e. displacement) between native and relocated populations of the two species were measured in both short-term (weeks) and long-term (quarterly) intervals. Results pertaining to population enhancement strategies, specifically field methodologies used for *in-situ* rearing of juvenile *P. capax* along with growth and survival rates of field reared and lab reared individuals are presented.

### Introduction

Society has placed a value, though economic value is often difficult to estimate, on appropriately functioning ecosystems and the species that inhibit those environs (Wilson and Carpenter 1999). This is evidenced by the multiple pieces of federal legislation enacted, such as the Clean Water Act (CWA), the Endangered Species Act (ESA) and the National Environmental Policy Act (NEPA). Because of these legislative actions, most activities, such as point source discharge, wetland filling, and non-point discharge are regulated and mitigation measures to buffer against unavoidable negative impacts are required. However, in many cases and especially those pertaining to endangered species, a widely accepted mitigation measure and implementation process may not have necessarily gone through a critical evaluation process. Rather, *ad hoc* responses to expected disturbances may have been established and implemented due to the nature and requirements of the authoritative legislation and the need for the given project.

One such example of this management scenario is mitigation prescribed for impacts to freshwater mussels (Mollusca: Unionoida). Freshwater mussels have gained increasing focus over the past three decades as researchers have been able to vastly expand the general knowledge base (Haag and Staton 2003; Strayer et al. 2004) and better understand the ecosystem function of these organisms (Howard and Cuffey 2006; Spooner and Vaughn 2006; Vaughn and Hakenkamp 2001; Welker and Walz 1998). Unfortunately, the impetus for this flurry of activity revolves around the fact that ~ 72% of North American freshwater mussel species have been accorded some protection designation such as endangered, threatened or special concern status (Bogan 1997; Williams et al. 1993). The causes of declines have historically been attributed to habitat degradation, commercial harvesting, and the introduction of exotic species (Anthony and Downing 2001; Bogan 1997; Williams et al. 1993). Other threats have also been identified, including landscape context (Arbuckle and Downing 2002; Poole and Downing 2004), diseases and parasites (Chittick et al. 2001), eutrophication (Patzner and Muller 2001), and host fish loss (Haag and Warren 2003). One major factor contributing to populations and species declines is the complex life history traits of these organisms, which allow freshwater mussels to be susceptible to a wide variety of environmental threats.

Anthropogenic activities linked with freshwater mussel declines include hydrologic alteration (Vaughn and Taylor 1999), sedimentation (Brim Box and Mossa 1999), incompatible land use (Arbuckle and Downing 2002; Poole and Downing 2004), eutrophication (Patzner and Muller 2001) and point source contamination (Gagne et al. 2001). The sources of these threats include conversion from forest to urban or agricultural land uses, transportation construction projects, dredging activities and mining. The unintended consequences of these activities can include in-stream habitat changes via sedimentation, increased sunlight exposure, nutrient enrichment, and hydrologic alteration.

Since 2002, the Federal Highway Administration (FHWA)-Arkansas Division, U.S. Fish and Wildlife Service Arkansas Ecological Services Field Office, U.S. Army Corps of Engineers Memphis District, Arkansas Game and Fish Commission, Arkansas Department of Environmental Quality, Arkansas Highway and Transportation Department (AHTD), and Arkansas State University have collaborated to construct and implement a local recovery strategy for the endangered fat pocketbook mussel, *Potamilus capax* (Green 1832), that is anticipated to lead to stabilizing and restoring habitat, increasing the number of reproducing and recruiting populations, and recovery of the species so that Federal Endangered Species protection is no longer required..

The fat pocketbook mussel, *Potamilus capax*, was listed as endangered throughout its native range in 1976 by the USFWS (USFWS 1989). The historic range of *P. capax* includes the upper and middle reaches of the Mississippi River and the middle and lower reaches of the Ohio River. Major tributaries to these systems where the fat pocketbook has been documented include the Wabash River in Indiana and Illinois and the lower White River of Arkansas (Cummings and Mayer 1993; USFWS 1989). Perhaps the best remaining population, however, is found in the St. Francis River Drainage of southeastern Missouri and eastern Arkansas (Ahlstedt and Jenkinson 1991). Habitat harboring populations of *P. capax* has been described as moderate to large rivers with slow moving water and mud, sand, and clay substrates (Ahlstedt and Jenkinson 1991; Cummings and Mayer 1993; USFWS 1989). More specifically in the St. Francis Drainage, this species has been found in habitats ranging from the downstream, inside vertical clay banks of meanders to mid-channel habitats with soft substrates consisting of a sand, silt and clay mixture. This species, however, appears to be more abundant in lower reaches of the main river channel and the larger drainage ditches.

Specific information needs were identified by the *Potamilus capax* work group in 2003, and in 2004, the FHWA and AHTD requested letters of interest from qualified governmental agencies, research institutions, and regional universities to conduct ecological research to address these information needs. Subsequently, a proposal was submitted by Arkansas State University (ASU) to address each of the information needs identified by the work group.

The ASU proposal included two major research components or tasks. Task I – Effects of Construction and Mitigation Efforts - included 1) determining the success of relocation efforts for *Potamilus capax* associated with highway construction projects (i.e. survivorship, movements and/or mortality, condition factor, fecundity of relocated and non-relocated adults and sub-adults, and genetic considerations for maintaining genetic diversity), 2) determining the success of propagation efforts for *P. capax* resulting from highway construction projects (i.e. survivorship of juveniles after return to field and population enhancement (recruitment)), and 3) determining impacts to *P. capax* and associated mussel community at highway construction sites (i.e. pre- and post-construction community composition, sediment deposition downstream of construction site, mussel condition factor pre- and post-construction).

Task II - Tyronza River Drainage Restoration - centered around restoring a degraded river system and included 1) determining the status of the freshwater mussel community of Tyronza River (i.e. survey for mussels, summarize existing physical and chemical data for Tyronza River, summarize existing land use patterns in Tyronza River drainage), 2) determining the suitability of Tyronza River for reestablishment of *P. capax* (i.e. toxicity to juveniles, sediment deposition rates vs. survivorship of juveniles and survivorship of trans-located adults, stream restoration and sediment reduction techniques to benefit mussels, availability of host fish for natural reproduction and recruitment, locate “preferred” sites for *P. capax* reestablishment), and 3) preparing an Ecosystem Recovery Plan for Tyronza River Drainage (i.e. target mussel community restoration, *P. capax* restoration, and fish community restoration).

A contract was issued by the AHTD in 2004 to implement Task I research. This paper focuses on results of research directed towards assessing the success of mussel relocation combined with mussel population augmentation as a mitigation technique.

### Mitigation Practices

Transportation projects have produced a relatively large footprint on the North American landscape. For example, Forman and Alexander (1998) estimated 15 – 20% of the United States is influenced by road networks. These networks are necessary for social and economic reasons. However, they do cause habitat fragmentation and degradation of both terrestrial and aquatic systems (Forman and Alexander 1998; Jones et al. 2000; Trombulak and Frissell 2000; Wheeler, Angermeier, and Rosenberger 2005). Understanding the expected ecological consequences of transportation development can potentially provide critical information to aid in the conservation and restoration of threatened ecological systems and biota. Mitigation techniques, such as wetland mitigation banking and stream restoration (i.e. bio-engineering) to counteract the negative aspects of development, have recently begun to gain acceptance in both the political and science arenas (Bonnie 1999; Fox and Nino-Murcia 2005; Green and O’Connor 2001). Though these techniques may not completely negate the impacts of development and policies governing their implementation are still being developed, the application of techniques at the interface between ecosystems and development are quite promising (Fox and Nino-Murcia 2005; Mills 2004).

Some states require impact mitigation when specifically dealing with freshwater mussels and bridge construction. The U. S. Fish and Wildlife Service almost always requires mitigation when an endangered or threatened mussel is present. Typically, impact mitigation is achieved through relocation of mussel aggregations within the estimated construction footprint and a larger zone of potential impact. This entails the total removal of individuals within a pre-defined area at the construction site, and the subsequent relocation to suitable safe habitat within the same stream or a nearby stream within the same drainage. This practice has received the scrutiny of scientific research (Cope and Waller 1995; Dunn, Sietman, and Kelner 1999; Hamilton, Brim Box, and Dorazio 1997; Newton et al. 2001) though the efficiency and efficacy of the practice is still in question, due to observed mortality rates. In Arkansas, the success of relocations is unknown because, in many instances, relocated individuals have not been found in follow-up surveys, thus their fate (live or dead) is unknown (J. Harris, personal communication).

**Relocation Analysis**

Relocating mussels from areas of perceived threats to suitable safe habitat has been occurring in the United States for more than 30 years (Cope and Waller 1995). Relocation is a logical response to policy and legislative authorities implemented at the federal level and resource management objectives applied at the state and local levels. However, evaluations of relocation as a viable technique did not begin to appear in the literature until the mid 1990s. In one of the first such efforts, Cope and Waller (1995), reviewed 33 papers and/or reports discussing relocation activities and found that nearly 90,000 mussels had been relocated during 37 projects. The impetus for 43% of these relocations was construction or dredging activities in proximity to endangered species, which invoked statutes of the Endangered Species Act of 1973 (ESA). The remaining projects were associated with management objectives such as population enhancement, protection from invasive species, and research efforts.

Their initial review estimated that the survival rate for relocated animals was ~50%, but more accurate estimates were not possible due to inadequate post-relocation monitoring efforts in 78% of the cases. The effectiveness of relocation was left in question due to inconsistent reporting, lack of long-term monitoring, and difficulty in recapturing relocated animals. More specifically, the authors pointed out that 30% of reports documented mortality rates >70% and a mean mortality rate of 49% (based on a 43% recovery rate). The authors also noted that half of the reported relocation efforts occurred in the southern and southeastern United States from July through September. Furthermore, the authors noted that the factors influencing survival rates were not well understood and recommended a research agenda that included improved habitat characterization of relocation sites, better defined test methods, increased duration of post-relocation monitoring, and greater publication of relocation projects.

Another technique often employed by resource managers is the captive propagation of juvenile mussels to augment impacted aggregates (Neves 1997). Propagation involves a multi-step process from collecting gravid target species females to placing the propagated juveniles at the impacted (Barnhart 2003, 2004, 2005; Barnhart and Roberts 1997, 1997). Briefly, gravid females are collected in the field and transported to a propagation facility. Larval mussels are non-lethally removed from the marsupia of the gravid female and exposed to suitable host fish for encystment via either direct or indirect techniques. Exposed host fish are held in tanks modified for the collection of excysted larvae for several weeks until glochidia have had time to develop on the host fish and are ready to excyst (Barnhart 2005). Excysted larval mussels are collected from the collection tanks periodically and held in a culturing tank until release into the field. Costs for such mitigation activities can swell into the many of thousands of dollars for relocation alone and can, in some cases, substantially delay the construction permit process, ultimately increasing construction costs and time to completion.

**<u>Methods</u>**

Two mussel species, *Potamilus capax* and *Quadrula quadrula*, exhibiting contrasting life history traits (Subfamily Lampsilinae versus Subfamily Ambleminae), were used for the relocation study that was conducted in the Mississippi Delta Ecoregion of eastern Arkansas. Much of this region is included in the St. Francis River Watershed, and land use is generally characterized by row crop agriculture, with the primary products being rice, soybeans, and cotton. Because of the negligible topographic relief in the region, many of the stream systems have been dredged and channelized to facilitate hydraulic conveyance. The resulting drainage ditches are maintained through dredging activities managed by local water management districts and the Army Corps of Engineers. However, several of these ditches also harbor the endangered mussel species *P. capax*, as well as representative large river species. Due to the presence of *P. capax*, management activities, such as dredging and highway bridge and culvert construction, require mitigation that has been historically achieved through relocation.

Ditch 10, west of Truman, Poinsett County, Arkansas, was scheduled for dredge maintenance during late Summer 2005 and harbored a known population of *P. capax* and several associated Mississippi Delta mussel species, including *Q. quadrula* (figure 1). A similar dredging operation in 2003 on Stateline Ditch north of Dell, Mississippi County, Arkansas revealed a similar species composition and harbored large numbers of *P. capax* (J. Harris, unpublished data). Both drainage systems facilitate agricultural land use, with the main crops consisting of cotton and soybeans, and they are managed for water evacuation. Based on the similarity of the two systems and the presence of large *P. capax* populations in Stateline Ditch, it was determined by the Army Corp of Engineers and the U.S. Fish and Wildlife Service that mussels found in the footprint of the Ditch 10 dredge operation would be relocated into a reach of Stateline Ditch (subsequently named Stateline Ditch Experimental Reach). One of the deciding factors in this decision was that this reach of Stateline Ditch had recently (2003) undergone maintenance dredging and represented a safe harbor against being disturbed in the foreseeable future. Relocation activities were completed by Ecological Specialists, Inc. in the Spring 2005, using previously described methods (Cope and Waller 1995; Dunn, Sietman, and Kelner 1999).

Upon collection of *P. capax* and *Q. quadrula* individuals at the impact site (Ditch 10), standard measurements including length, width, depth, and wet mass were recorded in the field. A unique identification number was etched into each mussel shell using a handheld rotary drill, and a passive integrated transmitter (PIT) tag (Germano and Williams 1993; MacGregor and Reinert 2001) was attached to the dorsal posterior margin near the hinge and umbo using a waterproof epoxy. The location of PIT tag placement was selected based on the size of the tag and the desire to not impede mobility, feeding, or respiration. Relocation activities for Ditch 10 animals began in April 2005 and continued through May 2005, and individuals were corralled until their transfer to Stateline Ditch Experimental Reach.

Following transit to the relocation site (Stateline Ditch Experimental Reach), the mussels were placed into one of two 5 m x 5 m grid systems constructed in the stream. These grids were divided into 1-$m^2$ cells with a rebar pin placed in the center and the relocated mussels were placed against the pin. Each cell was given a unique number and the individual mussels placed within each cell were recorded. GPS coordinates were collected for each pin, and the grid system allowed for free movement into and out of the system. Due to low numbers of P. capax collected at Ditch 10 (n = 18), other sites were searched for individuals and treated similarly. One additional specimen was relocated from the St. Francis River at Parkin, Cross County, Arkansas, and 11 specimens were relocated from a reach of Stateline Ditch substantially downstream (> 5.0 mi) of the relocation study site in October 2005.


Figure 1. *Potamilus capax* distribution within Arkansas and identification of study reaches. Solid black circles represent distribution records prior to 1986, and solid black squares represent distribution records acquired 1986-1996. Black dashed ovals indicate relocation study areas with the southern oval representing Ditch 10 (evacuation reach) and the northern most red oval representing Stateline Ditch (receiving reach).

### Condition Factor Sampling and Analysis

Monitoring events were conducted in August 2005, October 2005, and June 2006. The first step was to visit the relocation grids and search for relocated mussels by hand. When a mussel was located, a buoy containing the individual ID number written in wax was used to mark the location until the mussel could be processed, thus minimizing emersion time of individuals (Greseth et al. 2003). Mussels were removed from the substrate, processed, and returned to their capture location that was recorded using a Trimble GPS unit.

Following the grid search, the entire relocation reach (~300 m) was searched using hand techniques. The search began at the downstream extent of the reach and proceeded by systematically moving bank-to-bank and upstream. Native, naïve (i.e. never being collected before) *P. capax* and *Q. quadrula* individuals encountered through this effort were measured, etched, and affixed with a PIT tag. Capture location of the individual was obtained via GPS and recorded. Upon initial capture and each successive recapture, a 50 mg mantle tissue snip was taken from each individual, placed on dry ice in the field, and stored in a -80o C freezer until analysis.

In the laboratory, tissues were processed for condition factor analysis focused on two macro-molecules assays: glycogen and lipids. Each 50 mg mantle tissue sample was portioned into 10 mg (± 2 mg) sub-samples and collection data, animal identification, and sub-sample mass for each portion was recorded. Tissue portions were stored in a -80o C freezer. Glycogen concentration (mg glycogen per g tissue mass) analysis was conducted according to Naimo *et al.* (1998) with aliquots reserved for future analysis, if necessary. Lipid concentration (mg lipids per mg tissue) analysis followed van Handel (1985), except for the addition of a 1 hr sonication step to facilitate lipid extraction from whole tissue sub-samples. A portion of the lipid extraction liquid was used for analysis.

Statistical analysis for condition factor consists of repeated measures ANOVA, as the goal is to sample multiple individuals from each treatment group on multiple occasions. Species, treatment group, and season serve as effects and the appropriate condition factor indicators serve as analytical response variables.

**Movement Study**

Because recapture rates using PIT tags were not efficient due to the unexpected movement distances of *P. capax*, radio telemetry techniques were implemented to monitor movement patterns of *P. capax* following relocation. Transmitters, specifically designed to match the water quality conditions (primarily conductivity) at Stateline Ditch and the shell sculpturing of *P. capax*, were used to track a sub-set of both native and relocated *P. capax*. Transmitter battery life was limited to 3 months due to size and signal strength requirements. Transmitters were placed on the dorsal posterior shell margin so transmitters would not interfere with feeding or vertical and/or horizontal movement. Two sampling periods have been completed and include October 2005 - January 2006 and July - October 2006. Transmitters were affixed to equal numbers of resident and relocated animals and positions were recorded with GPS. Locations of mussels carrying transmitters were monitored bi-weekly to monthly. Displacement was measured using GIS (ESRI 2002). Upon confirmation of identification, mussels were immediately placed back to the point of capture; neither size measurements nor tissue snips were collected upon recapture during these trials.

Statistical analysis of displacement was conducted in two forms. First, for individuals fitted with transmitters, repeated measures ANOVA served to analyze short-term movement patterns both between and within transmitter monitoring periods. A second repeated measures ANOVA compared long-term movement patterns of those individuals not fitted with a transmitter with the effects of species, treatment group, and season associated with monitoring events. In both cases, total displacement was used as the response.

**In-situ Juvenile Rearing**

In order to assess the effectiveness of propagation efforts, four gravid *P. capax* females were collected from Ditch 10, transported to the lab facility, and following the propagation procedure in April 2005, they were relocated to the Stateline Ditch Experimental Reach in July 2005. Juvenile *P. capax* propagated in the lab facility were reared using a bucket grow out method (Barnhart 2005) for several months prior to placement into either constructed cages or *in-situ*.

From this propagation effort, three groups of juveniles were exposed to 2 different rearing treatments: in laboratory bucket rearing (1 group) and *in-situ* cage rearing (2 groups). In September 2005, the first treatment of cage-reared juveniles (n = 400) was placed in Stateline Ditch Experimental Reach in a cage constructed of 2 in. x 6 in. untreated lumber with a screen top enclosure and then filled with surrounding sediments. An additional 1600 juveniles from the propagation effort were placed in Stateline Ditch Experimental Reach *in-situ* with locations referenced with GPS coordinates. In December 2005, another treatment of caged reared juveniles (n = 500) was placed into a second cage with a solid bottom and welded frame covered with screen, and this cage was also filled with surrounding sediment. At this time, an additional 200 juveniles were placed *in-situ* of the State Line Ditch Experimental Reach. In June 2006, the third group of juveniles (n = 129), entirely bucket reared, were measured and released in-situ at the State Line Ditch Experimental Reach. Also in June 2006, the sediments from both grow out cages were sieved and individuals were counted and measured to determine survival and growth of cage-grow out juveniles. Individuals from each group were analyzed via ANOVA using mean length and survival as the factors and the release date as the treatment groups.

## Results

**Condition Factor**

Initial results of the condition factor, movement, and *in-situ* rearing are providing insight to effects of relocation on freshwater mussels. The repeated measures ANOVA for glycogen concentration (mg/g) showed no significant differences between or within any of the factors ( $F = 0.31$; df = 3, 12; $p = 0.33$). The native, naïve treatment groups for both *P. capax* and *Q. quadrula* show a decreasing trend in glycogen stores through time, but the remaining treatment groups of native, recapture, and relocated are consistent through time (figure 2). Glycogen stores at any one time ranged between 0.08 mg/g to 9.80 mg/l in *P. capax* samples and 0.30 mg/g and 18.07 mg/g in *Q. quadrula*.

Lipid concentrations (mg/g) were analyzed using repeated measures ANOVA and provide greater insight to energy storage. The overall model for lipid concentration was significant ($F = 3.02$; df = 3, 10, $p = 0.002$) with a significant species difference ($F = 1.01$; df = 1, 10; $p = 0.01$). The temporal trend between the study species show lipid stores at Time 1 (August 2005) are similar between the species but as time progressed *Q. quadrula* increased at a greater rate and to higher concentrations than *P. capax* (figure 3). The temporal trend of lipid concentrations for native individuals of both species showed an increasing trend from Time 1 to Time 2 (October 2005), and a stable energy reserve from Time 2 to Time 3 (June 2006). The trend for relocated individuals indicated a stable lipid concentration between Time 1 and Time 2 followed by an increase from Time 2 to Time 3. The overall trend for all specimens was relative stability between Time 1 and Time 2 with an increasing lipid concentration between Time 2 and Time 3.

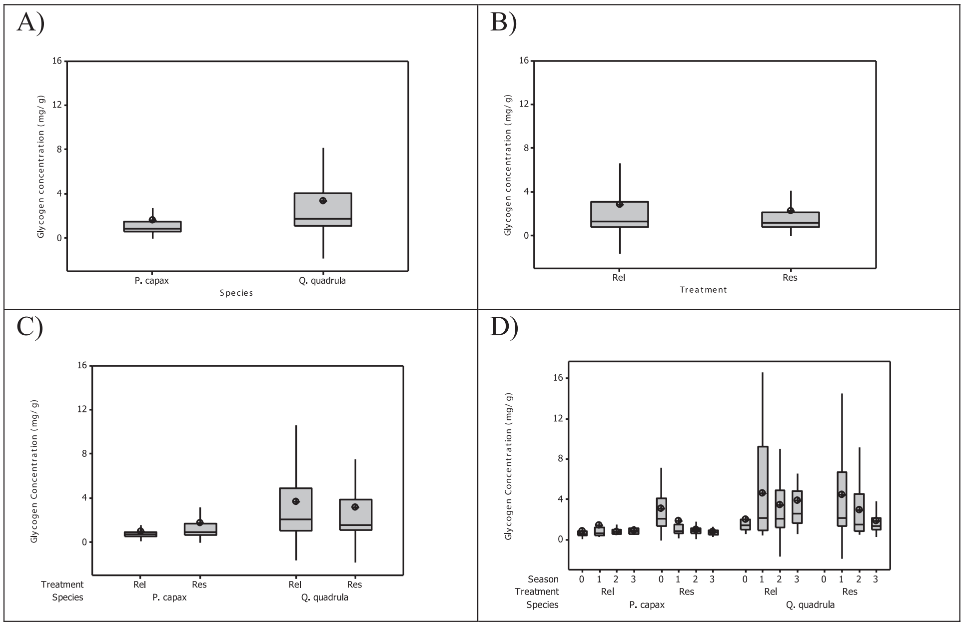



Figure 2. Box and whisker plots of glycogen concentration data with shaded areas representing interquartile range (25% - 75%), lower whiskers represent lowest values (Quartile 1 – 1.5), upper whiskers represent highest values (Quartile 1 + 1.5), horizontal bars within the shaded box represents the median value, stars represent the mean value. Panels represent glycogen concentration by A) species, B) treatment, C) species and treatment, D) species, treatment, and sample period/season after relocation (1 = August 2005 2 = October 2005 3 = June 2006).

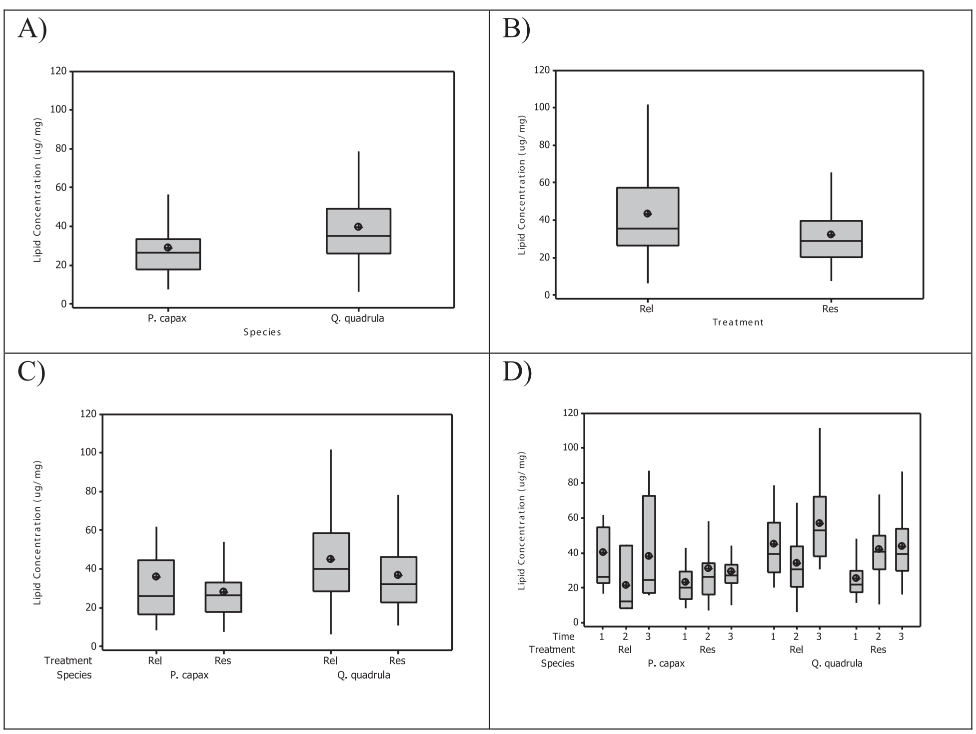



Figure 3. Box and whisker plots of lipid concentration with shaded areas representing interquartile range (25% - 75%), lower whiskers represent lowest values (Quartile 1 – 1.5), upper whiskers represent highest values (Quartile 1 + 1.5), horizontal bars within the shaded box represents the median, stars represent the mean value. Panels represent lipid concentration by A) species, B) treatment, C) species and treatment, D) species, treatment, and sample period after relocation (1 = August 2005 2 = October 2005 3 = June 2006).

## Movement

Total displacement during two short-term monitoring periods, utilizing only *P. capax* individuals, showed no significant treatment group differences. Overall, individuals from both treatment groups tended to move greater distances immediately following initial handling (figure 4). However, as the study progressed, the displacement distances decreased dramatically toward the end of both trials. Displacement distances ranged from 0 m to 27 m over the course of both three month trials.

Long term displacement measured from location of initial capture to location of last recapture over the course of all four intensive sampling periods provide greater insight to movement patterns. This data set was analyzed with a 3-way ANOVA, with the overall model being significant (F = 8.68; df = 3, 107; p = < 0.0001). Species differences were significant with P. capax having an average displacement of 19.5 m (± SD 25.4 m) and Q. quadrula having an average displacement of 3.8 m (± SD 5.4 m; p = 0.016). The range of P. capax displacement was 0.8 m to 151.9 m. while the range of Q. quadrula displacement was 0.1 m to 30.8 m. Interestingly, resident individuals had significantly (p = 0.043) greater displacement distances than relocated individuals (figure 5).

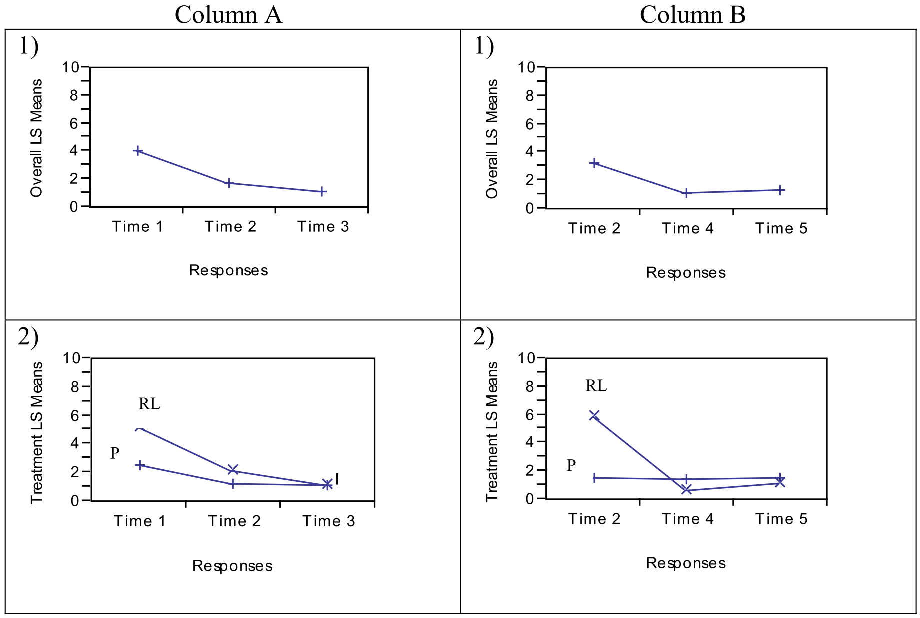



Figure 4. MANOVA repeated measures results of short-term (3 month) monitoring associated with total displacement (m) of *P. capax* by treatment ( P = native animals, RL = relocated animals). Column A shows overall model results (1), treatment effects (2), and statistical analysis (3) of the first trial (October 2005 to January 2006). Column B shows identical information associated with the second monitoring period (July to September 2006); total displacement from Time 1 and Time 3 were omitted due to insufficient sample sizes. The Y-axis represents the response variable Treatment Least Squares (LS) Mean in m.

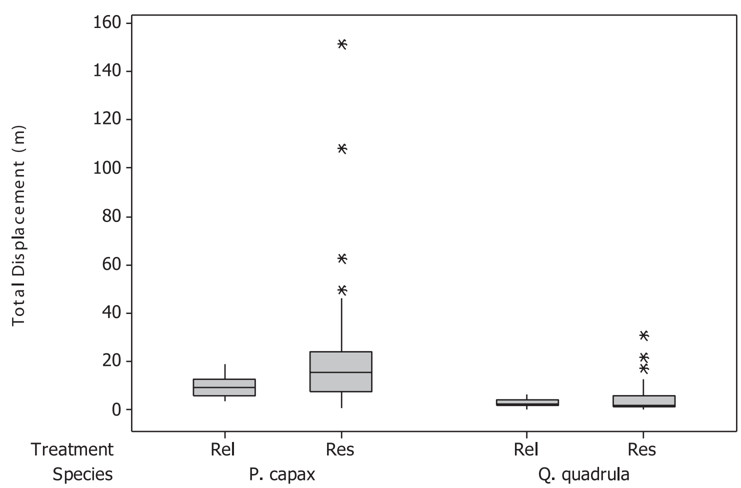



Figure 5. Boxplot of mean total displacement (August 2005 to June 2006) between species and treatment groups monitored for long-term movement study; boxplots as previously stated and asterisks representing statistical outliers.

**Juvenile In-situ Rearing**

The overall 1-way ANOVA model of P. capax juvenile growth in relation to rearing treatment was significant (F= 65.49; df = 2, 517; p = <0.0001). Even though all individuals were propagated in April 2005, and all measurements were obtained in June 2006, the Tukey's Honest Significant Difference (HSD) post-test showed that the September 2005 and January 2006 cage-reared cohorts were not significantly different from each other, both were significantly larger than the lab reared cohort. The average length of the group placed in the cage in September 2005 was 6.55 mm (± SD 3.82 mm, n = 18) with a 4.5% survival rate. The average length of the December 2006 caged reared group was 7.14 mm (± SD 2.05 mm, n = 371) with a 74.2% survival rate. The bucket-reared group had an average length of 4.83 mm (± 1.23 mm, n = 129; figure 6), survival rates of this group are unknown.

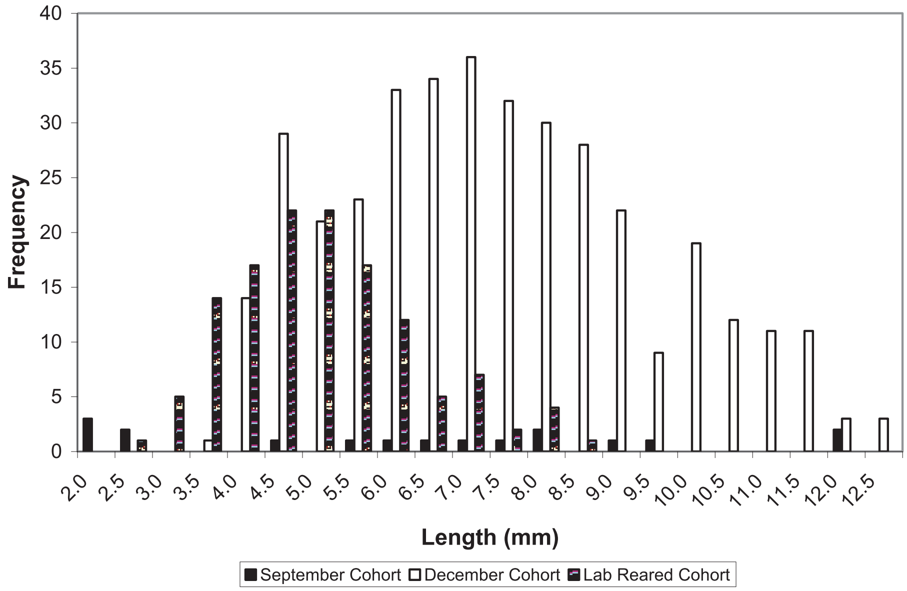



Figure 6. A bar graph depicting the frequency and distribution of measured shell lengths (mm) of the juveniles propagated in April 2005. Solid black bars represent the cohort placed in-situ September 2005 (n = 18); solid, unfilled bars represent the cohort released in December 2006 (n = 371); and the cross-hatched bars represent the laboratory reared cohort (n = 129).

## Discussion

The results to date for the examination of freshwater mussel relocation as a viable mitigation method are promising on many levels. First, condition factor testing shows that repeated monitoring via non-lethal tissue samples is possible as no mortality has been detected as direct result of the relocation or tissue sampling. Most fatalities have been attributed to predation based on small mammal teeth marks on shells or midden (dead shell) piles surrounded by tracks. However, shell deformities have been observed, with greater deformities in *Q. quadrula* shell shape than in *P. capax (A. Peck, personal observation)*.

Lipid analysis appears to show the most promise for molecular testing on mussels, though other macro-molecules and methods are currently being tested and developed as part of this study. Glycogen concentration of the mantle tissue has not shown significant differences among treatments. This is interesting, as the original hypothesis was that glycogen concentrations would be a good predictor of intermediate effects of stress and that lipids would show the longer-term effects of stress.

Because the test species exhibit very different life history characteristics (e.g. brooding period and duration, movement behavior), significant species level differences were expected. Both the condition factor and movement data support this hypothesis. The causation of differences in molecular concentration will be difficult to pinpoint until better information regarding mussel diets, storage locations, and energy use are produced. One viable explanation, however, may be attributable to the difference in food types between the evacuation site and the relocation site. For example, Silverman et al. (1995; 1997)showed different species of mussels filtered different size particles. On the other hand, stable isotope studies have suggested that different species of freshwater mussels are feeding on the same food resource within a given system (Christian et al. 2004; Nichols and Darling 2000). Food selection was not tested in the present study, therefore there is no data to tease out potential differences in food and feeding (Christian et al. 2004; Nichols and Darling 2000).

The results of movement analysis indicate that relocation of more mobile species, like *P. capax*, may result in significant displacement patterns. This suggests that monitoring of the relocation reach areas should be adjusted to include a larger area than the initial relocation area to ensure recapture of highly mobile individuals.

Finally, *in-situ* rearing appears to not only be possible, but a viable and potentially a more biologically beneficial alternative (or supplement) to lab rearing based on the greater growth in the cage-reared group. Furthermore, appropriately designed cages increase the overall survival and growth rates of field reared individuals.

Data collection for this project continues, but the results analyzed to date related to survival, growth, fitness, and movement suggest that revised recommendations will be forthcoming regarding best management practices for mussel mitigation. The intensive relocation study will be continued in Summer 2007 and will include a modified short-term displacement study using radio telemetry. The bridge construction impact study, not addressed in this paper, where mussels were left in place during the construction period will continue. One pre-construction sample and one during construction sample have been collected, and two more sampling efforts will be conducted to address potential post-construction impacts and recovery. Finally, the policy evaluation will use all of the research results to develop an initial decision framework that will better incorporate site conditions, mussel community attributes, and construction methods into mitigation method selection. A final product reporting the findings associated with this research is expected by 2009.

**Acknowledgements:** Funding for the project was provided by two grants: a Federal Highway Administration and Arkansas Highway and Transportation Department grant (AHTD Job 001983) to ADC and JLF and a U.S. Fish and Wildlife Service grant (1448-40181-06-XXX) to AJP, ADC, and JLF. Assistance for the project was provided by personnel of the Arkansas Highway and Transportation Department, Arkansas Game and Fish Commission, Ecological Specialist, Inc, U.S. Army Corps of Engineers – Memphis District, and U.S. Fish and Wildlife Service – Arkansas Field Office. We thank R. Reed for assistance with the P. capax distributional map and M. Barnhart at Missouri State University for assistance in propagating juveniles. We also thank Josh Seagraves (AHTD), Leighann Gipson (US Army Corps of Engineers), members of the ASU Aquatic Ecology Lab, Bill Posey (AR Game and Fish Commission), Chris Davidson (US Fish and Wildlife Service), and Dr. Jeanette Loutsch (ASU Biology Department)for field and laboratory assistance.

## References

Ahlstedt, S. A., and J. J. Jenkinson. 1991. Distribution and abundance of *Potamilus capax* and other freshwater mussels in the St. Francis River System, Arkansas and Missouri, USA. *Walkerana* 5 (14):225-261.

Anthony, J. L., and J. A. Downing. 2001. Exploitation trajectory of a declining fauna: a century of freshwater mussel fisheries in North America. *Canadian Journal of Fisheries and Aquatic Science* 58:2071-2090.

Arbuckle, K. E., and J. A. Downing. 2002. Freshwater mussel abundance and species richness: GIS relationships with watershed land use and geology. *Canadian Journal of Fisheries and Aquatic Science* 59:310-316.

Barnhart, M. C. 2003. Culture and restoration of mussel species of concern. Final Report. Columbia, Missouri: Missouri Department of Conservation and US Fish and Wildlife Service.

———. 2004. Propagation and restoration of mussel species of concern. Interim Report. Columbia, Missouri: Missouri Department of Conservation.

———. 2005. Buckets of muckets: a compact system for rearing juvenile freshwater bivalves. *Aquaculture* 254:227-233.

Barnhart, M. C., and A. D. Roberts. 1997. Reproduction and fish hosts of the Fat Pocketbook, *Potamilus capax. Triannual Unionid Report* 11:24.

———. 1997. Reproduction and fish hosts of Unionids from the Ozark Uplifts. In *Conservation and management of freshwater mussels II: initiatives for the future*., edited by K. S. Cummings, A. C. Buchanan, C. A. Mayer and T. J. Naimo. Rock Island, Illinois: Upper Mississippi River Conservation Committee.

Bogan, A. E. 1997. The silent extinction. *American Paleontologist* 5 (1).

Bonnie, R. 1999. Endangered species mitigation banking: promoting recovery through habitat conservation planning under the Endangered Species Act. *The Science of the Total Environment* 240:11-19.

Brim Box, J., and J. Mossa. 1999. Sediment, land use, and freshwater mussels: prospects and problems. *Journal of the North American Benthological Society* 18 (1):99-117.

Chittick, B., M. Stoskopf, M. Law, R. Overstreet, and J. Levine. 2001. Evaluation of potential health risks to Eastern Elliptio (*Elliptio complanata*) (Mollusca: Bivalvia: Unionida: Unionidae) and implications for sympatric endangered freshwater mussel species. *Journal of Aquatic Ecosystem Stress and Recovery* 9:35-42.

Christian, A. D., B. N. Smith, D. J. Berg, J. C. Smoot, and R. H. Findlay. 2004. Trophic position and potential food resources of 2 species of unionid bivalves (Mollusca:Unionidae) in 2 small Ohio streams. *Journal of the North American Benthological Society* 23 (1):101-113.

Cope, W. G., and D. L. Waller. 1995. Evaluation of freshwater mussel relocation as a conservation and management strategy. *Regulated Rivers* 11 (2):147 - 157.

Cummings, K. S., and C. A. Mayer. 1993. Distribution and host species for the federally endangered freshwater mussel, *Potamilus capax* (Green 1832), in the lower Wabash River, Illinois and Indiana. Illinois Natural History Survey, Center for Biodiversity.

Dunn, H. L., B. E. Sietman, and D. E. Kelner. 1999. Evaluation of recent Unionid (Bivalvia) relocations and suggestions for future relocations and reintroductions. *Proceedings of the First Freshwater Mollusk Conservation Society Symposium*:169-183. ArcMap™ 9.1, Redlands, CA.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecological Systematics* 29:207-31.

Fox, J., and A. Nino-Murcia. 2005. Status of Species Conservation Banking in the United States. *Conservation Biology* 19 (4):996-1007.

Gagne, F., C. Blaise, M. Salazar, S. Salazar, and P. Hanson. 2001. Evaluation of estrogenic effects of municple effluents to the freshwater mussel *Elliptio complanata. Compartive Biochemistry and Physiology* 128:213-225.

Germano, D. J., and D. F. Williams. 1993. Field evaluation of using passive integrated transponder (PIT) tags to permanently mark lizards. *Herptological Review* 24 (2):54-56.

Green, G. P., and J. P. O'Connor. 2001. Water banking and restoration of endangered species habitat: an application to the Snake River. *Contemporary Economic Policy* 19 (2):225-237.

Greseth, S. L., W. G. Cope, R. G. Rada, D. L. Waller, and M. R. Bartsch. 2003. Biochemical composition of three species of unionid mussels after emersion. *Journal of Molluscan Studies* 69:101-106.

Haag, W. R., and J. L. Staton. 2003. Variation in fecundity and other reproductive traits in freshwater mussels. *Freshwater Biology* 48 (12):2118-2130.

Haag, W. R., and M. L. Warren, Jr. 2003. Host fishes and the infection strategies of freshwater mussels in large Mobile Basin streams, USA. *Journal of the North American Benthological Society* 22 (1):78-91.

Hamilton, H., J. Brim Box, and R. M. Dorazio. 1997. Effects of habitat suitability on the survival of relocated freshwater mussels. *Regulated Rivers: Research & Management* 13:537 - 541.

Howard, J. K., and K. M. Cuffey. 2006. The functional role of native freshwater mussels in the fluvial benthic environment. *Freshwater Biology* 51 (3):460-474.

Jones, J. J., F. J. Swanson, B. C. Wemple, and K. U. Snyder. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. *Conservation Biology* 14 (1):76-85.

MacGregor, G. A., and H. K. Reinert. 2001. The use of passive integrated transponders (PIT Tags) in snake foraging study. *Herptological Review* 32 (3):170-172.

Mills, C. S. 2004. Incentives and the ESA: can conservation banking live up to potential? *Duke Environmental Law & Policy Forum* 14 (2):523-561.

Naimo, T. J., E. D. Damschen, R. G. Rada, and E. M. Monroe. 1998. Nonlethal evaluation of the physiological health of unionid mussels: methods for biopsy and glycogen analysis. *Journal of the North American Benthological Society* 17 (1):121-128.

Neves, R. J. 1997. A national strategy for the conservation of native freshwater mussels. In *Conservation and management of freshwater mussels II: initiatives for the future*, edited by K. S. Cummings, A. C. Buchanan, C. A. Mayer and T. J. Naimo. Rock Island, Illinois: Upper Mississippi River Conservation Committee.

Newton, T. J., E. M. Monroe, R. Kenyon, S. Gutrueter, K. I. Welke, and P. Thiel. 2001. Evaluation of relocation of unionid mussels into artificial ponds. *Journal of the North American Benthological Society* 20 (3):468-485.

Nichols, S. J., and D. Darling. 2000. Food-web dynamics and trophic-level interactions in a multispecies community of freshwater unionids. *Canadian Journal of Zoology* 78:871-882.

Patzner, R. A., and D. Muller. 2001. Effects of eutrophication on Unionids. In *Ecology and evolution of the freshwater mussel Unionoida*, edited by K. Wachtler. Berlin: Springer-Verlag.

Poole, K. E., and J. A. Downing. 2004. Relationship of declining mussel diversity to stream-reach and watershed characteristics in an agricultural landscape. *Journal of the North American Benthological Society* 23 (1):114-125.

Silverman, H. E. C., J. W. L. Achlberger, and T. H. Dietz. 1995. Filtration and utilization of laboratory-cultured bacteria by *Dreissena polymorpha, Corbicula fluminea and Carunculina texasensis. Biological Bulletin* 189:308-319.

Silverman, H. E. C., S. J. Nichols, J. S. Cherry, J. W. L. Achlberger, and T. H. Dietz. 1997. Clearance of laboratory-cultured bacteria by freshwater bivalves: differences between lentic and lotic unionids. *Can. J. Fish. Aquat. Sci.* 75:1857-1866.

Spooner, D. E., and C. C. Vaughn. 2006. Context-dependent effects of freshwater mussels on stream benthic communities. *Freshwater Biology* 51 (6):1016-1024.

Strayer, D. L., J. A. Downing, W. R. Haag, T. L. King, J. B. Layzer, T. J. Newton, and S. J. Nichols. 2004. Changing perspectives on pearly mussels, North America's most imperiled animals. *BioScience* 54 (5):429-439.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14 (1):18-30.

USFWS. 1989. A Recovery Plan for the Fat Pocketbook Pearly Mussel, *Potamilus capax* (Green 1832). Atlanta, GA: U.S. Fish and Wildlife Service.

van Hendel, E. 1985. Rapid determination of total lipids in mosquitoes. *Journal of the American Mosquito Control Association* 1 (3):302-304.

Vaughn, C. C., and C. C. Hakenkamp. 2001. The functional role of burrowing bivalves in freshwater ecosystems. *Freshwater Biology* 46:1431-1446.

Vaughn, C. C., and C. M. Taylor. 1999. Impoundments and the decline of freshwater mussels: a case study of an extinction gradient. *Conservation Biology* 13 (4):912-920.

Welker, M., and N. Walz. 1998. Can mussels control the plankton in rivers? -- a planktological approach applying a Lagrangian sampling strategy. *Limnology and Oceanography* 43 (5):753-762.

Wheeler, A. P., P. L. Angermeier, and A. E. Rosenberger. 2005. Impacts of new highways and subsequent landscape urbanization on stream habitat and biota. *Reviews in Fisheries Science* 13:141-165.

Williams, J. D., J. Warren, Melvin L., K. S. Cummings, J. L. Harris, and R. J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. *Fisheries* 18 (9):6-22.

Wilson, M. A., and S. R. Carpenter. 1999. Economic valuation of freshwater ecosystem services in the United States: 1971 - 1997. *Ecological Applications* 9 (3):772-783.

## Canasawacta Creek Project: Chenango County, New York

**Mary O'Reilly** (607-721-8138, moreilly@dot.state.ny.us), Region 9 Operations, and **David MacEwan**, Region 9 Geographic Information Systems Coordinator, New York State Department of Transportation, 44 Hawley Street Binghamton, NY 13901

**Brandon Greco** and **Debra Nelson**, Environmental Analysis Bureau; **George Long**, Main Office Hydraulics; and

**John Rowen**, Main Office Operations, New York State Department of Transportation, 50 Wolf Road, POD 41, Albany, NY 12232

Abstract: The Canasawacta Creek Watershed Initiative grew out of a desire to address the root causes of flooding, bank erosion, bridge scour and property damage that was a recurrent problem for both the New York State Department of Transportation (NYSDOT) and the inhabitants of the creek valley. Rather than continue with the old paradigm of fixing the problem spots NYSDOT, working through Region 9 office in Binghamton and its Main Office in Albany, requested the help of environmental specialists within the department as well as from other state and county agencies to address the problem more holistically and permanently. The first public meeting was held in the Town of Plymouth, Chenango County, in March of 2006. Over forty people attended; half were townspeople. The rest represented various entities including the New York State Department of Environmental Conservation (NYSDEC), the Chenango County Soil and Water Conservation District, the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, the Federal Highway Administration and the Upper Susquehanna Coalition. An interagency technical team was formed and an initial evaluation of a four mile stretch of the creek was performed in early June, 2006. Despite devastating flooding that occurred at the end of June, an action plan was developed and presented at a second public meeting at the end of August, 2006. NYSDOT began work in the stream in September and October of 2006. Additional work is planned for the summer of 2007. Armed with the findings of the interagency technical team, the residents of the watershed have organized themselves into a watershed committee that is working through the town to implement the parts of the plan that address private property. The watershed committee has spearheaded a town newsletter to keep everyone informed, and there is a watershed blog available on the Internet. The watershed committee has received a $179,000 grant from the NYSDEC. The grant requires a 50% match in funds which can be met by agencies such as NYSDOT and NYSDEC working in the watershed, as long as the work is in conformance with the overall watershed plan.

There are several interesting aspects of the watershed approach used in the Canasawacta Creek Project. The watershed approach requires cross-jurisdictional communication and cooperation, although there are unresolved issues such as funding and liability. The social and organizational skills necessary for a successful project are as important as the scientific and engineering expertise. The methodology used to prioritize various sites for remediation is supported by classic risk assessment methodology. Finally, because of the extensive baseline data recorded by NYSDOT during the past several decades, the project offers the opportunity to evaluate the effects of the interventions undertaken in the watershed.

### Introduction and Background

Canasawacta Creek, located west and north of Norwich in central New York State, traverses a narrow valley and meanders along a two-lane rural state highway. A linear community of houses in the Town of Plymouth (population 2,070) has been established along this valley, often in the flood plain between the creek and the highway. Canasawacta Creek is one of the headwater watersheds of the Susquehanna River Basin. It flows into the Chenango River that, in turn, joins the Susquehanna River in Binghamton, New York. Once a high-quality trout stream, it has deteriorated in recent years as a result of its long history of manipulation which includes redirection, straightening, and channelization.

The Canasawacta Watershed covers approximately 61.7 square miles with 108 miles of stream including tributaries, and 139 miles of roads. Most of the watershed is forested or engaged in agriculture. Only about 4% of the surface area is currently impervious. The soils in the watershed are primarily heterogeneous, non-cohesive gravelly silt loam. Frequent flooding of these soils often results in the shifting of soil material from place to place (USDA, 1981). The stream rests on bedrock in some locations and has meandered across the entire valley floor during geologic time.

The problems that prompted this initiative are occurring in the upper part of the watershed, on the main branch of the creek upstream of the confluence with the East Branch of Canasawacta Creek. The East Branch seems to be relatively stable. The highway running through the valley of the East Branch is not as closely associated with the stream, and the highway itself is a Chenango County route. This means that the New York State DOT, a major player in the Initiative and a source of matching funding for grant eligibility, could have no direct involvement in that sub-watershed. Therefore, although problems downstream of the confluence will eventually be addressed, the initial focus has been upstream of the junction with the East Branch.

Hydrologic analysis indicates that the main branch of Canasawacta Creek, above the confluence, is 12.4 miles long and drains 25.4 square miles. The channel slope is moderately steep at 1.1%. The average daily stream flow is about 43 cubic feet per second (cfs), with a summertime average over the month of August about 1 cfs. Normal spring flooding exhibits stream flows of about 900 cfs. Estimated flows for a 50 year flood are about 2300 cfs.

Flashy mountain streams, such as the headwaters and tributaries to Canasawacta Creek, transport large amounts of coarse sediment (gravel and cobble) from the steep side valleys down to the main stream during floods. Some of this material then settles out in the form of alternating point bars as the flatter slopes of the valley floor make for slower flow velocities. The stream must then regain its lost cross sectional area by either flushing this sediment downstream, or by eroding the opposite bank. In Canasawacta Creek, the latter is often the case due to the valley's easily eroded soils and general lack of woody vegetation. The eroding banks in turn supply more sediment to the channel, and the cycle of instability continues.

The valley was home to the Haudenesaunee for centuries before the first Europeans settled the area in the late 1700s. Although each group would have established their own paths, the earliest recorded highway plans in the valley date back to 1910. These plans describe a road from "Stewarts Corners westerly to the Hamlet of Kirk, a distance of 4.9 miles, in the town of Plymouth, Chenango County." Record plans indicate that construction of the current State Route 23 in 1931 also relocated and channelized Canasawacta Creek in several locations. Many of the locations where the creek was modified correspond to areas of concern today.

Several factors have converged to worsen problems that have been developing for the last hundred years including increased habitation of the valley, increased awareness of the adverse impact of engineering practices that were commonplace during the mid-twentieth century, climate changes that are associated with increased intensity of rainfall, and decreased manpower within the NYSDOT. During high water the highway is flooded in several locations and at least one bridge is inspected after each flooding event. When State Route 23 was built one accepted practice was to bulldoze the stream and remove any sediment that accumulated along the stream bed. This practice kept water flows moving quickly and prevented water from overflowing the banks of the stream. Unfortunately, this practice also prevented dissipation of the energy associated with flowing water and contributed to destruction of aquatic habitat.

There are no USGS gauging stations currently active in the Canasawacta Creek Watershed, although one did operate some 2.6 miles downstream of the confluence from 1945 to 1975. Records from gauging stations in adjacent watersheds indicate that annual flows in the area were 20-30% higher in 2003 and 2004. One of the effects predicted to accompany climate change in the northeast U.S. is not only an increase in the average annual rainfall but also an increase in the intensity of individual storm events. Without adequate and effective energy dissipation, the increased runoff associated with increased intensity of individual storms threatens both the homes of the people living in the valley and State Route 23. NYSDOT, being limited to working within the highway right-of-way, has neither the equipment nor the employees necessary to repair infrastructure every year, much less after every storm event.

**The Problem**

Recurrent flooding problems have resulted in ongoing maintenance issues for NYSDOT throughout the state, as well as along State Route 23. Maintenance forces return year after year to the same location and perform the same activity. At the same time that people in operations were identifying the ineffectiveness of such an approach, the regional hydraulics engineer was trying to engage the group designing and delivering capital projects to address the issue. NYSDOT did not really have a conceptual framework within which to place the problem. Furthermore, solution of the problem involved addressing watershed issues; something that NYSDOT had not done in the past. Because NYSDOT does not have the ability or the authority to address watershed issues unilaterally, it must form partnerships with others who have a stake in the watershed.

**Materials and Methods**

Canasawacta Creek is located in Region 9 of NYSDOT. Through Main Office staff in Albany, Region 9 staff in the Binghamton office and Chenango Residency staff, NYSDOT collects a tremendous amount of information but, unfortunately, the information is often disjointed. The NYSDOT resources that were used during this project included record plans, bridge inspection data, hydrology and hydraulic engineering expertise, and maintenance expertise. Methodologies employed by these disciplines were all used during the development of this project.

In addition, expertise in natural habitat, stream restoration, land use and community planning was incorporated by partnering with various agencies. Methodologies developed by these various agencies were also used during the development of this project. The partner agencies and organizations are as follows:

- New York State Department of Environmental Conservation (NYSDEC)
- Chenango County Soil and Water Conservation District (SWCD)
- Army Corps of Engineers (USACOE)
- U.S. Fish and Wildlife (USFWS)
- Federal Highway Administration (FHWA) and
- Upper Susquehanna Coalition (USC)

A team of experts, including hydraulics engineers, aquatic biologists, and stream geomorphologists, analyzed a four mile stretch of Canasawacta Creek. The stretch began just below the confluence of the east branch with the Creek's main stem and included two bridges that are part of State Route 23. The bridge at Moon Hill Road is downstream from the bridge at Chan Aldridge Road. Data collected included flow estimates, gravel bar volumetric estimates, stream cross sections, and identification of problem areas with photos. To assist in the analysis stations were marked every 500 feet on 2003 orthophotos scaled to 1 inch equal to 200 feet (figures 1 and 2). Station numbers increased from downstream to upstream. Left and right are referenced by looking downstream, with left facing north and right facing south.

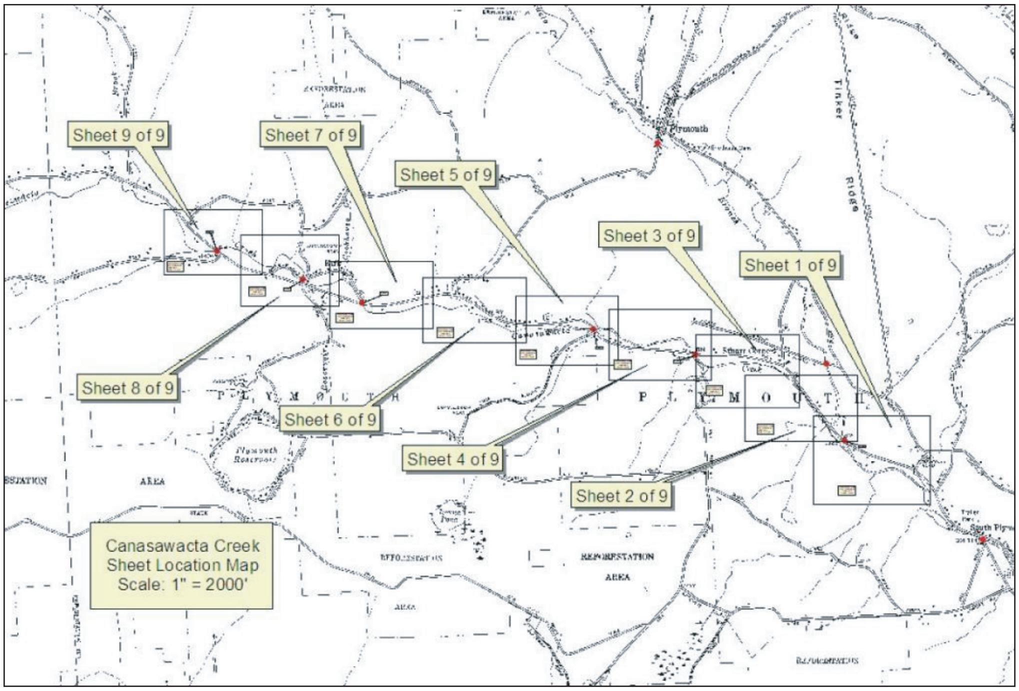



Figure 1. Reference map showing the location of the 9 individual orthophotos used in the stream evaluation.


Figure 2. 2003 orthophoto of Canasawacta Creek and Route 23. Ashcraft Road is perpendicular to Route 23 in the upper right quadrant of the photo. The white lines represent the stations that were located 500 feet apart.

Staff from the Department's Chenango Residency constructed stream intervention structures, guided by principles described by Rosgen (2004) and the Federal Highway Administration (2001). The work was performed under the guidance of an employee of the U.S. Fish and Wildlife Service and NYSDOT hydraulics engineers.

## Results

### Organizing Activities

NYSDOT held the first public meeting at the Town of Plymouth fire station on March 14, 2006, as a result of complaints, from people who lived along State Route 23, received by the NYSDOT Resident Engineer for Chenango County. The meeting was to establish a cooperative framework among stakeholders in the Canasawacta Creek Watershed, to enable them to minimize flood damage to homes and infrastructure and to create a healthy watershed ecosystem/environment. Twenty townspeople and twenty-one people from seven government and non-government agencies attended the first meeting.

A smaller meeting with representatives from the NYSDOT, NYSDEC, USACOE and the SWCD was held on May 1 to plan how to implement the ideas discussed at the public meeting. The Stream Corridor Restoration Guide (1998), published by the Federal Interagency Stream Restoration Working Group, highlighted the following key points:

- Stream restoration is a multi-year process
- There needs to be an organizational decision structure and points of contact identified
- The problem needs to be investigated and identified and
- Consensus reached on the mission of the restoration initiative

One of the problems discussed at this meeting was identifying who would be responsible for implementing any project designed by the group. The Town of Plymouth was concerned because it does not have resources or experience in construction oversight. The town was also concerned about liability, if something went wrong. Other candidates to administer stream restoration projects included the Chenango County SWCD and the USC. The Pennsylvania Organization for Watershed and Rivers (POWR) publication, *How to Form Your Own Watershed Organization in Pennsylvania*, was discussed. Without resolving the issue, the group decided to plan the stream evaluation for early June and identified the participants that were essential to achieving this goal.

After a planning meeting on May 22, 2006, the stream evaluation team walked Canasawacta Creek on June 5 and 6. Field notes from the evaluation identified over 40 areas of varying degrees of degradation along the four-mile stretch of stream from just below the confluence of the East Branch with the main branch of Canasawacta Creek to almost a mile upstream from the bridge by Chan Aldridge Road (BIN 1053490). Hundreds of pictures were taken during the evaluation; figures 3 and 4 illustrate some of the detail that was captured during the stream evaluation.

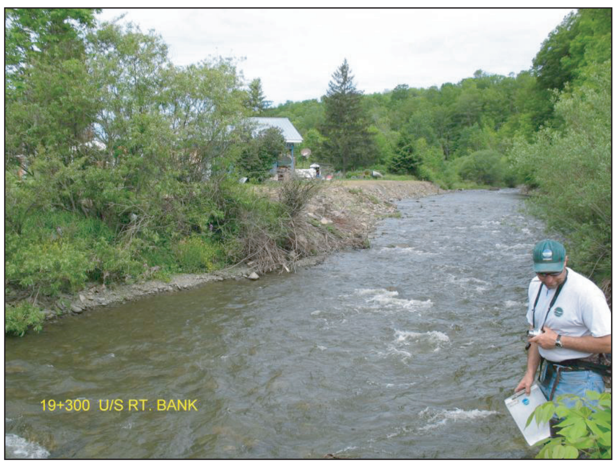



Figure 3. Looking upstream from the bridge at Moon Hill Road. The bridge is just out of the picture to the left. One of the houses located between Route 23 and Cansawacta Creek can be seen in the center of the photo.


Figure 4. Looking upstream from the Chan Aldrich bridge. The utility pole is located between Route 23 on the right and Canasawacta Creek.

At the end of June 2006, unprecedented flooding occurred throughout the Susquehanna River Basin, exceeding 500-year flood levels in numerous locations. Cannasawacta Creek was no exception. Areas identified as problematic in early June got worse. The back yard of the house and the trees along the south bank of the creek seen in Figure 3 were washed away. In some cases, erosion moved either upstream or downstream from where previous bank stabilization was located. No area of the stream was improved from the flooding. In some areas the stream formed new channels. The June 2006 flood highlighted the urgent need for intervention as well as the serious consequences of doing nothing.

In preparation for a second public meeting the technical team met on August 2, 2006, to discuss findings from the June stream evaluation and the impact of the flooding at the end of June. Each participant group, NYSDEC, Chenango County SWCD and NYSDOT, prepared lists of sites that required remediation. Each site on the lists was given a priority and an ease-of-fix ranking. The priority ranking was based on the amount of damage likely to occur to people, property and infrastructure if stability of the stream fails. In addition, the priority ranking took into consideration the overall health of the stream. The ease of fix ranking considers design simplicity, the site accessibility, and the cost of construction, technical solutions and maintenance. Sixteen sites were identified in total; seven were assigned high priority and one was assigned medium priority (Table 1). Low priority sites did not threaten homes or public safety. Of the seven high priority sites, four were identified as easy to fix. These four sites are being addressed by NYSDOT. Three of the sites ranked as high priority were also ranked as difficult or moderately difficult to fix.

The second public meeting took place on August 21, 2006. People were concerned about their homes and property. Several topics were discussed during the meeting including hydraulics, principles of stream restoration, and the summary of the findings. The idea of forming a watershed committee began to take shape at this meeting and community leaders stepped forward.

Soon after this August meeting the Canasawacta Creed Watershed Committee was formed. The group has spearheaded a town newsletter to keep staekholders informed. The newsletter is distributed to agencies as well as the towns residents. There is a watershed blog available on the internet. The watershed committee applied for funding and received a $179,000 grant from NYSDEC in March of 2007. The grant requires a 50% match in funds. This requirement can be met by agencies, such as NYSDOT and NYSDEC, working in the watershed as long as the work is in conformance with the overall watershed plan.

**Stream Activity**

The bridge by Moon Hill Road is on the flood watch list which means that the regional hydraulics engineer checks the bridge after every flood. This bridge was built in 1931. There are scour problems at the footings, which are not supported by piles. The stream bank is armored upstream and downstream from the bridge, but NYSDOT has not done any work in the stream in the vicinity of this bridge for many years. There is a 50 foot high eroding embankment upstream from the bridge on private property (figure 5). In addition several of the properties upstream from the bridge have lost significant portions of their backyards due to erosion during high water. Several homes have been repeatedly flooded during the past ten years.


Figure 5. Eroding south bank of Canasawacta Creek just upstream of the Moon Hill Road bridge. Material is continually sloughing off into the creek.

NYSDOT has intervened in the stream in three places:

1. By Ashcraft Road (below the confluence of the east and main branches)
2. Just above the confluence because of road flooding
3. The “new” bridge by Chan Aldrich Road

*Area 1*

Canasawacta Creek was eroding the south shoulder of State Route 23 in 2004. In the summer of 2004, stream bank between the stream and the road was armored with heavy stone to prevent further encroachment onto the shoulder of Route 23. At that time placement of rock vanes was considered but rejected because it required work off the DOT right-of-way and permission to work on private property was not forthcoming (figure 6). During the flooding of June 2006 the bank reinforcement held, but there was extensive damage to the stream bank further downstream (figure 7). This damage now threatens State Route 23.

Figure 6. Looking downstream at the bank stabilization installed in 2004 before the June flooding. Route 23 is seen in the photo. Ashcraft Road intersects Route 23 just out of view to the left in the photo.

Figure 7. This photo was taken just upstream from the rip-rap shown in Figure 6 after the June flooding. The creek has cut a new channel closer to Route 23. The vegetation blocks a clear view of the road but the location of Route 23 can be surmised by guide rail and highway sign.

*Area 2*

Record plans indicate that Canasawacta Creek was moved from the north to the south side of Route 23 during the 1931 construction project. This area of the road repeatedly floods during any high water event. The June 2006 flooding eroded the shoulder up to the edge of blacktop; the bed of the creek was almost at the same level as the top of the road (figure 8). NYSDOT personnel removed some of the sediment that was deposited in the bed of the creek. Further work is planned for the summer of 2007.

Figure 8. Canasawacta Creek is undermining Route 23. This is where the creek was moved from the north side of the road to its present location. Flooding occurs often in this location.

*Area 3*

The bridge by Chan Aldridge Road was initially built during the 1931 project. At that time the creek was straightened at the bridge location. In the 1990's a curve in Route 23 at the bridge was straightened and the new bridge built. The stream banks, both upstream and downstream from the bridge, have suffered from erosion during the past 10 years. Downstream from the bridge there are several homes on the south side of the creek. These homes have been repeatedly flooded.

Upstream from the bridge the utility pole between the north side of the creek and the south side of the highway was moved repeatedly because of bank erosion. In addition to threatening the utility pole the creek also threatens State Route 23 upstream from the bridge. Figure 9 shows the location of the utility pole before the June 2006 flood, after the June 2006 flood. Figure 10 shows a view of the same area from the bridge before and after the June flooding. The creek moved closer to the highway and cut a new channel that was closer to the original 1931 channel.

Figure 9. Looking downstream just above of the Chan Aldridge bridge in March 2006. Notice that the utility pole is several feet from the creek. It had already been moved once so that it was not engulfed by the stream.

Figure 10. Looking downstream just above the Chan Aldridge bridge (same location as figure 9) just after the June 2006 flood. The utility pole is now on the bank of the creek.

Figure 11 shows the south side of the creek near the Chan Aldridge bridge. A small tributary enters Canasawacta Creek from the south at this location. After the June flooding, the utility poles on the south side of the creek as well as a town road (Chan Aldrich) were also threatened.

Figure 11. South side of Canasawacta Creek looking upstream from the Chan Aldridge bridge after the June 2006 flooding.

In September of 2006, NYSDOT installed rock vanes and one cross vane upstream from the bridge. The design originally included three rock vanes (figure 12), but four were actually installed. The design included building a bench to increase the distance between Route 23 and the creek. The bench also acts as an overflow area during high water. The cross vane was installed immediately upstream from the bridge to direct energy away from both banks of the creek and direct the main flow towards the center of the bridge. Willows that were plentiful at the location were used to stabilize the rock structures.

Figure 12. One of the rock vanes built on the north bank of Canasawacta Creek. The photo was taken looking downstream.

Figure 13. The bench provides an area for high water between the creek and Route 23. The willows were planted and they are doing quite well. The utility pole is not shown but the bench protects it from the creek.

The Canasawacta Creek watershed experienced a second flood in November of 2006. Three of the rock vanes survived the flooding with minor damage; one had to be re-built. The cross vane was filled in with silt on one side.

**Discussion**

This project is interesting for several reasons. First, NYSDOT Region 9 had never done anything exactly like this before, perhaps because there was no framework for the project, or perhaps because it required considerable coordination. Maintenance forces have been well aware for a long time that they return to the same location year after year to perform the same work. It was clear to people in the field that the root causes of problems impacting roads and bridges were often removed from DOT infrastructure and out of the direct control of DOT. It was also clear that the interventions that DOT put in place affected areas removed from DOT ROW.

The watershed concept offers a format to deal with these concerns. It gives local people local control. The control, however, is based on consensus. Currently watersheds are governed by a patchwork of government entities and private landowners. Watershed boundaries do not respect political boundaries. No one entity is responsible for each watershed. Watershed committees fill that void, but there are many unresolved issues not the least of which are funding and liability.

Secondly, the social, organizational and administrative/budgeting skills required to progress this type of project are as important as scientific and engineering skills (Golet et al. 2007). During the course of the project many people, both from agencies and the town, were upset. None of the groups were completely satisfied with the outcomes. It was important to allow individuals to express their anger, frustration and opinion without loosing sight of the common goal. At first, county people were angry that NYSDOT did not step forward sooner. The townspeople were angry that the government did not just fix the problem. The NYSDEC wanted to restore the environment; NYSDOT wanted to maintain the roads and bridges. Everyone had to communicate and to compromise. In the end, it is rewarding to see the townspeople take control of their own lands and creek, and government agencies work with them to improve the situation. It is important to remember, however, that cooperation among people and groups with very different goals and missions requires continual effort. The story is not yet finished and the final outcome is not a given.

Because this is a new method of responding to a problem, it requires administrative and budgetary flexibility and innovation. An agency participating in a watershed partnership cannot disregard legal mandates for procurement or project design and construction. However, it can innovatively use existing organizations and administrative mechanisms to support common goals. For example, to address severe flooding problems in a timely manner, NYSDOT coordinated considerable expertise in its Main and Regional offices. Other agencies might have had to contract with consultants to receive the same expertise but NYSDOT was able to access this information in real time through intra-agency cooperation.

Once the watershed group developed suggested solutions, NYSDEC and USACE could approve required permits in a more timely manner because they were participating in the problem solving. They were not waiting in a remote office for a proposal to arrive.

NYSDOT's Chenango Residency provided another element of flexibility. The Residency has supplies, materials and staff who are highly trained in operating heavy equipment. As improvement plans were developed, the Residency staff could undertake improvements in real time. The watershed committee could evaluate the improvements as they went along and not have to wait until the end of a large construction contract.

Thirdly, the risk assessment methodology used to prioritize the sites for remediation is a simple, easy to use adaptation of classic risk assessment methodology. Typically, the risk severity and probability are used to make a table in which high risk-high probability events occupy one corner and low risk-low probability events occupy the opposite corner (Manuele, 2006; Mattson and Angermeier, 2007). In this case, the sites were ranked high, medium or low based on the amount of damage that failure of the site would cause to private homes or public infrastructure. They were also ranked high, medium or low based on how easily they could be fixed. The ease of fix took into account the design simplicity, site accessibility and the cost of construction, technical solutions and maintenance. The sites that had a high priority and were easy to fix occupied one corner of the table, and the sites that had a low priority and were hard to fix occupied to opposite corner of the table. Obviously, the high priority, easy to fix sites should be addressed first. The low priority, hard to fix sites may never get addressed. Eventually, however, it is necessary to address the high priority sites that are difficult to fix.

Finally, this project offers an opportunity to evaluate the effect of the practices that are used, as well as the structures that are installed, in the watershed. NYSDOT has detailed records of the two bridges in the project. These records have been kept for many years. Once the stream restoration efforts have been implemented the effect of these efforts on DOT infrastructure can be monitored and documented. This is important because, although there is an abundance of anecdotal evidence in support of environmental practices, fewer studies have been published in peer-reviewed journals.

The story of the Canasawacta Creek Project is one example of a watershed approach. The watershed approach provides a mechanism to solve problems on a smaller scale, and to break a big problem into bite size chunks. The approach requires expertise, dedication, hard work and a great deal of flexibility. It requires everyone to communicate and to cooperate. It offers an alternative to the status quo and the way things have been done in the past seventy-five years. Critical evaluation of the long term effect of the stream restoration techniques used in this project remains to be done.

Table 1: Summary of Findings - Summer 2006

| location | priority | Ease of fix | Description of problem | Possible intervention | Actions |
|---|---|---|---|---|---|
| **10 + 500 Ashcroft Rd** | high | easy | Bank erosion threatens Route 23 | Clear obstruction; armor bank upstream and downstream from work done in 2004; use rock vanes and/or stream bank plantings | DOT, 2007 |
| 11 + 500 | low | Medium/ easy | 6 to 12 foot high bank erosion | | |
| **15 + 000 to 15 + 500** | high | easy | Flooding on Route 23 | Deepen and narrow cross section to provide greater channel capacity and improve sediment transport; rock vanes to protect bank | DOT, 2006 |
| **18 + 500 Moon Hill Rd** | high | Medium/ difficult | Right bank erosion, up to 10 feet high; gravel bar formation; drainage from small trib and pipe culvert | Re-grade rt bank (2:1); possibly protect with rock vane; vegetate bank; | Soil and Water District seeking funding |
| BIN 1017430 bridge | low | medium/ easy | Scour; top 2 feet of foundation at left abutment is exposed | Scour protection; possibly protect with rock vane upstream; leave vegetated bank downstream from bridge | |
| **Bridge to 20 + 100** | high | difficult | Rt bank erosion; very high left bank erosion (50 foot esker) | Move stream channel away from esker; rock vanes to maintain alignment and dissipate energy | |
| 21 + 500 to 22 + 200 | high | medium/ difficult | Grade control rock structure; backwater: flow.overflow right along back of houses | Remove dam-like structure to prevent backwater from causing excess deposition and flow divergence; install bank protection along rt bank | |
| **BIN 1017420** "new" **bridge** | high | Easy | Streambed aggraded under the bridge; backwater downstream from bridge | Remove material from under bridge | DOT, 2006 |
| **Bridge to 24 + 000 telephone pole** | high | easy | Rt bank erosion; left bank erosion; debris | Adjust upstream approach to bridge; grade left bank; create bankfull bench; rock vanes to relieve bank stress | DOT, 2006 |
| 24 + 200 | low | easy | Right bank failure | Rock vanes and stream bank plantings | |
| 24 + 700 to 25 + 000 | medium | easy | Left bank failure | Rock vanes and stream bank plantings | |
| 27 + 000 to 27 + 200 | low | easy | Bank erosion | Rock vanes and stream bank plantings | |
| 28 + 200 | low | medium | Right bank erosion; potential for increased erosion | Rock vanes to direct flow away from right bank | |
| 29 + 000 | Low | Easy | Left bank erosion | Bankful bench and rock vanes | |
| 32 + 000 | low | Easy | Erosion due to cattle use | Cattle fencing; stream bank planting | |
| 35 + 000 | low | difficult | Tall eroding/slumping right bank | Willows on slope; bankful bench and rock vanes | |

**Acknowledgements:** This work would never have been accomplished without the leadership of Jack Williams, Regional Director (Region 9), Frank Nachman, Director of Operations (Region 9), Wayne Gannett, Hydraulics Engineering Unit Manager (Main Office), Tom Rook, Hydraulics engineer (Region 9), Mike Dale, Resident Engineer (Chenango County), and Tom Smith, Assistant Resident Engineer (Chenango County).

**Biographical Sketches:** Mary O'Reilly, PhD, CIH, CPE, received her doctorate in Human Anatomy and Cell Biology from the University of Michigan. After completing her post doctoral work which addressed chemical-viral co-carcinogenicity, Mary worked as an environmental toxicologist at Syracuse Research Corporation. She has worked as an industrial hygienist for the New York State Department of Labor and currently works as an environmental specialist for the New York State Department of Transportation. She has served on the Board of Directors for the American Board of Industrial Hygiene and as a voting member of the AMSI Z-10 Committee, and currently serves on the Board of Directors for the American Conference of Governmental Industrial Hygienists. Mary is on the faculty of the SUNY School of Public Health as well as the advisory board of the Institute for Health and the Environment. Her current interests include phytoremediation, water quality, herbicide application, life cycle analysis, brownfields and risk assessment and has numerous publications. Outside of work she practices and teaches Tae Kwon Do and plays the Irish harp.

Brandon F. Greco, MS, is an Environmental Specialist in the Water/Ecology Section of NYSDOT's Environmental Analysis Bureau. Previous to his employment at NYSDOT, Brandon served as a Natural Resource Specialist and Field Manager at the Albany County (NY) soil and Water Conservation District, and as an Environmental Scientist at KCI Technologies, Inc., in Raleigh, NC. He has been involved with several geomorphic stream assessments and ecological restoration projects throughout the Southeast US and New York State. Brandon has completed the full suite of training offered by David Rosgen (Wildland Hydrology, Inc.). His formal education includes a Bachelor of Science degree from the New York State College of Environmental Science and Forestry at Syracuse, and a Master of Forestry degree from North Carolina State University.

David S. MacEwan is Geographic information Systems Coordinator for NYSDOPT Region 9, a position he has held for 12 years. He is responsible for software and application support, data collection efforts, and special mapping projects. Dave was honored with an NYSDOT Excellence in Engineering award for the development and publication of a multi-region bike route map, which he displayed at the 2002 ESRI User Conference. Dave has also been Regional Web Content Coordinator since 2001. He spearheaded a contemporary redesign of the regional intranet in 2002 and managed a highly successful public website for a major NYSDOT construction project in 2004-05. Dave is currently completing a Master degree in Geography at Binghamton University (SUNY). His MA project involves spatial analysis of emergency animal shelters in Broome County, New York, in light of record region-wide flood events in 2006.

John Rowen, MPA, is the vegetation and environmental program manager for NYSDOT's Office of Operations Management, a position he has held for three years. He oversees vegetation management and environmental stewardship programs, including the Green and Blur Highways Initiative, undertaken by operations forces throughout the State. The position includes budget preparation, training programs, contract management and helping operations staff advance environmental stewardship activities. Before taming this position, he worked on NYSDOT's High Speed Rail Program, special projects concerning transportation and the environment and served in the New York State Division of the Budget as a capital budget examiner for the Department of Environmental Conservation, statewide energy programs and several design and construction agencies. He is a free-lance writer and broadcaster who specializes in book review and features on authors, fishing and other outdoor topics.

George H. Long, MS, PE, is a professional engineer licensed in New York and works as a hydraulics engineer with the New York State Department of Transportation. He performs hydrologic and hydraulic analyses and provides oversight and assistance throughout the state. His work focuses on the development of engineering and operational policies to meet program needs including stream stabilization and restoration, slope protection and bridge hydraulic design issues. George has served on the Standards Subcommittee of the NYS Conference on Local Bridges since 1995. He received the NYSDOT Excellence in Engineering award in 2003 and has authored numerous papers.

## References

FISRWG (10/1998). Stream Corridor Restoration: Principles, Processes, and Practices. By the Federal Interagency Stream Restoration Working Group (FISRWG) (15 Federal agencies of the US government). GPO Item No.0120-A; SuDocs No. 57.6/2:EN 3/PT.653. ISBN -0-934213-59-3.

Golet, G.H., M.D. Roberts, R.A. Luster, G. Werner, E.W. Larsen, R. Unger and G.G. White. 2007. Assessing societal impacts when planning restoration of large alluvial rivers: a case study of the Sacramento River Project, California. Environ Manage 37: 862-879.

Manuele, F.A. 2005. Risk assessment and hierarchies of control. Professional Safety (May 2005): 33-39.

Mattson, K.M. and P.L. Angermeier. 2007. Integrating human impacts and ecological integrity into a risk-based protocol for conservation planning. Environ Manage 39: 125-138.

Rosgen, D.L. 2001. The Cross-vane, W-weir and J-hook vane structures: their description, design and application for stream stabilization and river restoration. ASCE Conference Proceedings. Ed. D. F. Hayes, Wetlands Engineering and River Restoration Conference 2001, August 27-31, Reno, Nevada, USA.

USDA, 1981. Soil Survey of Chenango County, New York. National Cooperative Soil Survey in cooperation with the U. S. Department of Agriculture and the Cornell University Agricultural Experiment Station.

# Combining Aquatic and Terrestrial Passage Design into a Continuous Discipline

**Sandra L. Jacobson** (541-678-5240, sjacobson@fs.fed.us), Wildlife Biologist, USDA Forest Service, Pacific Southwest Research Station, Arcata, CA (Contact Address: 19546 Meadowbrook, Bend, OR 97702) USA

**Robert Gubernick** (907-772-5840, rgubernick@fs.fed.us), Engineering Geologist, USDA Forest Service, Tongass National Forest, Box 309, Petersburg, AK 99833 USA

**Michael J. Furniss** (707-825-2925, mfurniss@fs.fed.us), Hydrologist, USDA Forest Service, Pacific Northwest and Pacific Southwest Research Stations, Redwood Sciences Lab, 1700 Bayview Street, Arcata, CA 95521 USA

**Abstract:** Transportation planners occasionally notice a curious lack of consistency and communication between hydrologists, fisheries biologists and wildlife biologists regarding passages designed for their respective specialties. Several substantial differences in treatments between aquatic and terrestrial passages at highways masks the majority of similarities. At one end of the continuum, aquatics passages can be characterized by a total containment within a watercourse, with no need for modification of the shape or size of water conveyance structure as long as the structure maintains hydrological functionality. At the opposite end of the continuum terrestrial passages can be intentionally designed to avoid water conveyance entirely. Between these two extremes lie similarities in the need for functional streamcourses that allow passage for all age classes of fish and wildlife, as well as high water events. Our paper discusses the common mistakes made when considering only one passage category and suggests remedies designed to integrate the needs of terrestrial and aquatic organism passages. Our paper also discusses the professional basis for the occasional forgetfulness in dealing with other disciplines using lessons learned on this topic by the USDA Forest Service as an interdisciplinary land management agency.

## Introduction

Designing passages across roads for aquatic and terrestrial animals, separately or together, is relatively new. Examples of successful and unsuccessful passage designs are available and instructive. As time passes, and adequate performance becomes more common for both general categories of taxa, it appears the science and practice of aquatic passage design compared to terrestrial passage design might be diverging rather than converging. Fisheries biologists often do not discuss terrestrial passage needs with wildlife biologists and wildlife biologists often fail to recognize important cues where terrestrial passage needs are important.

Limited funding, limited time, and unpredictable weather patterns resulting from climate change are all excellent reasons why transportation ecologists can no longer afford to consider aquatic or terrestrial passages separately. Opportunities to increase habitat connectivity taken when they arise may cost considerably less and provide timely restoration or maintenance of passage needs for all taxa as well as ecological processes. This paper attempts to identify barriers to simultaneous consideration of passage needs for all vertebrate species, and to suggest solutions for a new paradigm broadly considering all species. This paper primarily considers the lessons we have learned on integrating vertebrate passage needs.

In this paper, aquatic organism passage (AOP) will broadly refer to passage opportunities and planning for fish and other organisms that are primarily confined to the watercourse or wetted streambanks; terrestrial organism passage (TOP) will be applied for vertebrates that are not confined to water or wetted streambanks, although they may use riparian systems as a necessary habitat component.

Although we have considered these questions primarily from the perspective of a federal land management agency, our experiences indicate that the USDA Forest Service is not alone in experiencing the issues identified here.

## Objectives

The objectives of this paper are:

- To identify characteristics of passages effective for both aquatic and terrestrial species
- To identify practices effective for either aquatics or terrestrials but not both
- To identify practices that cause problems for one group while solving problems for the other group
- To identify planning solutions to obtaining passages effective for all taxa

## Aquatic and Terrestrial Passages are Often Considered Separately

In the USDA Forest Service, fisheries and wildlife biology responsibilities are usually borne by different people. Because there is always more work to do than people to do it, biologists often do not interact on projects, especially where past experience has led them to believe there are no substantive issues. Some passage situations clearly do not require both disciplines to provide planning input.

Our experience and those of many others is that fisheries biologists and wildlife biologists view passage needs differently. Commonly, both biological disciplines assume that small roads, especially native surface roads or those with low traffic volume, do not require TOP consideration because they do not cause obvious mortality problems for large mammals and less obvious disruption of movements. This is usually true, so it masks the cases where those problems do occur. Mitigation may be needed for mortality and habitat connectivity issues even on small, low volume roads especially in cases where slow reptiles and amphibians occur in populations of management concern, where road surfaces are anticipated to be upgraded or widened, or where traffic volume is anticipated to grow within the next decade.

Both wildlife and fisheries biologists have limited knowledge and training of passage needs for their discipline. Fisheries biologists tend to have greater knowledge and training on passage issues than wildlife biologists. Fewer still have training in passage needs for both disciplines, and we are aware of no integrated training currently available that is as detailed as training available separately. This may result in unsophisticated or uninformed input, or overlooking important passage needs, on projects in the planning phase.

There has been and continues to be a legal imperative to find passage solutions particularly for endangered anadromous fish. The urgency and magnitude of these needs have led some managers to avoid considering other species of any type because it may slow progress towards these mandated goals. Funding sources based on annual appropriations or special budget line items do not lend themselves to careful deliberation, and funds not spent on passage needs for the species targeted are not likely to be available in the future. Thus urgency is combined with the practical approach that passage for some species is better than passage for no species.

As the science and practice of AOP has matured, increasingly well-defined and specific guidelines have emerged. For examples, see Gubernick et al (2003), Furniss et al (1999), and Conner et al (2003). Wildlife biologists have been invited to participate in these efforts but have not had as mature practice to inform TOP.

Terrestrial organism passage is fundamentally different than aquatic organism passage. The most obvious difference is that terrestrial animals are not confined to water, so the intersection of crossing locations with roads is not necessarily an identifiable point. Other differences such as the relatively high intelligence of some terrestrial animals means that behavior can be highly unpredictable even in well-studied species. Nothing analogous to the level of detail of such predictive modeling tools as Fish Xing (http://www.stream.fs.fed.us/fishxing/index.html) is available for terrestrial species, and even limited guides with recommendations on sizes and other attributes of crossing structures are properly laced with qualifiers. Although some organizing principles have emerged on TOP practice in the last two decades, terrestrial biologists are still far from the level of detailed guidance and training that AOP practitioners have obtained.

Aquatic passages are more technically complex than upland terrestrial passages in considerations of the range of changes and fluctuations of the stream throughout the life of the structure. Terrestrial passages are more complex than aquatic passages in considerations of the range of sizes and intelligence levels of multiple target species, and the difficulty of determining the best location and configuration for the structure. For both, a major complexity is determining whether or not a structure is needed and for which species.

## Identification of Passage Needs For AOP and TOP

A primary need in the search for an integrated AOP and TOP practice is identifying barriers, passage impediments and the degree of importance for animals to move across a road without suffering population-impacting mortality. This has been much more refined in AOP than TOP, with some agencies and states having procedures and policies to identify and prioritize AOP needs (Forest Service Regions 6 and 10, for example). Few efforts have been made to integrate large-scale AOP or TOP needs, and we are aware of only a few large project-level integration attempts. The Interstate 90 Snoqualmie Pass, Washington, improvement project has integrated AOP and TOP objectives and has performance measures identified to meet both needs. For example, alternatives recommend replacing existing bridges confining the channel at Gold Creek with bridges that would provide better channel functionality as well as greater opportunities for wildlife passage (figure 1). On smaller projects, such as individual Forest Service culvert replacement projects, we are aware of many individual specialists who attempt to integrate disciplines. In some of these cases, a greater understanding is needed to identify the trigger points for when both AOP and TOP are needed.

Figure 1. Aerial view of Gold Creek on Interstate 90 (Washington DOT image). At this site, project objectives include providing wildlife and fish passage for the full range of lake elevations.

Although we have much to learn about what triggers the need for passage in both taxa groups, some organizing principles can be identified.

**Considerations for AOP**

Certain stream/road intersection issues can be more associated with AOP than TOP. Many complex factors contribute to effective AOP design, however our discussion is limited to those that contrast or compare to TOP considerations.

Obviously, streamflows constrain fish presence and location. Other aquatic taxa are similarly dependent on watercourses. Aside from the simple presence of water, stream and channel characteristics also govern what species are present and what passage needs and constraints they have. Roadway elevation can affect the options available for underpasses, and therefore the effectiveness of the structure for the target species. The road condition at the streamcourse/road intersection influences AOP when it affects water quality such as sedimentation, and the shape and length of underpasses. For example, a wide road may affect AOP because of the length of the passage through the fill. Streams are rarely straight for long distances whereas structures may be. This may cause delays for fish attempting to pass through, which can be critical for some species. Multiple culverts on the same stream may also cause critical delays.

AOPs can be planned for the conditions of the watershed rather than the conditions of the road surface itself. AOPs can be sized to allow for the expected range of hydrologic conditions, including debris passage and the avoidance of pressurized flow conditions, rather than additional headroom for species that use the air above the surface. To the extent that water conveyance structures are planned to simulate the natural flow conditions, AOP is probably maintained.

**Considerations for TOP**

Terrestrial animals may travel far away from water even if they prefer riparian habitats. This makes their road crossing locations much more difficult to pinpoint for planning passage structures, and makes it important to consider characteristics of the entire floodplain even in riparian obligates. Sizes of terrestrial animals cover a wider range than aquatic species, ranging from tiny shrews to moose or elephants, thus requiring consideration for a physical structure that at the very least will encompass the basic size of the animal plus a behavioral comfort factor that varies by species. Conditions within the structure also constrain how terrestrial animals move through it. As with some fish, light or lack of light or air temperature can be important, while water temperature is not important because terrestrials may avoid walking in the water itself. While designing passages to avoid fatigue in migrating fish is important, terrestrial animals may not suffer appreciably more fatigue than walking over normal terrain unless they are trying to swim upstream in a culvert or negotiate boulder armaments at bridge abutments.

The greatest difference in aquatic and terrestrial considerations is the condition of the roadway and traffic in addition to the passage structure itself. For permeable-skinned animals such as salamanders, frogs and toads, the road surface can preclude passage due to the dry, hardened road surface or contaminants including deicing or dust abatement agents. As the number of lanes increase, the more time individuals spend on hostile surfaces during crossing attempts and the greater their opportunity for perishing.

Traffic volume and the capacity improvements (including additional lanes or median barriers) that transportation departments use to manage volume have a major effect on the probability of successful TOP (Hels and Buchwald 2001, Van Langevelde and Jaarsma 2005). The presence of a median barrier and guardrails may affect the ability of animals to cross a highway. Many other factors affect successful TOP, but in comparison to AOP the primary difference is that what happens on the road itself has as much of a bearing on the ability of terrestrial animals to pass as the size, gradient and location of passages for aquatic species.

Traffic volume can be very low for impacts to begin to manifest in vehicle-caused mortality or loss of permeability. Breeding European common toads (*Bufo bufo*) suffered 30% mortality while crossing a 6 m wide road with 10 vehicles per hour (Van Gelder 1973). Excessive adult mortality of the slowly reproducing wood turtle (*Clemmys insculpta*) was found at around 100 vehicles/lane/day (Gibbs and Shriver 2002). Intensively graded forest roads 12 m wide were a significant barrier for three species of terrestrial salamanders investigated in Maine (DeMaynadier and Hunter 2000). Narrow gravel roads were determined to be partial barriers to salamander movement and steep roadside verges may contribute to the effect (Marsh et al 2005). Indigo snakes (*Drymarchon corais*) that respond to passing traffic can be restricted from crossing with as few as 10 vehicles per hour (Andrews and Gibbons 2006). Even large mammals, especially wary ones, can be adversely affected by small amounts of traffic; grizzly bears (*Ursus arctos horribilis*) begin to avoid roads at traffic volumes of less than 10 vehicles per day (Mace et al. 1996). Movements were impaired for carnivores in winter in Canada when traffic ranged from 300-500 vehicles per day, and for ungulates between 500 and 5000 vehicles per day (Alexander et al 2005). While these studies and others do not necessarily support the need for TOP on all roads, they do suggest that roads with very low volume can be impermeable to some species due to mortality and barrier effects. Slow species are at greater risk because of greater exposure to mortality risk on the road (Hels and Buchwald 2001). Especially for reptiles and amphibians, speed of vehicles is unlikely to be a factor in mortality because of the low visibility of these animals. Thus, while increasing traffic volume and width of the road cause increasing impacts to slow and small animals, even relatively low volume and low speed roads can cause substantial adverse impacts. The context of these impacts including the legal status of the species involved as well as the management objectives will determine the degree and type of mitigation required.

While designs for AOP need to predict a watershed's changes and fluctuations over time, designs for TOP need to predict the increases in traffic volume over time (figure 2). For both groups, the temporal considerations would ideally span the expected lifespan of a prospective underpass design, but in reality structures may last far longer than a reasonable forecast for either traffic volume or watershed conditions.

Figure 2. Predicting traffic volume is important when considering terrestrial passage needs within the functional lifespan of a proposed water conveyance structure. Although gravel only few decades ago, this highway has a current ADT at this location of 22,760 and is projected to be 38,700 by 2028 (Oregon DOT). Photo S. Jacobson.

## Passage Conditions That are Ineffective for Both AOP and TOP

Passages designed for effective passage for only one taxa group may or may not be suitable for both groups. However, conditions that are unsuitable for one taxa group suggest that conditions may be unsuitable for the other as well. In general, a passage that simulates natural conditions to the extent possible is more likely to meet the needs of all of the species in the area. Stream simulation in culvert design is one approach used in some western states; this approach assumes that while we may not understand all the factors involved in designing effective stream crossings, a stream/road intersection that appears and functions similar to the way the original stream functioned prior to the presence of a road will likely meet the needs of the original inhabitants of the stream.

If a stream crossing is not designed to function like the original channel, several construction methods adversely affect the passage of both aquatic and terrestrial animals. High gradient culverts, especially if they are long and more than 25% of the natural gradient of the stream, are difficult for fish to swim up without exhaustion, and they are difficult or impossible for most terrestrial animals to climb. Perched outlets higher than fish can jump are well-known fish barriers, but they are also barriers to terrestrial species. Conversely, shallow inlets and outlets, or shallow water spread out all through a culvert can be a depth barrier to fish, yet even a shallow skim of water in a structure may be enough to hinder terrestrial animals that prefer dry areas to walk through a structure. The type of substrate on the structure floor may hinder aquatic or terrestrial species if it does not provide suitable soil, gravel size, and moisture conditions (moist to dry). Box culverts with an inch of water might create a shallow depth barrier for fish but a deep barrier for mice. Slick concrete aprons are also often depth and velocity barriers for fish, and may not allow a purchase for terrestrial species.

## Passages that are Effective for one TAXA Group but Ineffective or Dangerous for the Other

Because TOP can occur far away from water and would not be designed to handle AOP, these types clearly do not afford AOP. A special case where dry underpasses for TOP are constructed high in the fill slope of a highway that also has a water conveyance structure are not dangerous for AOP but, by mitigating only for TOP, planners may lose an opportunity to replace a long or steep gradient culvert with one suitable for AOP. A bridge would handle both needs. Because not all streams and stream reaches have aquatic passage needs, this may not be an issue if carefully analyzed during planning. Several terrestrial species are known to prefer traveling on dry surfaces alongside watercourses. Shelves of concrete or other material placed along the side of a culvert that is wall to wall water provides dry passage for animals (Foresman 2004). This is an effective retrofit for terrestrial animals but does not remedy any aquatic passage issues present, such as shallow depth barriers in box culverts.

Fish passage structures can sometimes be dangerous to terrestrial species. Typically, these are structures that have been designed to slow high flows and provide resting areas for passing organisms, and so few terrestrial species may try to use them unless forced to seek a way across a road. Fish ladders or weirs with deep submerged sides may trap terrestrial species that attempt to use the underpasses (figure 3). The shelves mentioned above would be a possible retrofit for some of these structures provided they did not unduly hinder the hydrologic function of the structure.

Figure 3. Vertical walls used to provide resting pools for fish may trap terrestrial animals. A horizontal shelf along the edge of the culvert is a possible retrofit to allow terrestrial animals dry walking space. Photo from Fish Xing.

Effective AOPs that are not dangerous to terrestrial animals but may cause avoidance include structures with very low headroom inadequate for an animal to use either behaviorally or simply due to size, or box or metal culverts with deep outlets that reach both sides of the structure with no unsubmerged areas (figure 4).

Figure 4. The right culvert chamber has a perched inlet (shown left). Combined with the same culvert's inundated outlet (right), it is difficult for many terrestrial animals to use. Photos S. Jacobson.

Many bridge replacements are being constructed with boulder armament protection from the water line to the abutments (figure 5). These bridges are often sized large enough to be superb crossing structures for many species of wildlife but fail to be useful because the armament only allows passage for nimble species that can safely clamber over rocks. Small animals including turtles can get trapped in the spaces between rocks, and ungulates avoid riprap altogether.

Figure 5. Bridge replaced in 2007 with excellent shape and size to allow passage for all terrestrial species present in the area, but rendered impermeable for many terrestrials due to the large boulder armament. This type of abutment protection is very common in current bridge replacements. Photos S. Jacobson.

## Attributes of Effective Integrated Passages

Several principles can be identified for creating effective passages. First and foremost, specialists need to jointly consider the passage needs of any and all organisms early in any project, especially in site assessment and the early determination of design criteria. Passages that retain the natural gradient, substrate and width of a streamcourse along with unwetted sides provide good insurance for any principles not yet clearly identified. These features add complexity and hydraulic condition variability that are found in the natural stream. Underpasses that consider adequate headroom for terrestrial species while designing for flood events also allow for debris passage and avoid pressurized flow conditions that cause damage to streamcourses. Climate change models suggest that extreme events will become more frequent, so a prudent practice may be oversizing culverts and bridges to accommodate larger flood events than past records allow us to predict. Several states including Arizona, Vermont and California are considering climate change as a planning factor. These features can be designed into culverts or bridges as needed, and bridge replacements offer an excellent opportunity to incorporate integrated aquatic and terrestrial passage principles into the designs.

## Social and Agency Solutions to Integrating TOP and AOP

Identifying the need to integrate terrestrial and aquatic passages entails two conceptual frames. The large-scale, long term transportation planning process can provide consideration of habitat connectivity and mortality reduction needs for both broad taxa groups, while project-level planning can provide information on site specific needs. Ideally, connectivity needs would be identified prior to transportation project planning, both at the large scale and project scale, but in practice the transportation planning process often provides the catalyst for change. Thus far, identification and prioritization of AOP and TOP needs has been mostly done separately on a broad scale. Examples are the Forest Service's Region 6 aquatic passage priority setting process, and the growing number of state wildlife habitat connectivity plans. To some extent, the separation is due to inadequate funds for a comprehensive integrated process.

Research is needed on how best to identify the highest priority sites so that scarce resources are not expended on retrofitting or replacing structures that were built, but have neglected to consider all species' needs. Policy direction for land management agencies and departments of transportation would be useful in breaking down administrative barriers. Processes such as the interagency Eco-Logical planning approach (Brown 2006) hold promise for helping to accomplish integrated planning and design, while State Wildlife Action Plans could be integrated better with the few aquatic organism passage priority systems available. Agencies that take full advantage of the collaboration intent of SAFETEA-LU's Section 6001 and 6002 will be further ahead on interagency cooperation and efficient use of limited resources.

Evaluation of the passage and mortality reduction needs at each site is a primary need before we can effectively integrate AOP and TOP. This will require a better understanding of the temporal and spatial triggers for the need for habitat connectivity and mortality reduction for aquatic and terrestrial resources.

Training in channel types such as the Rosgen (1994) classification system would enable wildlife biologists to have a common language with physical scientists, engineers, hydrologists, and fisheries biologists on the engineering limitations and geomorphic requirements for each situation. Understanding channel types can help determine where crossing structures might be placed to best accommodate AOP and TOP together, or if it would be necessary to treat them separately. For example, road crossings over Rosgen channel types B, C, D, DA, and E have the potential to readily accommodate both AOP and TOP if the crossings are designed with those needs in mind, while other channel types may be possible but require more challenging engineering solutions.

Identifying project level sites where mitigation is needed for passage for both groups of taxa can be best accomplished with an interdisciplinary team early in the project planning process. Even when interdisciplinary teams are employed, it is necessary for each member of the team to have adequate knowledge of the factors that influence the need for each type of passage. Currently, both halves of this equation, involvement and knowledge, are inconsistently available. One objective of this paper is to identify some of the attributes of road/stream crossings that are ripe for consideration for both taxa groups.

Interdisciplinary teams that consider the long-term conditions of both the road and the stream will likely be more able to identify and prioritize passage opportunities. Knowledge of this topic is rapidly growing, so teams that investigate solutions through innovative methods can make significant contributions to integrating passage needs for both aquatic and terrestrial organisms that need to cross roads and highways.

**Biographical Sketches:** Sandra Jacobson is a wildlife biologist specializing in wildlife and highway interactions with the USDA Forest Service, Pacific Southwest Research Station.

Robert Gubernick is an engineering geologist and the lead fish passage/ hydraulic engineer for the Tongass N.F. Alaska Region of the USFS.

Michael J. Furniss is a hydrologist and boundary spanner with the USDA Forest Service, Pacific Northwest and Pacific Southwest Research Stations, located at Redwood Sciences Lab, Arcata, CA.

## References

Alexander, S.M., N.M. Waters and P.C. Paquet. 2005. Traffic volume and highway permeability for a mammalian community in the Canadian Rocky Mountains. The Canadian Geographer 49:321-331.

Andrews, K.M. and Gibbons, J.W. 2006. Dissimilarities in behavioral responses of snakes to roads and vehicles have implications for differential impacts across species. IN: Proceedings of the 2005 International Conference on Ecology and Transportation, Eds. Irwin, C.L, Garrett, P.; McDermott, K.P. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC; pp. 339-350.

Brown, J. 2006. Eco-Logical: an ecosystem approach to developing infrastructure projects. FHWA Report FHWA-HEP-06-011. Washington DC. 83 pages.

Connor, A. Clarkin, K., Furniss, M., Gubernick, R., Moynahan, K., Wilson-Musser, S. 2003. National Inventory and Assessment Procedure for Identifying Barriers to Aquatic Organsim Passage at Road-Stream Crossings. USDA Forest Service.

DeMaynadier, P.G. and M. L. Hunter Jr. 2000. Road effects on amphibian movements in a forested landscape. Natural Areas Journal 20: 55-65.

Foresman, K.R. 2004. Small mammal use of modified culverts on the Lolo South project of Western Montana - an update. IN: Proceedings of the 2003 International Conference on Ecology and Transportation, Eds. Irwin CL, Garrett P, McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 342-343.

Furniss, M., Moore, T., Love M., Dunklin, T., Gubernick, R., Firor, S., Lang, M., Roelofs, T. and B. Rush. 1999. FishXing: New Software under Development to Assist in the Analysis of Fish Passage Through Culverts. Engineering Field Notes Volume 31.

Gibbs, J.P. and W.G. Shriver 2002. Estimating the effects of road mortality on turtle populations. Conservation Biology 16 (6), 1647–1652.

Gubernick. R. and K. K. Bates. 2003. Designing culverts for aquatic organism passage: stream simulation culvert design. IN: Proceedings of the 2003 International Conference on Ecology and Transportation, Eds. Irwin CL, Garrett P, McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 42-52.

Hels, T. and E. Buchwald. 2001. The effect of road kills on amphibian populations. Biological Conservation 99: 331-340.

Mace, R.D, J.S. Waller, T.L. Manley, L.J. Lyon, and H. Zuuring. 1996. Relationships among grizzly bears, roads and habitat in the Swan Mountains, Montana. Journal of Applied Ecology 33: 1395-1404.

Marsh, D.M, G.S. Milam, N.P. Gorham, and N.G. Beckman. 2005. Forest roads as partial barriers to terrestrial salamander movement. Conservation Biology 19: 2004-2008.

Rosgen, D.L. 1994. A classification of natural rivers. Catena 22:169-199.

Van Gelder, J.J. 1973 A quantitative approach to the mortality resulting from traffic in a population of *Bufo bufo* L. Oecologia 13: 93-95.

Van Langevelde, F. and C.F. Jaarsma. 2005. Using traffic flow theory to model traffic mortality in mammals. Landscape Ecology 19: 895-907.

# Habitat Restoration and Mitigation the Impact of Transportation Network on Hyporheic Organisms Dwelling in the Upper Ganges, India

**Ramesh C. Sharma** (91-1370-267740, drrameshcsharma@yahoo.com), Professor and Head, Department of Environmental Sciences, H.N.B. Garhwal University, Post Box-67, Srinagar-Garhwal 246174, Uttarakhand, India

**Abstract:** Integrated ecosystem approach is essential to offset adverse impact of transportation network on aquatic habitats in the fragile ecosystem of the Himalayan mountains. It is a cause of concern that the poorly designed network of roads and trails in mountain areas are expanding, without giving due consideration to natural processes of ecosystem function and climatic severity in the Himalayas. These effects have been quantified for a period of three-year (January 2003-December 2005) for hyporheic biodiversity (microphytobenthos, microzoobenthos and macro-zoobenthos) inhabiting upper Ganges, India (Latitude $29^{0}$ $61'$-$30^{0}$ $28'$ N; Longitude $77^{0}$ $49'$-$80^{0}$ $6'$ E). Transportation network of 495 km long passing along the upper Ganges, a project of US$ 250 million, is one of the most important networks in the mountain region of Garhwal Himalaya. Hyporheic organisms are instrumental for self purification of in-filtrated water through filtration, sedimentation, deposition and biological decomposition. Hyporheic biodiversity is less known or not at all known in Africa, Latin America, Australia and East Asia. Construction of roads and their widening along the upper Ganges, through massive cutting of mountain slopes, and disposal of tons of the cut material downhill into the waterways has resulted in intensive accumulation of soil, woody debris into the aquatic ecosystem from accel-erated erosion, gulling and landslides resulting in drastic changes in the physico-chemical and biological profile of the hyporheic biotope. Detrimental effects on conductivity, bottom substrate composition, dissolved oxygen and hyporheic organisms of upper Ganges have been documented. Subsequent to construction and widening activities of roads along the upper Ganges, a decline of 61% in annual mean density, 45% in alpha diversity and 21% in Shannon Wiener index ($\overline{H}$) of hyporheic microphytobenthos was recorded during a three-year period. Hyporheic microphytobenthos of upper Ganges were represented by thirteen genera (*Diatoma, Navicula, Nitzchia, Pinnularia, Synedra, Acnanthes, Amphora, Coconeis, Cymbella, Fragilaria, Gomphonema, Gryosigma and Hantzchia*) of Bacillariophyceae, seven genera (*Hydrodictyon, Microspora, Pootococcus, Tetraspora, Spirogyra, Ulothrix and Cladophora*) of Chlorophyceae, five genera (*Anabena, Nostoc, Oscillatoria, Polycystis and Rivularia*) of Myxophyceae and four genera (*Gonatozygon, Closterium, Cosmarium, Desmidium*) of Desmidiaceae. A decline of 18% in mean annual density, 6% in alpha diversity and 7% in Shannon Wiener index ($\overline{H}$) of hyporheic microzoobenthos was estimated. Hyporheic microzoobenthos were represented by seven genera of Rotifera (*Ascomorpha, Asplanchna, Brachionus, Lecane, Philodina, Trichocera and Rotaria*), nine genera of Copepoda (*Diaptomus, Epischura, Cyclops, Mesocyclops, Microcyclops, Achnanthocyclops, Phyllognathopus, Bryocamptus and Parastenocanis*) and one genera each of Cladocera (*Ceriodaphnia*), Ostracoda (*Cypridopsis*) and Malacostraca (*Stygobromus*). A depletion of 43% in annual mean density, 38% in alpha diversity and 9% in Shannon Wiener index ($\overline{H}$) of macrozoobenthos was computed. Hyporheic macrozoobenthos of upper Ganges were represented by seven genera (*Ecdyonurus, Rhithrogena, Ephemerella, Caenis, Baetis, Heptagenia and Cloeon*) of Ephemeroptera, nine genera (*Hydropsyche, Psychomyia, Polycentropus, Leptocella, Glossoma, Hydroptila, Rhyacophila, Limniphilius, Mystacides*) of Trichoptera, eleven genera (*Chryogaster, Philorus, Tendipes, Limnophora, Forcipomyia, Pentaneura, Tabanus, Simulium, Dixa, Atherix, Antocha*) of Diptera, three genera (*Psephanus, Heterlimnius, Dinutes*) of Coleoptera, four genera (*Architestes, Octagomphus, Epicordula and Symptrum*) of Odonata and two genera (*Perla and Isoperla*) of Plecoptera. Most of the members of hyporheic organisms, sensitive to dis-turbance were completely missing at the impacted sites. The environmental degradation of hyporheic zone, decline in quantity and missing of sensitive hyporheic organisms are believed to have been caused by increased in water temperature, turbidity, total dissolved solids and biological oxygen demand, accompanied by a decline in dissolved oxygen, accumulation of fine silt and suspended solids blocking interstitial spaces in the hyporheic zone. We have recommended the following mitigation measures to restore habitat quality and protection of hyporheic organisms: 'functional habitat' recovery by physical reconstruction of channels based on geomorphological principles, removal of obstructions (gravel mining, and dredging in the impacted site), protecting of riparian vegetation, natural recovery of watersheds, sustainable approaches to road construction and widening, proper drainage of water saturated mountain slopes and spring runoff during heavy precipitation, sealing of side drains against water penetration into the under-ground alongside fragile sections of the highway, construction of check dams for protection of steep gullies and side erosion of the river bed for maintaining rich heterogeneity of river bed habitats, following minimum flow principle in the river and the establishment of strong co-ordination among transport planners, geologists, civil engineers, structural engineers, environmental biologists.

## Introduction

Biodiversity is an object of a large international programme of the IUBS/SCOPE/UNESCO and is important for many scien-tific, economic and ethical means (Solbrig 1992). Biodiversity has been recently recognized as one of the most potential and essential characteristics of life for the proper functioning of fluvial ecosystem and a means of coping with natural and anthropogenic environmental changes. India is famous for its rich biodiversity. It is one of the twelve mega biodiversity countries of the world. Biodiversity of the hyporheic zones are largely overlooked in the calculation of global biodiversity and are less known than the diversity of organisms dwelling surface water. The state of knowledge on the biodiversity of hyporheic habitats of Africa, Latin America, Australia and South-East Asia are still poorly or not at all known.

The newly carved out state of Uttarakhand is one of the most important sites of rich biodiversity of the country due to its physiographic and climatic variability. The Ganges is the Holy River of India. A very long stretch of upper Ganges passes through Uttarakhand in addition to its origin from the Himalayan glaciers. A strong transportation network is necessary for human mobility and fast development of Uttarakhand. It is a cause of concern that the poorly designed network of roads and trails in mountain areas are expanding, without giving due consideration to natural process of ecosystem function and climatic severity in the Himalayas. These effects of transportation network have been quanti fied for a period of three years (January 2003-December 2005) for hyporheic biodiversity inhabiting upper Ganges, India. This is for the first time that hyporheic zone in terms of impact of transportation has been explored in India in the form of present work.

The term 'hyporheic' was coined by Orghidan (1991). Schwoerbel (1961) defined the hyporheic zone to be an intermediate zone, bordered by the epigean water of the stream above and by the true water groundwater below. Gilbert (1991) defined hyporheic zone as an ecotone (overlapping zone) between groundwater and surface water, blending properties of both water sources. Edwards (1998) defined hyporheic zone as the volume of saturated sediment beneath and beside streams and rivers where groundwater and surface water mix. Where groundwater refers to the subsurface water that has not yet entered a surface flow channel, however, the surface water refers to water that has entered the stream channel directly as rainfall or surface runoff or indirectly from groundwater. The mixing of these two masses which often significantly stimulates biological activity. White (1993) defined hyporheic zone as the saturated interstitial areas beneath the stream banks that contain some proportion of channel water or that have been altered by channel water infiltration.

Williams and Hynes (1974) gave the term 'hyporheos' to the fauna of the hyporheic zone. According to Gilbert *et al* (1990), hyporheic zones are the important landscape features due to their physical and biological characteristics, their unique value and these spatial and temporal characteristics. These zones are water flow regulators, permanent sinks for organic and mineral matter and contaminants from watersheds, filter and buffer systems that protect groundwater quality and improve surface water quality. Supply of water and nutrients of hyporheic zone is maintained by interstitial spaces between substrata (boulder, cobbles pebbles, sand, *etc.*). Hyporheic zone is completely absent where the streambed is impermeable (bedrock or impermeable mud or clay). Hyporheic zones exist where the river flows through porous gravel that allows high infiltration rates of surface water (Clinton and Edwards, 2000).

The hyporheic zone *i.e.* groundwater/surface water ecotone exists in the different types of environment in all the countries. The main characteristics of these interfaces are their great variety of elasticity, permeability, biodiversity and connectivity (Gilbert *et al.* 1990). Ecotones are the zones where ecological processes are more diversified. Most of the stream limnologist regard hyporheic zone as refuge or/and hatchery for the stream fauna which is supposed to be continued to or very near to the sediment surface. Phreatobiologist regard hyporheic zone as the top most layer of the groundwater system, a zone with most intense interactions between epigeic and hypogeic systems. This hyporheic zone acts as a self purification zone.

The present paper attempts to provide manifestation of adverse impact of construction and widening activities of roads along the upper Ganges on the water quality and to quantify the impact on the density and diversity of hyporheic organisms during a three-year period. Several remedial measures for restoration of habitat quality and mitigation the deleterious effects of construction and widening of roads for the protection of hyporheos of the upper Ganges have been suggested and tried on many stretches of Upper Ganges.

## Materials and Methods

### Physiography of the Study Area

The study area is located in the Garhwal Himalayas, an important zone of the Himalaya and a part of the new state of Uttarakhand of North India (Latitude: 29 degrees 26 minutes-31 degrees 28 minutes N; Longitude: 77 degrees 49 minutes-80 degrees 6 minutes E). It encompasses six districts (Dehradun, Tehri, Pauri, Uttarkashi, Chamoli and Rudraprayag) and covers an area of 30,029 $Km^2$. the area is very rich in terms of terrestrial and aquatic biodiversity. The entire region is bestowed with tremendous freshwater resources in terms of major fluvial systems of holy rivers of Ganges, Yamuna and their tributaries. Two major parent streams – Alaknanda and Bhagirathi form the Ganges after the confluence at Deoprayag. All the four world famous Indian Shrines (Badrinath, Kedarnath, Yamanotri and Gangotri) are located in this region. To cater the needs of heavy influx of pilgrims, a thick network of roads and national highways has been launched. Most of the roads and highways in Garhwal Himalayas have been constructed in the river valleys along the major rivers including the Holy River Ganges.

### Geology of the Study Area

The study area encompasses the watersheds of two parent streams of Ganges- Alaknanda and Bhagirathi. The watershed of Alaknanda is characterized by flat-topped ridge, steep slopes and wide valley. The area is covered by three types of rocks of the upper Proterozoic ages (Valdiya, 1984). The area is represented by huge thinly foliated, highly folded, fractured and joined phyllite rock traversed by quartz veins and few basic intrusive in the form of sill and dykes. The phyllite is called Pauri phyllite (Kumar and Aggarwal 1975). Vertically folded, highly fractured, pinkish ripple and current bended quartzite rocks and intercalated with massive intrusive of meta volcanic rocks are under Garhwal groups of rocks. The tectonic features generally control the landform of an area; slopes of a drainage pattern are more sensitive to recent neotectonic activities. Wide valley of Alaknanda is characterized by the set of terrace formed by the river sifting and reducing the water discharge. The river flowing in the area was assumed to have heavy water discharge with laminar flow that reduced to its present level. Therefore, the sediments and load are deposited along the riverside in the form of terraced. Most of the lowest terraces are in contact of the river.

The stretch of the Bhagirathi of upper Ganges (Gangotri to Rishikesh) falls under four major stratigraphic units; the Central Crystalline, the Garhwal Group, the Kumaun Group, Krol Formation and Tal-Quartzite. The Central Crystalline thrusts upon the Garhwal Group along the Main Central Thrust (MCT), while the North Almora Thrust delineates the Garhwal Group for the Kumaon Group. The Central Crystalline extends from Gomukh to Sanj, the Garhwal Group from Sanj to Dharasu, and the Kumaun Group from Dharsu to Sanknidhar. The Krol Formation extends from Sanknidhar to Byasi and the Tal-Quartzite extends from Byasi to Rishikesh.A tremendous increase in the gradient (10.3-30.0m $km^{-1}$) of the river channel was observed upstream of Uttarkashi. The gradient decreases to an average of 3.7 m $km^{-1}$ between Uttarkashi to Deoprayag and about 1.0 m $km^{-1}$ upto Rishikesh. The tributaries of Bhagirathi have a much steeper gradient. The upper most stretch of Bhagirathi (up to Harsil and adjoining areas) has cliff type slopes. Downstream at Dabrani, the cliff type slope has taken the form of repose slope at certain places, implying the remnant of old landslides. The repose type of slope was seen from Uttarkashi to Deoprayag. However, the cliff slope was again observed between Tehri and Deoprayag.

### Mountain Specific Preconditions for Road Construction

Road construction and widening are very much dependent on the natural preconditions (climate, geology, topography and environment) in mountainous areas. Favourable preconditions generally result in modest construction/widening volume per km, whereas unfavourable preconditions can bring enormous work volume and be very expensive. The climate of Garhwal Himalaya is mainly dependent on the altitude and varies from sub-tropical to alpine and temperate. The annual rainfall differs from place to place, ranging from less than 250mm to 3,500mm. Most of the precipitation (80%) occurs during the monsoon period (July-August) creating tremendous problems for the road builders.

Garhwal Himalaya is affected by a constant tectonic uplifting which is accompanied by a down cutting of the river systems. The results of these natural forces are slopes which become steeper and steeper and therefore unstable. It is evident that such conditions make road widening a difficult task. The hilly belt of Garhwal Himalaya generally consists of rugged topography with tremendous difference in elevation ranging from 350 m above m.s.l. to 3,500 m above m.s.l. The resulting steep slopes are divided into many gullies and small valleys and the valley floors are extremely narrow. Such extreme conditions demand a very careful road construction and widening activities. Forest and vegetation cover is a must for a balanced ecosystem. Depletion of forest resources by cutting of trees for firewood (the source of energy) and the extension of farmland into steep and unstable areas has made the entire mountain area of Garhwal Himalaya as vulnerable. Such deforested and abandoned land has an accelerated water run-off in volume as well as in speed and is prone to slides. These four mountain specific preconditions have a negative influence on road construction and widening in Garhwal Himalaya.

### Salient Features of Transportation Network Project Passing Along the Upper Ganges

The transportation network of 495 km long passing along the upper Ganges, a project of US $250 million is one of the most important networks in the mountain region of Garhwal Himalayas.It is a Y shaped transportation network. It is 230 km long passing along the Alaknanda River, 195 km long passing along the Bhagirathi River and 70 km long passing along the Ganges (figure 1). Alaknanda and Bhagirathi are the two major parent streams of Ganges. This transportation network caters the need of heavy traffic (0.85 million people per year), as it is used by the pilgrims for visiting the world famous Indian Shrines of Gangotri, Yamanotri, Badrinath, Kedarnath and Hemkunth Sahib.

Figure 1. Road passing along the holy River Ganges in Garhwal Himalaya.

## Methodology

### Sampling Protocol

Monthly sampling was conducted for a period of three-year (January 2003 to December 2005) at 0800-1100 hrs at all the sampling sites (two reference sites and two impacted sites; one each on Bhagirathi and Alaknanda). Samples for the analysis of physico-chemical and biological parameters were collected from the hyporheic biotope using stand pipe traps (Bretschko and Klemens, 1986). These traps consisted of metal tubes having a diameter of 10 cm and overall length of 177 cm. Some catching holes of 8mm diameter were made near the bottom of each tube. These tubes were sealed from the bottom. The interstitial dwellers along with substrate and water can only enter the loop through the catching holes. Three such traps were constructed and placed at different depths (15cm, 30cm and 50cm) for one hour period to obtain hyporheos from the hyporheic zone of Upper Ganges. Five replicates were collected from each depth for each sampling site.

The Siphoning Method of Sterba (1990) was employed for the collection of hyporheic organisms. Under this method, a plastic pipe was inserted into the stand pipe from the upper end and water was sucked from the free end of the pipe and collected into a bucket.

### Substrate Composition and Particulate Analysis

Sediment particles ranged in from a fraction of micron to huge boulders measuring many meters in diameter. Geologists had developed grade scale consisting of named classes, each having definite lower and upper limits. From smallest to largest, the class names are clay, silt, sand, pebbles, cobbles and boulders. Pebbles, cobbles and boulders collectively form gravel. The size of substrate was measured following the phi (Φ) scale (Friedman and Sanders, 1978).

Where, $\Phi = -\log_2 d$
d = diameter of particles in mm

The value obtained in 0 units converted into mm following the Table of standard size classes of sediment given by Friedman and Sanders (1978).

### Analyses of Physico-chemical Parameters

Samples were collected from hyporheic zone by Siphoning Method of Sterba (1990) from different depths (15cm, 30cm, 50cm) of hyporheic biotope. Physico-chemical parameters (temperature, conductivity, turbidity, total dissolved solids, pH, dissolved oxygen, free carbon dioxide, alkalinity, phosphates, nitrates and biochemical oxygen demand) were analysed following the methods outlined in Wetzel and Likens (1991) and APHA (1998).

### Qualitative and Quantitative Analyses of Hyporheos

Biological components of the hyporheic zone included microphytobenthos, macrozoobenthos and microzoobenthos. These were collected by filtering 5 litre water sample obtained by Sterba's siphoning method through a plankton net (48 μ m mesh). Retained material was washed with 4% formalin and stored in a sample jar. The collection was identified in the laboratory following Ward and Whipple (1992) and several keys of Fresh Water Biological Association, U.K. along with the help of several experts. Macrozoobenthos were separated from the sediment portion collected in the stand pipe traps. The sediment collected in different traps was transported to the laboratory separately within 1-2 hrs and were examined for the presence of macrozoobenthic organisms before being discarded. The organisms thus collected were identified and preserved in 4% formalin solution.

## Results and Discussion

### Direct Impacts/Primary Effects

The impact of transportation network on aquatic environment and hyporheic organisms dwelling in the upper Ganges were of three types- direct or primary impacts; indirect or secondary impacts; and cumulative and synergistic impacts. A large scale transformation in the geomorphology of upper Ganges at several places has taken place due to construction, widening and repairing activities of roads along the upper Ganges. A large stretch of fluvial system has been transformed into tench and dammed pool of sluggish currents of water from rapids, cascades, part of high water form riffles. The other section of the river has been converted into narrow, turbulent and turbid riffles from white and clear water pools as a result of large scale disturbances caused by disposal of tons of cut material downhill into the water ways of upper Ganges.

For roads, the frequency of erosion and landslide is generally related to the depth of the cuts, steepness of the slope, degree of vegetative cover, climatic conditions, geological structure and lithology. The higher the road cut, the greater the structural weakness that is created. The steeper the hill slope, the more likely it is that the forces of instability, such as gravity of saturation, will be greater than the forces for resistance, such as soil cohesion and root anchoring. Failure to establish protective vegetation on newly exposed slopes promptly following construction, allows running water to excerbate slope stability problems. Inadequate drainage slopes has the same effect. Errors during construction including uncontrollable blasting can create road cuts, leading eventually to landslides (figure 2).

Figure 2. Landslides caused by uncontrolled blasting during road construction and widening along the upper Ganges.

Erosion from poorly constructed and inadequately rehabilitated sites can lead to downstream siltation and filling up of interstitial spaces by fine silt choking the flow of water into the hyporheic biotope of Upper Ganges. Serious impacts can occur because of the disruption and outright removal of streambed habitats and sometimes habitat isolation from the main fluvial system. These direct impacts are the easiest impacts to understand and predict because of the straight forward cause-effect relationships that are evident.

The composition of bottom substrate has been drastically altered by the construction, widening and repairing of roads along the Upper Ganges. Improper management of the slopes has resulted in increasing accumulation of silt, woody debris into the aquatic ecosystem from accelerated erosion.

**Indirect Impacts/ Secondary Impacts**

Indirect impacts are the consequences of direct impacts. The indirect impacts or secondary impacts of transportation network are environmental degradation and shrinking of population of hyporheos dwelling in the Upper Ganges.

*Degradation in Water Quality*

Degradation in the mean physico-chemical parameters of hyporheic biotope of Upper Ganges caused by the transportation network over a three-year period (January 2003-December 2005) has been presented in table 1.

Table 1: Degradation in the mean physicochemical parameters of the hyporheic biotope of Upper Ganges caused by transportation network during a three-year period (January 2003-December 2005)

| Environmental Parameters | Reference site $\overline{X} \pm$ S.D. | Impacted Site $\overline{X} \pm$ S.D. |
|---|---|---|
| Water Temp. ($^0$C) | 15.2 ± 2.95 | 16.4 ± 3.28 |
| Conductivity (μ S.cm$^{-1}$) | 140.2± 12.95 | 143.6± 16.68 |
| Turbidity (NTU) | 64.5 ±110.20 | 70.6± 123.46 |
| TDS (mg.l$^{-1}$) | 190.4 ± 81.12 | 197.5 ±89.96 |
| pH | 7.5 ± 0.25 | 7.8 ± 0.35 |
| DO (mg.l-1) | 13.6 ± 2.19 | 11.4 ± 1.81 |
| Free CO2 (mg.l$^{-1}$) | 0.40 ± 0.07 | 0.45 ± 0.08 |
| BOD (mg.l$^{-1}$) | 1.10 ± 0.78 | 1.45 ± 0.85 |
| Total Alkalinity (mg.l$^{-1}$) | 65.1 ± 9.33 | 69.8 ± 10.12 |
| Nitrates (mg.l$^{-1}$) | 0.029 ± 0.02 | 0.044 ± 0.12 |
| Phosphates (mg.l$^{-1}$) | 0.088 ± 0.15 | 0.097 ± 0.85 |

Analysis of the data revealed that a considerable change in the water temperature in year 2005 (16.4 ± 3.28°C) was recorded in comparison to the temperature recorded at the reference sites (15.2 ± 2.95°C) in 2003. A minor change in the conductivity was also recorded from 140 ± 12.95 to 143.6 ± 16.68 μ S $cm^{-1}$ over a three-year period. The drastic change in turbidity and total dissolved solids was recorded at the impacted sites. A slight change in the pH was also noticed. It increased from 7.5 ± 0.25 to 7.8 ± 0.35. A considerable reduction in the dissolved oxygen from 13.6 ± 2.19 to 11.4 ±1.81 was recorded in the hyporheic zone of upper Ganges. A minor change in other chemical parameters (free carbon dioxide, nitrates, phosphates and total alkalinity) was also recorded. A prominent change in the BOD was noticed. It increased from 1.10 ± 0.78 to 1.45 ± 0.05 mg $l^{-1}$ due to construction, widening and repairing activities of roads over a three year period in hyporheic biotope of Upper Ganges.

*Shrinking of Population of Hyporheos*

The hyporheic biodiversity of upper Ganges is characterized by the presence of microphytobenthos, microzoobenthos and macrozoobenthos. Subsequent to construction and widening activities of roads along the upper Ganges, annual mean density of hyporheic microphytobenthos was reduced from 184.8 ± 174.5 ind.$l^{-1}$ to 71.8 ± 75.96 ind. $l^{-1}$, a 61% decrease (figure 3). Hyporheic microphytobenthos of upper Ganges were represented by thirteen genera (*Diatoma, Navicula, Nitzchia, Pinnularia, Synedra, Acnanthes, Amphora, Coconeis, Cymbella, Fragilaria, Gomphonema, Gryosigma and Hantzchia*) of Bacillariophyceae, seven genera (*Hydrodictyon, Microspora, Protococcus, Tetraspora Spirogyra, Ulothrix, and Cladophora*) of Chlorophyceae, five genera (*Anabaena, Nostoc, Oscillatoria, Polycystis and Rivularia*) of Myxophyceae and four genera (*Gonatozygon, Closterium, Cosmarium and Desmidium*) of Desmidiaceae.

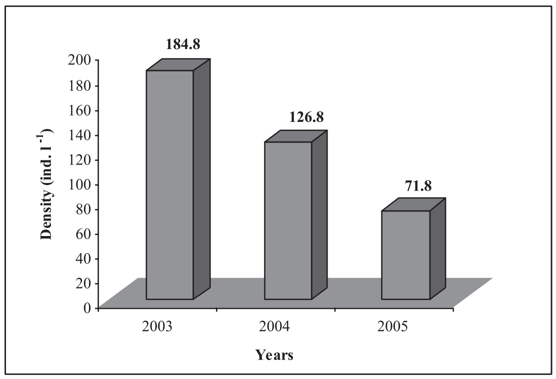



Figure 3. Impact of construction and widening of roads on the annual mean density (ind. $l^{-1}$) of hyporheic microphytobenthos dwelling Upper Ganges over a period of three-year (61 percent decrease).

Subsequent to construction and widening activities of roads along the upper Ganges, alpha diversity of hyporheic microphytobenthos decreased from 11 to 6 (45% decrease) and Shannon Wiener index ($\overline{H}$) from 1.92 to 1.52 (21% decrease) during a three-year period. Concentration of dominance (C) calculated for hyporheic microphytobenthos increased as a consequence of the impact during a period of three-year (table 2).

Table 2: Mean monthly variations in alpha diversity, Shannon and Wiener diversity index ($\overline{H}$) and concentration of dominance (C) of hyporheic microphytobenthos dwelling Upper Ganges caused by transportation network during a three- year period (January 2003-December 2005)

| **Month** | **Alpha Diversity** | | H? | | **C** | |
|---|---|---|---|---|---|---|
| | **2003** | **2005** | **2003** | **2005** | **2003** | **2005** |
| January | 19 | 08 | 2.15 | 1.95 | 0.16 | 0.16 |
| February | 19 | 08 | 2.25 | 1.90 | 0.15 | 0.16 |
| March | 15 | 08 | 2.17 | 1.85 | 0.15 | 0.17 |
| April | 13 | 08 | 1.99 | 1.72 | 0.21 | 0.22 |
| May | 09 | 05 | 2.07 | 1.53 | 0.12 | 0.20 |
| June | 08 | 04 | 1.94 | 1.37 | 0.14 | 0.20 |
| July | 04 | 02 | 1.33 | 0.69 | 0.22 | 0.33 |
| August | 05 | 02 | 1.39 | 0.69 | 0.21 | 0.33 |
| September | 06 | 04 | 1.63 | 1.30 | 0.17 | 0.26 |
| October | 09 | 07 | 2.01 | 1.69 | 0.14 | 0.19 |
| November | 14 | 08 | 2.06 | 1.76 | 0.18 | 0.20 |
| December | 15 | 08 | 2.10 | 1.77 | 0.17 | 0.19 |
| **Annual ( $\bar{X}$ )** | **11.33** | **6.0** | **1.92** | **1.52** | **0.17** | **0.22** |

The annual mean density of hyporheic microzoobenthos dwelling upper Ganges declined from 225.6 ± 130.8 units l-1 to 186.0 ± 130.1 units $l^{-1}$, a decrease of 18% due to the adverse impact of transportation network during a three- year period (figure 4). Hyporheic microzoobenthos were represented by seven genera of Rotifera (*Ascomorpha, Asplanchna, Brachionus, Lecane, Philodina, Trichocera and Rotaria*), nine genera of Copepoda (*Diaptomus, Epischura, Cyclops, Mesocyclops, Microcyclops, Achnanthocyclops, Phyllognathopus, Bryocamptus and Parastenocaris*) and one genus each of Cladocera (*Ceriodaphnia*), Ostracoda (*Cypridopsis*) and Malacostraca (*Stygobromus*).

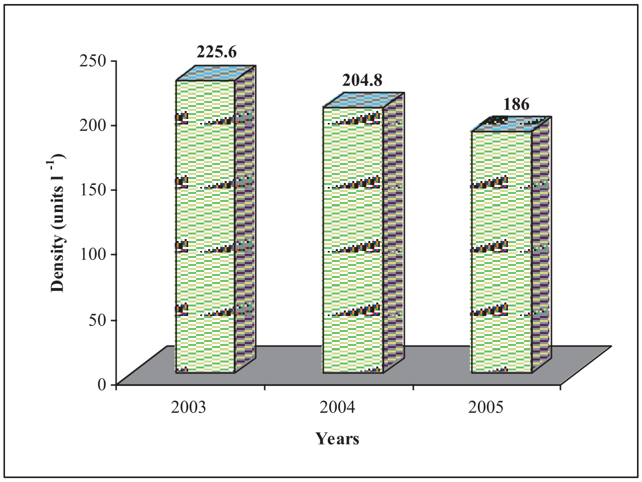



Figure 4. Impact of transportation network on the annual mean density (units $l^{-1}$) of hyporheic microzoobenthos inhabiting Upper Ganges over a period of three-year (18 percent decrease).

Alpha diversity of hyporheic microzoobenthos dwelling in Upper Ganges decreased from 16.83 to 15.83 (6% decrease) and the Shannon Wiener index ($\bar{H}$) decreased from 2.73 to 2.53 (7% decrease) due to the deleterious impact of transportation network during a three-year period. Concentration of dominance (C) did not show any change in hyporheic microzoobenhos (table 3).

Table 3: Mean monthly variations in Alpha diversity, Shannon Wiener diversity index ($\bar{H}$) and concentration of dominance (C) of hyporheic microzoobenthos dwelling Upper Ganges caused by transportation network during a three-year period (January 2003- December 2005)

| Month | Alpha Diversity | | H' | | C | |
|---|---|---|---|---|---|---|
| | 2003 | 2005 | 2003 | 2005 | 2003 | 2005 |
| January | 19 | 19 | 2.90 | 2.72 | 0.05 | 0.05 |
| February | 19 | 19 | 2.88 | 2.70 | 0.05 | 0.05 |
| March | 19 | 18 | 2.87 | 2.69 | 0.05 | 0.05 |
| April | 19 | 17 | 2.87 | 2.69 | 0.05 | 0.05 |
| May | 19 | 17 | 2.81 | 2.65 | 0.05 | 0.07 |
| June | 13 | 13 | 2.51 | 2.25 | 0.08 | 0.08 |
| July | 14 | 12 | 2.30 | 2.14 | 0.08 | 0.04 |
| August | 14 | 13 | 2.26 | 2.10 | 0.04 | 0.04 |
| September | 15 | 14 | 2.51 | 2.30 | 0.05 | 0.04 |
| October | 16 | 15 | 2.85 | 2.71 | 0.05 | 0.05 |
| November | 17 | 16 | 2.90 | 2.72 | 0.05 | 0.05 |
| December | 18 | 17 | 2.92 | 2.72 | 0.05 | 0.05 |
| **Annual ($\bar{X}$)** | **16.83** | **15.83** | **2.72** | **2.53** | **0.05** | **0.05** |

A detrimental impact on the hyporheic macrozoobenthos of upper Ganges was also observed. Annual mean density of hyporheic macrozoobenthos declined from 419.2 ± 124.1 n. $m^{-2}$ to 240 ± 116.9 n. $m^{-2}$, a decrease of 43% as consequence of transportation network during a three-year period (figure 5). Hyporheic macrozoobenthos of natural environment of upper Ganges were represented by seven genera (*Ecdyonurus, Rhithrogena, Ephemerella, Caenis, Baetis, Heptagenia and Cloeon*) of Ephemeroptera, nine genera (*Hydropsyche, Psychomyia, Polycentropus, Leptocella, Glossoma, Hydroptila, Rhyacophila, Limniphilius and Mystacides*) of Trichoptera, eleven genera (*Chryogaster, Philorus, Tendipes, Limnophora, Forcipomyia, Pentaneura, Tabanus, Simulium, Dixa, Atherix and Antocha*) of Diptera, three genera (*Psephanus, Heterlimnius, Dinutes*) of Coleoptera, four genera (*Architestes, Octagomphus, Epicordula*, and *Symptrum*) of Odonata and two genera (*Perla* and *Isoperla*) of Plecoptera. Most of the members of hyporheic organisms, sensitive to disturbance were completely missing at the impacted sites.

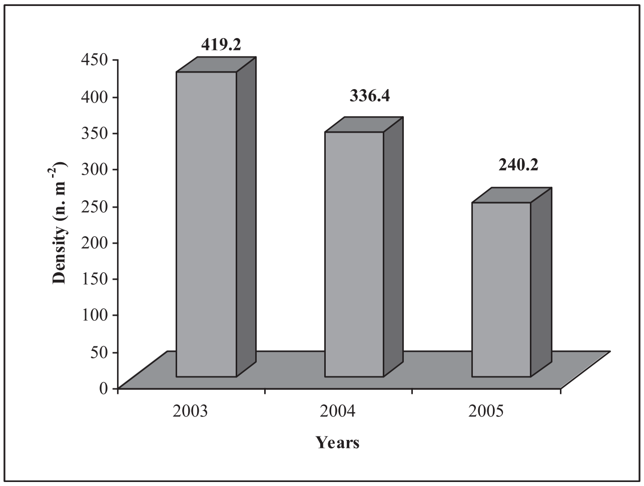



Figure 5. Impact of transportation network on the annual mean density (n. $m^{-2}$) of hyporheic macrozoobenthos inhabiting Upper Ganges over a three-year period (43 percent decrease).

Alpha diversity of hyporheic macrozoobenthos inhabiting Upper Ganges decreased from 16.0 to 9.58 (38% decrease) and Shannon Wiener index ($\bar{H}$) reduced from 2.35 to 2.01 (9% decrease) as a consequence of transportation network during a period of three-year. Concentration of dominance (C) of hyporheic macrozoobenthos increased during a period of three-year as a consequence of construction and widening of roads along the Upper Ganges (table 4).

Table 4: Mean monthly variations in alpha diversity, Shannon Wiener diversity index ($\bar{H}$) and concentration of dominance (C) of hyporheic macrozoobenthos dwelling Upper Ganges caused by transportation network during a three-year period (January 2003-December 2005)

| Month | Alpha diversity | | | | C | |
|---|---|---|---|---|---|---|
| | 2003 | 2005 | 2003 | 2005 | 2003 | 2005 |
| January | 22 | 12 | 2.85 | 2.30 | 0.07 | 0.13 |
| February | 22 | 12 | 2.81 | 2.28 | 0.07 | 0.14 |
| March | 16 | 10 | 2.36 | 2.04 | 0.12 | 0.15 |
| April | 16 | 10 | 2.43 | 2.10 | 0.11 | 0.14 |
| May | 14 | 09 | 2.15 | 1.77 | 0.15 | 0.22 |
| June | 13 | 09 | 1.98 | 1.71 | 0.19 | 0.24 |
| July | 12 | 08 | 1.81 | 1.61 | 0.14 | 0.24 |
| August | 10 | 07 | 1.51 | 1.45 | 0.10 | 0.18 |
| September | 14 | 08 | 2.30 | 2.14 | 0.11 | 0.10 |
| October | 15 | 09 | 2.50 | 2.20 | 0.10 | 0.11 |
| November | 17 | 10 | 2.65 | 2.25 | 0.09 | 0.13 |
| December | 21 | 11 | 2.80 | 2.27 | 0.07 | 0.12 |
| **Annual ($\bar{X}$)** | **16.00** | **9.58** | **2.35** | **2.01** | **0.11** | **0.16** |

**Cumulative and Synergistic Impacts**

Cumulative and synergistic impacts are generally the consequences of single impact, multiple interrelated impacts or multiple unrelated direct and indirect impacts. In all cases, individual impacts cannot be considered in isolation, but rather must be seen as components of the more serious cumulative or synergistic effects. Prediction of cumulative and synergistic impacts is difficult because of uncertainties regarding the interrelationships of individual impacts (Spaling and Smith 1993; Lawrence 1994; Bedford and Preston 1996; CEAA 1998). The cumulative and synergistic impacts of transportation network on the hyporheic organisms and the physico-chemical environment of the vulnerable and fragile hyporheic biotope of upper Ganges was seen in the form of impairment of ecosystem function and loss of biodiversity under ecological stress. Overall quality of surface water and ground water was also degraded due to shrinking of population of hyporheos of upper Ganges as a consequence of construction, widening and repairing of roads and highways along the Holy River. Consequences of transportation network on hyporheic zone of upper Ganges in terms of primary, secondary and cumulative effects have been depicted in figure 6.

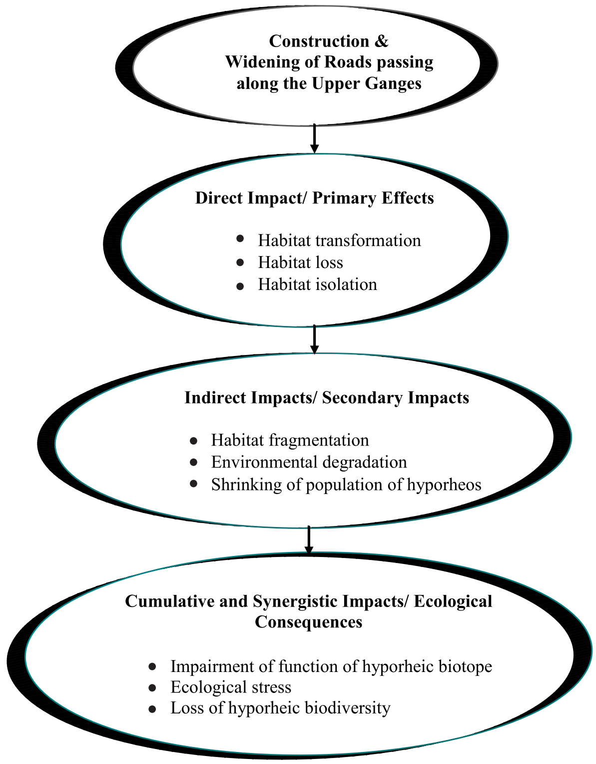



Figure 6. Consequences of construction and widening of roads in terms of direct, indirect and cumulative impacts on hyporheic organisms.

The environmental degradation of hyporheic zone and decline in quantity and missing of sensitive hyporheic organisms are believed to have been caused by increase in water temperature, turbidity, total dissolved solids and biological oxygen demand, accumulation of fine silt and suspended solids blocking interstitial spaces in the hyporheic zone of upper Ganges, Garhwal Himalaya. In order to protect and restore hyporheic biotope for hyporheos survival, the complex inter-relationships between hyporheic organisms and their habitat must be understood.

The construction of roads affects soil and land stability. Instability tends to be most pronounced in hilly areas where geological features exacerbate construction related destabilization. Creation of steep cuts in rapidly weathering rock, removal of basal support of slopes, loading of unstable surfaces, inadequate drainage provisions, removal of  and vibrations from blasting and traffic may lead to slope failure and erosion (Sharma 2003).

Considerable research has established that most pervasive threats to biological diversity involve roads (World Bank 1997). There have been extensive studies done on the impacts of roads on the environment (Oxley et al 1974; Oxley and Fenton 1976; Waechter 1979; Clevenger 1998; Bryon 1999; Clevenger *et al*. 2002). They have concluded that roads can be a serious threat to the maintenance of biological diversity. Erosion from poorly constructed and inadequately rehabilitated sites can lead to downstream siltation, ruining aquatic life. Serious impacts can occur because of the disruption and outright removal of streambed habitats. According to Jackson (2003) the linear ecosystems, rivers and streams are particularly vulnerable to fragmentation caused by road construction. According to him little consideration is given to ecosystem processes such as natural hydrology, sediment transport and the movement of woody debris.

Aquatic ecosystems are dynamic assemblages supported by the interaction of physical, chemical and biological features within the environment. Biota within these ecosystems exhibit specific tolerances and limitations to various physico-chemical conditions of the environment they inhabit (Brookens *et al*. 2003). According to Armantrout (2001) anthropogenic pressure on river in turn affect the inhabiting biological communities which disturb the ecological balance of nature. The effects of construction of the M11 motorway in Essex, U.K were studied by Extence (1978). The macro invertebrate communities above and below the entry of motorway run-off became progressively dissimilar over the study period. Certain groups such as stoneflies, mayflies and caddis flies, were largely absent at the outset. These studies show that the high suspended solids carried by run-off during civil engineering operations can have a marked effect on the ecology of the received stream.

Ward and Voelz (1990) suggested that site specific geomorphic features are important in structuring the hyporheic communities of alluvial rivers. Creue des Châtelliers and Regrobellet (1990) also hypothesized a link between geomorphological and hydrological processes and the distribution and abundance of hyporheic organisms. Thus, it is very much clear about the consequences of construction, widening and repairing of roads and highways passing along the upper Ganges in terms of environmental degradation and shrinking of population of hyporheos.

## Habitat Restoration and Mitigation Measures

Habitat management of hyporheic biotope integrates the management of entire watersheds. Sustaining an optimum balance of surface water and ground water contribute to aquatic habitats controlling erosion of sediments and nutrients. The adverse impacts of environmental change on hyporheic organisms have been cumulative and interactive. Predictive understanding and effective management requires a more holistic ecosystem approaches. Recovery of ecosystem 'integrity', the most appropriate means for obtaining optimum sustained benefits has gained considerable credence. Aquatic habitat enhancement should be undertaken integrating the natural channel design techniques; aquatic vegetation restoration techniques and more traditional hydraulic and channel design engineering practices (Welsch, 1992; Nyman, 1998, 2003).Development of mountain specific and sustainable infrastructure in mountain areas require multidisciplinary inputs (Deoja 1994). As mountain ecosystem is characterized by temperate climate with large daily and seasonal variations in temperature and often harsh growing conditions. Mountain ecosystems tend to be less resistant than those that do not experience such harsh conditions and extremes, therefore, the impacts on mountains are generally longer lasting. Protecting and restoring hyporheic habitats of upper Ganges, the holy river of Indians, has become a priority, as Ganges water is considered sacred by Indians. Therefore, we have recommended the following mitigation measures to restore habitat quality and protection of hyporheic organisms:

### 'Functional Habitat' Recovery

River restoration is a complex science, combining hydrology, geomorphology and ecology. It has so far only been applied in such an integrated fashion to a few sites in Europe (Brookes 1995). 'Functional habitat' is a tool for evaluating the heterogeneity of existing rivers. It is a core biotope in river channels which controls the function of the entire ecosystem. It contains a distinct macro-invertebrate assembly and that habitat diversity controls biodiversity. The concept of a suite of 'functional habitat' in the river channels was introduced in U K in 1991.Impairment of 'functional habitat' may lead to the collapse of the entire ecosystem. Therefore, the recovery of 'functional habitat' in upper Ganges is very important. 'Functional habitat' recovery in the Upper Ganges is possible by physical reconstruction in terms of widths, depths, velocities and channel edges (which are readily achievable by technical means) based on geomorphological principles for maintaining the habitat diversity.

### Removal of Obstructions

Fine silt and suspended solids are accumulated in the interstitial spaces of hyporheic biotope, resulting in the choking of natural circulation of water in the interstitial spaces of hyporheic zone of upper Ganges. Suspended sediments can be traced to road construction source. Dredging out gravel mining is one of the important ways for removing obstruction and restoration of the impacted sites. Dredging also maintains the width, depth and flow of water and prevents from clogging with silt.

### Restoration of Riparian Corridor

Riparian vegetation, stream bank geomorphology, overhanging vegetation, undercut banks and hill slope vegetation of Upper Ganges have been drastically altered by the muck generated by the construction, widening and repairing of roads passing along the Upper Ganges. Riparian vegetation moderates stream temperature provides habitat cover and helps in stabilizing embankments. Maintaining proper amount of herbaceous vegetation is a critical part of increasing sediment deposition and enhancing channel restoration in hill stream system (Clary and Thornton 1996). Afforestation of hill slopes is instrumental for reducing the capacity of weathering and erosion caused by transportation network.

### d. Erosion Mitigation

Erosion of stream banks can be minimized through ecological and engineering approaches (Howell 1999; Sharma 2005). The following practices should be taken into consideration in the mountain areas:

- Grading slopes appropriately to provide traps for eroding debris;
- Strengthening the bases of slopes through enlargement of the toe of the rock to be slid;
- Securing steep cut slopes by the use of reinforcing structure at their bases;
- Construction of restoration walls to prevent mass movement of soil; and
- Netting exposed slopes with coir, jute or synthetic geotextile, followed promptly by revegetation by fast growing non palatable species suitable to climatic conditions of the site.

### Perforated Roadbeds

Groundwater flows and surface water flowing in rivers, streams and intermittent channels are frequently interrupted by road corridors or roadbeds. So, the common solutions are bridges, culverts and porous road bed material (Stoeckeler, 1965; Brown, 1982; Gilje, 1982; Swanson *et al.*, 1988; Forman and Deblinger, 2000). Excessive drainage may lead to a lowered water table and spread of wetlands on the upslope side, while down slope the water table drops. Pea stream flows may also rise where roads intercept groundwater and channelize the water into surface flow (Jones and Grant 1996, Wemple *et al.*, 1996). Therefore, a perforated road bed with an abundance of water crossing location, rather than a few major crossings, normally would better mimic natural flows as well as the resulting hyporheic habitats of upper Ganges. Early failures of toe walls due to heavy precipitation in monsoon season (July-August) are very common in Uttarakhand. Therefore, several big culverts and check dams are being constructed for proper drainage throughout the length of roads and highways passing along the Upper Ganges (figure 7).

Figure 7. Construction of big culvert and check dam for proper drainage throughout the length of the road passing along the Upper Ganges.

### Sealing of Side Drains

Sealing of side drains is an effective mechanism against water penetration into the underground alongside endangered sections of the road. Side drains should be discharged only into natural brooks, rivulets, rivers and side drain of the road. Steep gullies carrying an increased water volume due to road water discharge should be protected by check dams as far down as necessary to avoid depth and slide erosion of the river bed.

### Principle of Minimum Flow in River

Defining minimum stream flow requirements presents one of the top problems of aquatic biodiversity and water management almost all over the world. In Garhwal Himalaya, stream regulations during the last decade as well as increasingly intensive water uptakes for hydropower projects in addition to obstruction created by road construction in rivers and receding of Himalayan glaciers due to global warming contributed to the need of a new approach to maintain the minimum flow in the upper Ganges. Transportation network along the upper Ganges has caused a massive geomorphological transformation in the Bhagirathi and Bhilangana ecosystems. For the protection of the hyporheic organisms from the intensive sedimentation of suspended solids, a minimum flow of 25 cm of hydromedian depth is required throughout the year in upper Ganges.

### Sustainable Mountain Specific Road Construction

Development of mountain specific sustainable approaches for construction, widening and repairing of roads in Garhwal Himalayas requires multi-disciplinary inputs based on geological engineering (geo-environmental appraisal of the area in terms of slope stability, likely and debris flow material, avoiding construction of roads on the old paleochannels), socio-economic and environmental factors. Mountain specific design and approaches require access to comprehensive knowledge of geology, geo-tectonic, civil engineering, environmental biology and economic analysis.

**Acknowledgements:** I am pleased to acknowledge the financial support by the organizers of ICOET 2007 and the important role of K.P. McDermott, Director, Technology Transfer, CTE, NC State University, Raleigh, USA, in enabling me to contribute to the ICOET 2007.

**Biographical Sketch:** Professor Sharma has a distinguished academic career. He passed his graduation with Zoology Honours and obtained a masters degree in Zoology with Freshwater Fishery Biology. He obtained his doctorate (D. Phil.) and Doctor of Science (D. Sc.) in Environmental Biology. He has a wide experience of teaching and research for more than thirty two years on environmental monitoring, bioenergetics, biodiversity and transportation ecology in the Himalayas. More than 14 research projects have been completed on these aspects. Twenty three doctoral research students have been conferred to doctoral degrees and seven more students are engaged in research under his supervision. He has sufficient professional experience and exposure by way of visiting and working at different research laboratories in India and abroad (USA, Sweden, Poland, Czech Republic and Canada). He has published more than 114 research articles in the journals of international repute. He has been conferred several awards and gold medals (NATCON Environment Gold Medal 2001,

Zoological Society of India Gold Medal 2001, Environmentalist of the Year Award 2003, Recognition Award Gold Medal 2004, Indira Gandhi National Environment Award 2005). He is a fellow of many national and international societies. Currently, he is Professor and Chairman, Department of Environmental Sciences, H.N.B. Garhwal University, Srinagar-Garhwal, Uttarakhand, India.

## References


APHA 1998. *Standard Methods for the Examination of Water and Wastewater*. 20th edition. American Public Health Association, New York.

Armantrout, N.B. 2001. Aquatic habitat inventories using remote sensing. *Ecohydrology and Hydrobiology.* 1 (1-2): 117-132.

Bedford, B.L. and E. Preston (eds). 1996. *Cumulative Effects on Landscape Systems and Wetlands: Scientific Status, Prospects and Regulatory Perspectives*. Springer International, New York.

Bretschko, G. and W. Klemens, 1986. Quantitative methods and aspects in the study of the interstitial fauna of running waters. *Stygologia*. 2: 279-316.

Brookens, A., T. Schmidt, R. Morgan, M. Kline, K. Kline, and D. Gates. 2003. Restoration of an upper land water ecosystem in western Maryland utilizing passive treatment technology. *Proceedings of International Conference on Ecology and Transportation*, Lake Placid 2003.

Brookes, A. 1995. Challenges and objectives for geomorphology in UK river management. *Earth Surface Process and Landforms*. 20: 593-610.

Brown, S.A. 1982. Prediction of channel bed grade changes at highway stream crossings. *Transportation Research Record*. 896: 1-11.

Bryon, H. 1999. *Biodiversity and Environmental Impact Assessment of Road Schemes. Guidelines on a Systematic Approach*. Environmental Policy and Management Group. Imperial College of Science, Technology and Medicine, London, UK.

CEAA 1998. Cumulative Effects Assessment Practioner's Guide. Canadian Environmental Assessment Agency (CEAA), Ottawa, Canada (www.ceaa.gc.ca).

Clary, W.P. and S.R.Thornton. 1996. Riparian stabble height and recovery of degraded streambanks. *Rangelands*. 18: 137-140.

Clevenger, A.P. 1998. *Effect of Highways and Other Linear Transports on Wildlife Populations*. Literature Collection in Papyrus TM 7.0 Bibliography System.

Clevenzer, A.P., B. Chruszcz, K. Guson, and J. Wierzchowski. 2002. *Roads and Wildlife in the Canadian Rocky Mountain Parks- Movements, Mortality and Mitigation*. Final Report for Parks in Canada.

Clinton, S.M. and R.T. Edwards. 2000. Hyporheic flows in a riparian terrace of a coastal temperate rainforest river. *International Conference on Riparian Ecology and Management in Multilanduse Watersheds*. American Water Resources Association. 173-178.

Creuze des Chatelliers and J.L. Regrobellet, 1990. Interactions between geomorphological processes, benthic and hyporheic communities: First results on a bypassed canal of the French Upper Rhone River. *Regulated Rivers: Research and Management*. 5: 139-158.

Deoja, B.B. 1994. *Sustainable Approaches to the Construction of Roads and Other Infrastructure in Hindu Kush Himalayas*. ICIMOD Occasional Paper No. 24: 1-69.

Edwards, R.T. 1998. The hyporheic zone In: *River Ecology and Management*. R.J. Naiman and R.E. Bilby (eds). Springer Verlag, New York USA. 399-429.

Extence, C.A. 1978. The effects of motorways construction on an urban stream. *Environ. Pollut*. 17: 245-262.

Forman, R.T.T. and R.D. Deblinger. 2000. The ecological road-effect zone of Massachussetts USA. Suburban highway. *Conservation Biology.* 114: 36-46.

Friedman, G.M. and J.E. Sanders 1978. *Principles of Sedimentology*. John Wiley and Sons, New York: 1-792.

Gilbert, J. 1991. Groundwater systems and their: conceptual framework and prospects in groundwater ecology. Verhandlunger der International *Vereingung fur Theorestiche und Angewndte Limnologie*. 24: 1605-1608.

Gilbert, J., M.J. Dole-Oiver, P. Marmonier and P. Vervier. 1990. Groundwater ecotones. In: *Ecology and Management of Aquatic-Terrestrial Ecotones*. Naiman, R.J. and H. Decamps (eds). Parthenon Publishing Carnforth. 199-225.

Gilge, S.A. 1982. Stream channel grade changes and their effects on highway crossings. *Transportation Research Record*. 895: 7-15.

Howell, J.1999. *Roadside Bioengineering*. Reference Manual, Department of Roads, HMGN.

Jackson, S.D. 2003. Ecological considerations in the design of river and stream crossings In: *Proceedings of International Conference on Ecology and Transportation*, edited by Cleroy Irwin, Paul Garrett and K.P. McDermott. Raleigh, N.C: 20-29.

Jones, J.A. and G.E.Grant. 1996. Pea flow responses to clear cutting and roads in small and large basins, Western Cascades, Oregon. *Water Resources Research*. 32: 959-974.

Kumar, G. and N.C.Aggarwal. 1975. Geology of the Srinagar-Nandprayag area, Alaknanda Valley, *Himalyan Geology*. 5: 29-59.

Lawrence, D. 1994. Cumulative effects assessment at the Project Level. *Impact Assessment*. 12: 253-273.

Nyman, D.C. 1998. Restoring naturalized streams bed in an urban river channel: Engineering approaches to ecosystem restoration. *Wetlands Engineering and River Restoration Conference*. Denver, Colorado.

Nyman, D.C. 2003. Aquatic habitat enhancement for Mad River and Beaver Pond Brook in conjunction with the reconstruction of 1-82, Waterbay, Connecticut. *Proceedings of Intenational Conference on Ecology and Transport*, Lake Placid: 92-98.

Orghidan, T. 1991. Ein neuer lebens raum des unterirdischen wassers: Der hyporheissche biotope. *Archiv fur Hydrobiologie*. 55: 392-414.

Oxley, D.J. and M.B. Fenton, 1976. The harm our roads do to nature and wildlife. *Canadian Geographic Journal*. 92(3): 40-45.

Oxley, D.J., M.B. Fenton, and G.R. Canmody, 1974. The effects of roads on populations of small mammals. *Journal of Applied Animal Ecology*. 11: 51-59.

Schowoerbel, J. 1961. Under die Lebensbdingungen Und die besidlungdes hygorheichan lebensraumi. *Archiv fur Hydrobiologie Suuplement*. 25: 182-214.

Sharma, R.C. 2003. Protection of an endangered fish Tor tor and Tor putitora populations impacted by transportation network in the area of the Tehri Dam Project, Garhwal Himalaya, India. *Proceedings of the International Conference on Ecology and Transportation*, edited by C. Lewy Irwin, Paul Garrett and K.P. McDermott, Raleigh, N.C., North Carolina State University: 83-90.

Sharma, R.C. 2005. Restoration of aquatic habitat and fish passage degraded by widening of Indian Highway 58 in Garhwal Himalaya. *Proceedings of International Conference on Ecology and Transportation*, San Diego, California, USA: 40-51.

Solbrig, O.T. 1992. The IUBS-SCOPE-UNESCO Programme of Research in Biodiversity. *Ecological Applications*. 2: 131-138.

Spaling, H. and B. Smith. 1993. Cumulative environmental change: conceptual framework evaluation approaches and institutional prospectives. *Environmental Management*. 17(5): 587-600

Sterba, O. 1990. Riccidno a samocisteni Sbor. Ref. semi Ricini dna, CSIS a geographiky. *Ustav. CSAV Brno, Kuparovice Zari*. 69-78.

Stoeckeler, J.H. 1965. Drainage along swamp forest roads: lessons from Northern Europe. *Journal of Forestry*. 63: 771-776.

Swanson, G.A.T., T.C. Winder, V.A. Adomatis and J.W. La Baugh. 1998. Chemical characteristics of Prairie lakes in South-Central North Dakota- their potential for influencing use by fish and wildlife. *Technical Report 18. US Fish in Wildlife Science*, Washington, D.C.

Valdiya, K.S. 1984. *Environmental Geology, Indian Context*. Tata McGraw Hill Pub. New Delhi.

Waechter, A. 1979. Animal morbidity on a high traffic road. *Mammalia*. 434: 577-579.

Ward, H.B. and G.C. Whipple. 1992. *Freshwater Biology*, John Wilay and Sons, New York.

Ward, J.V. and N.J. Voelz. 1990. Gradient analysis of industrial meiofauna along a longitudinal stream profile. *Stygologia*. 5: 93-99.

Welsch, D.J. 1992. *Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources*. US Department of Agriculture, Forest Science, Rodo, P.A.

Wemple, B.C., J.A. Jones, and G.E. Grant. 1996. Channel network extension by logging roads in two basins, Western Cascades, Oregon, *Water Resources Bulletin*. 32: 1195-1207.

Wetzel, R.G. and G.E. Likens. 1991. Limnological Analysis. Springer-Verlag, NewYork.

White, D.S. 1993. Perspective on defining and delineating hyporheic zones. *Journal of the North American Benthological Society*. 6: 85-91.

Williams, D.D. and H.B.N. Hynes. 1974. The occurrence of benthos deep in the substratum of a stream. *Freshwater Biol*. 4: 233-256.

World Bank, 1997. *Roads and the Environment: A Handbook*, World Bank Technical Paper No. 376. The World Bank, Washington, D.C.

# Inventory and Sediment Modeling of Unpaved Roads for Stream Conservation Planning

**Ethan Inlander** (479-973-9110, einlander@tnc.org), Ozark Rivers Project Manager, Ozark Highlands Office, The Nature Conservancy in Arkansas, Fayetteville, AR 72701, Fax: 479-973-9135 USA
**Alan Clingenpeel** (501-321-5246, aclingenpeel@fs.fed.us), Forest Hydrologist, Ouachita National Forest, P.O. Box 1270, Hot Springs, AR 71902, Fax: 501-3215334 USA
**Michael A. Crump** (479-964-7513, mcrump@fs.fed.us), Forest Hydrologist, Ozark – St. Francis National Forest, 605 West Main Street, Russellville, AR 72801 USA
**Matthew Van Epps** (501-352-5252, vanepps@watershedconservation.org), Associate Director, Watershed, Conservation Resource Center, P.O. Box 250312, Little Rock, AR 72225 USA
**Sandi Formica** (501-352-5252, formica@watershedconservation.org), Executive Director, Watershed Conservation Resource Center, P.O. Box 250312, Little Rock, AR 72225 USA

**Abstract:** The streams and rivers of the Ozark Plateaus are an unrivaled natural resource for the region. They provide habitat to some of the North America's most abundant and rich biodiversity, while also serving as water sources for human drinking, agricultural, and recreational needs. The Nature Conservancy (TNC) has identified several priority watersheds through its Ozarks Ecoregional Conservation Assessment of 2003, where it focuses its on-the ground conservation planning and implementation efforts.

Sedimentation from unpaved roads is a primary threat to water quality in Ozark streams. TNC has partnered with various organizations including the US Forest Service (USFS), the Watershed Conservation Resource Center (WCRC), and others to develop a multi-phased approach to address the impacts of unpaved roads on these priority watersheds.

The first step in the approach utilizes advanced GIS/GPS technologies to develop a detailed vehicle-based road inventory of the target watershed or subwatershed. Sub-meter differential GPS with customized data dictionaries are used to characterize the location and function of sediment-producing and conveying features of the road infrastructure, including the road surface, prism and slope, ditches, bars, lead-offs, culverts, crossings, and outlets. The road inventory yields a comprehensive geodatabase and map series of the mapped features.

A stratified random sample of the inventoried road network is then measured to generate sediment yield predictions on ten percent of the road network. Detailed field measurements are collected with differential GPS and customized data dictionaries. The data are entered into the Water Erosion Prediction Project (WEPP) model, a process-based erosion prediction model developed by multiple federal agencies over the past 20 years. With sediment yields predicted for sample sites, erosion predictions are then extrapolated for the entire study watershed using the road inventory geodatabase.

Once sedimentation yields are predicted for each road segment in the entire study area, priority sub-watersheds are identified in the GIS using watershed sediment accumulation tools. These sub-watersheds with high potential for sediment yield may be compared to species inventory data, stream bank erosion surveys, and other land use information to set priorities for conservation planning and prioritization efforts. Priority infrastructure maintenance improvements are also identified through features that were flagged in the road inventory geodatabase as needing repair or replacement.

Road maintenance workshops are held with USFS engineers, county road crews, and other partners to transfer the inventory information, present the findings of the study and to demonstrate best management practices for road maintenance.

Since 2004, TNC and its partners in the Arkansas have worked in three priority Ozark watersheds to inventory over 600 miles of unpaved roads and 3000 associated point features in an area greater than 900 square miles. The area comprises over thirty 6th level (12-digit) HUCs.

## Introduction

The Ozarks ecoregion is one of 80 physiographic ecoregions in the US. This highland ecoregion occupies nearly 14 million hectares in Missouri, Arkansas, Oklahoma, Illinois, and Kansas. Along with the Ouachita ecoregion to the south, the Ozarks form the most significant highland region in mid-continental North America. Portions of the Ozarks have been exposed for over 230 million years, making it one of the longest-exposed land masses in North America. Because of its age, position in the middle of the continent, and other factors, the Ozarks ecoregion hosts a wide diversity of terrestrial and aquatic habitats, which has led to high species diversity and endemism (TNC 2003).

The rivers and streams of the Ozarks ecoregion harbors one of the greatest concentrations of freshwater fauna in North America, including over 160 fish species. Forty-three aquatic species are endemic to the Ozarks, including 21 crayfish, 16 fish, and 6 mussels. According to the Arkansas Wildlife Action Plan, about 55% of the state's fish, crayfish, and mussel species of greatest conservation need (SGCN) occur in the Ozarks portion of the state (AGFC 2006), while it comprises less than 25% of the State's total area.

Many Ozark streams and rivers have experienced significant impacts including hydrologic alteration, habitat destruction, nutrient loading, and sedimentation (TNC 2003). These impacts have led to many Ozarks streams being placed on the US EPA Impaired Waterbody List (303(d)) (ADEQ 2004, MO DNR 2002). They have also contributed to declines in the ranges and population of many of the Ozarks' aquatic species. Sedimentation of rivers and streams is particularly detrimental. Suspended sediment loads impact aquatic habitats by filling interstitial spaces of gravel stream beds, by clogging fish gills, and suffocating eggs and benthic insect larvae.

The primary sources of sediment into Ozark streams are eroding stream banks and unpaved roads. Unpaved roads have the potential to be a significant source of suspended sediment in rural watersheds, accounting for 25% or more of the sediment load (NRCS). Even during small rainfall events, storm water runoff from unpaved roads and ditches can contribute suspended sediment to streams and creeks resulting in elevated turbidity and total suspended solids concentrations.

The Nature Conservancy's Ozark Rivers Program is working to abate sedimentation from both stream banks and unpaved roads in priority watersheds. The project presented here focuses on methods for mapping and inventorying unpaved roads, modeling sediment yield from roads and delivery to streams, and implementation strategies for best management practices on unpaved roads. This project was initiated in 2004 and is ongoing at multiple sites.

## Methods

The description of methods presented here characterizes all the types of work.

### Study Area

The Nature Conservancy (TNC) has identified several priority watersheds through its Ozarks Ecoregional Conservation Assessment of 2003 (TNC 2003). The priority watersheds in Arkansas include eight HUC-08 lever watersheds, as shown in figure 1. TNC has conducted road sedimentation work in portions of three of these priority watersheds, including the Mulberry, Kings, and Strawberry River watersheds. In the Mulberry watershed, the study area included four HUC-12 catchments in the upper watershed. In the Kings watershed, work was completed in two HUC-12 catchments that comprise the Dry Fork subwatershed. For the Strawberry River, the study area includes the entire watershed, which is comprised of 27 HUC-12 catchments.

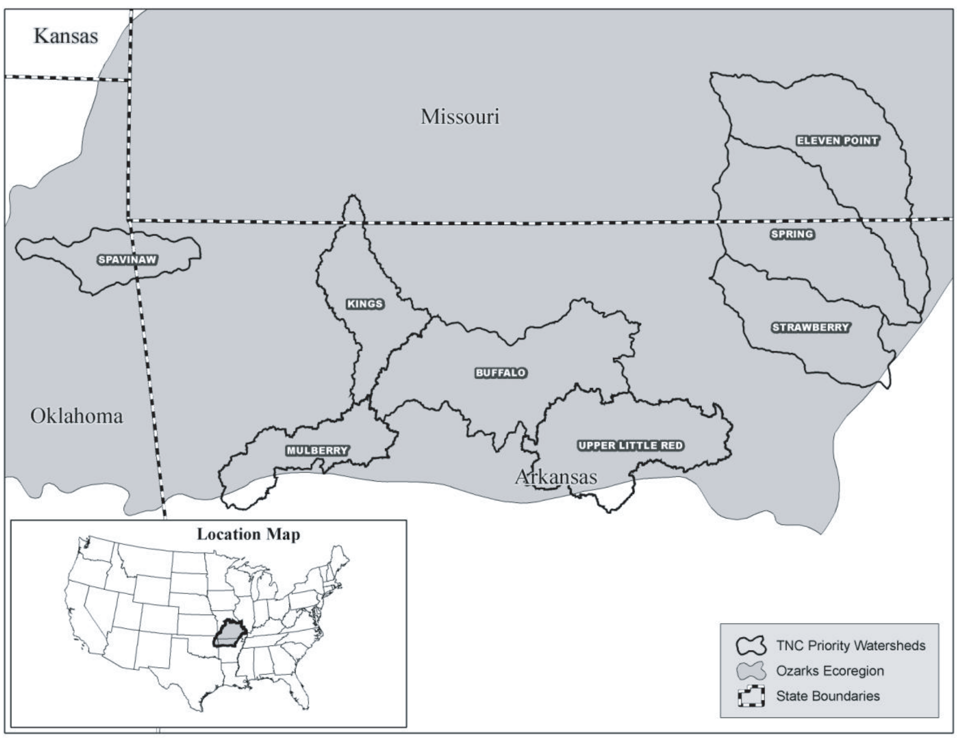



Figure 1. TNC priority watersheds in the Arkansas portion of the Ozarks ecoregion.

### Partnerships

The Nature Conservancy has partnered with several agencies and organizations to address sedimentation of Ozark Rivers from unpaved roads including the US Forest Service (USFS), the Watershed Conservation Resource Center (WCRC), and several county agencies.

### Road Inventory

The goal of an unpaved road inventory was to map the position and accessibility of roads, to document the sediment-related characteristics and conditions of the roads, and to document other road features such as stream crossings. Inventory generally occurred on all accessible, public unpaved roads outside of city limits. The road inventory methodology was initially developed by the USFS. TNC personnel were trained in the methodology by staff from the WCRC.

*Equipment*

The primary data collection tools for road inventory were Trimble GeoExplorer series units, which are Pocket PC Windows based field computers that are integrated with high-accuracy differential GPS receivers. Two models were used, including the GeoXT (sub-meter GPS accuracy) and the GeoXM (2 to 5 meter accuracy). These field computers have small color screens measuring about 6cm by 8cm (2” by 3in). Trimble TerraSync was the primary software used for mapping on the Trimble units. An external patch antenna was mounted to the top of the survey vehicle.

Recently, an advanced Vehicle Geographic Information System (VeGIS) setup was implemented for road inventory data collection. A Laptop PC was used to run TerraSync for data collection, with a GeoXT serving as an external GPS receiver. A 36cm (15”) touch screen LCD monitor was linked to the laptop and was mounted in the front passenger seat. See figure 2. This setup allowed for more efficient data collection and reduced mapper fatigue in comparison to using the small Trimble unit alone.

Figure 2. The VeGIS data collection system.

*Ancillary GIS Database*

The Inventory process was initiated by first developing a GIS database of relevant, existing, ancillary data layers such as road centerlines (from Arkansas Department of Highways and Transportation (AHTD) or USFS), stream channels (USGS NHD), jurisdictional boundaries (cities, counties, nation forest), topographic contours, and aerial photography background images. The database was used to identify total road miles and estimate the time it would take to complete the inventory. Plotted large-format maps were developed from the GIS database to aid in inventory planning and field navigation. Road layers were exported and placed into TerraSync as background files for aid in navigation.

*GPS Data Dictionary*

A data dictionary is a form within the Trimble TerraSync GPS software that allowed the mapper to enter descriptive attributes about a feature that is being mapped with the GPS. Custom data dictionaries were adopted from the USFS road inventory methodology, and were modified to incorporate new findings and techniques. The dictionaries were modified in the office using Trimble Pathfinder Office software, or in the field using TerraSync.

The data dictionary used for road inventory allows the user to collect a variety of features including line features representing road segments, and point features representing stream crossings, crossdrains, dips, wing ditches (lead-off ditches), road barriers, and others. See figure 3 below. Road segments were collected while the vehicle was moving at a logging interval of 15 meters (50’). Point features were collected with the vehicle stopped, the location of the point was averaged from at least five GPS positions.

| Type | Feature Name |
|---|---|
| | Road Segment |
| | Wing ditch |
| | Crossdrains |
| | Bridge (Box) Xing |
| | Culvert Stream Xing |
| | Slab Stream Xing |
| | Ford Stream Xing |
| | Road Barrier |
| | Untraveled Rd Inters |
| | Surface Deformation |
| | Location of Concern |
| | Photograph |
| | Point_generic |
| | Line_generic |
| | Area_generic |

Figure 3. Data dictionary feature types.

*Road Segments*. GPS line features representing road segments were usually collected at a speed of 8 to 30 km per hour (5 to 20 mph). Attributes of the road segment entered into the data dictionary include characteristics of the road surface, material, condition, ditch erosion and protection, and maintenance needs. The attributes collected and their default values are shown in figure 4. Attributes such as prism slope and ditch erosion depth were used in later sediment modeling efforts. If the mapper observed a change in the attributes of a road, the road feature was segmented in the GPS, and changes were applied to the new road segment in the attribute values of the data form. Road features with obvious sediment or maintenance issues were attributed with a moderate or high priority for later focus.

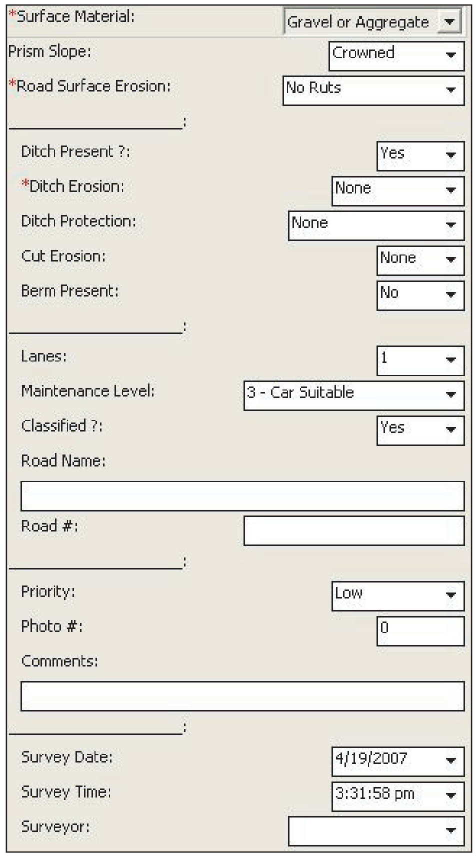

*Surface Material: Gravel or Aggregate
Prism Slope: Crowned
*Road Surface Erosion: No Ruts
Ditch Present ?: Yes
*Ditch Erosion: None
Ditch Protection: None
Cut Erosion: None
Berm Present: No
Lanes: 1
Maintenance Level: 3 - Car Suitable
Classified ?: Yes
Road Name:
Road #:
Priority: Low
Photo #: 0
Comments:
Survey Date: 4/19/2007
Survey Time: 3:31:58 pm
Surveyor:

Figure 4. Data form for road segments.

*Water-Routing Features*. Water-routing features of the road infrastructure were inventoried and represented as points. These features were characterized with the vehicle stopped, but the mapper did not generally exit the vehicle to collect these features. These features include wing ditches (also known as lead-off ditches), dips, bars, and crossdrains. These features route water off of the road surface, out of the road ditches, or from one side of the road to the other. The position function, and maintenance requirements of these features was attributed. See figures 5a and 5b below.

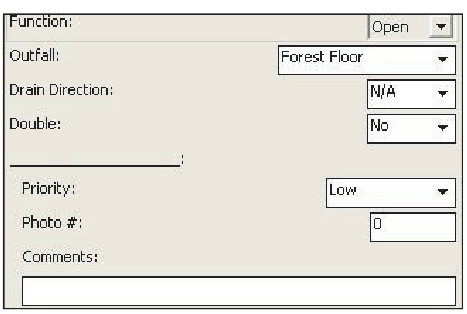

Function: Open
Outfall: Forest Floor
Drain Direction: N/A
Double: No
Priority: Low
Photo #: 0
Comments:

Figure 5a. Data form for wing ditches.

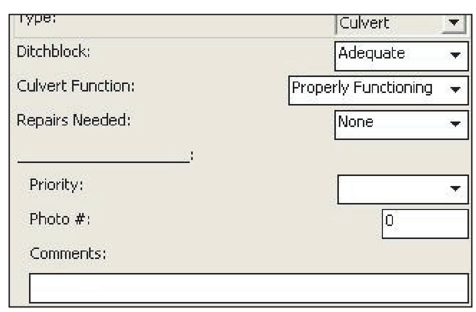
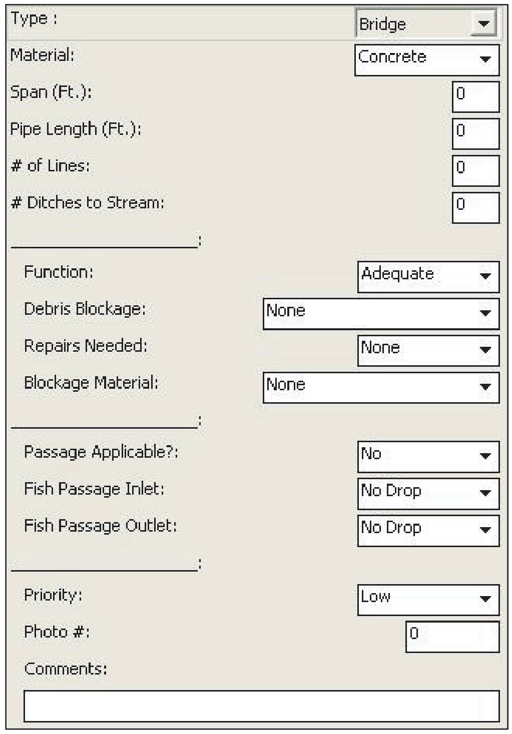

Type: Culvert
Ditchblock: Adequate
Culvert Function: Properly Functioning
Repairs Needed: None
Priority:
Photo #: 0
Comments:

Figure 5b. Data form for crossdrains.

*Stream Crossings*. All stream crossings that were encountered were inventoried by storing a point feature with appropriate attributes. Generally, the driver would exit the vehicle to inspect the crossing characteristics, and convey them verbally to the mapper, who would enter them into the GPS. Stream crossings were categorized into five major types: bridge, box culvert, pipe culvert, slab, and native ford. All five point types had similar attributes, and the data form for bridge (box) crossing is shown below in figure 6. The attributes included the general structural dimensions, the function and maintenance needs, and simple fish passage characteristics.



Type : Bridge
Material: Concrete
Span (Ft.): 0
Pipe Length (Ft.): 0
# of Lines: 0
# Ditches to Stream: 0
Function: Adequate
Debris Blockage: None
Repairs Needed: None
Blockage Material: None
Passage Applicable?: No
Fish Passage Inlet: No Drop
Fish Passage Outlet: No Drop
Priority: Low
Photo #: 0
Comments:

Figure 6. Data form for bridge (box) crossings.

*Surface Deformations*. Areas with significant surface deformations such as potholes and washboard were characterized when encountered. These were documented from within the vehicle. Other problem areas, such as locations that needed improved road infrastructure were documented. Figure 7 shows a location which was documented because sediment production might be reduced if a crossdrain were installed.

Figure 7. A location where a cross drain is needed to reduce sediment production.

*Road Barriers*. Road barriers and untravelled road intersections were documented as point features. Road barriers included gates, cables, and other intentional barriers, as well as impassible roads such as ATV/OHV trails and dangerous stream crossings. Untravelled road intersections were stored at locations such as private road entrances. The purpose of storing these features was to document reasons for not traveling roads that were shown maps and GIS datasets.

*GPS Data Processing*

Once the field effort for a road inventory was completed, GPS data files were differentially corrected in Trimble Pathfinder Office software. Pathfinder searches the internet to find the closest available base station for differential correction of files. This process generally improves the spatial accuracy of the collected data to reduce errors to less that one meter on GeoXT units and two to five meters on the GeoXM units.

Because data were stored in many files (usually two files per day per mapper, with multiple mappers working at a time) the differentially corrected data files were merged into single files when possible in Pathfinder. The merged files were then exported to ESRI shapefile format in Pathfinder. A shapefile was created for each feature type. These shapefiles were then converted to feature classes in an ESRI geodatabase.

Various edits were made to the feature classes in ArcMap. Many errors occurred in the road feature representations when GPS signals were temporarily lost or weakened. Such disruptions would cause “zig-zagging” and other errors in the line representations. The lines representing two roads at a road intersection were often not snapped to each other. Point features collected in the field were often collected slightly away from the road line. Manual editing and topological rules were implemented to straighten erroneous road lines, snap roads at intersections, and snap point features to the road network. The edited geodatabase represented the completion of the road inventory process. Maps and spreadsheets of the various inventoried features were also generated.

**Sediment Modeling**

Sediment modeling tools were implemented to estimate the sediment production from inventoried roads reaching streams. A sub-set of the inventoried roads were randomly selected for sediment modeling. Field measurements were taken on these roads for input into the sediment model. The sediment model was run for sample road segment. Sediment model results were then extrapolated to all inventoried roads.

*WEPP: Road*

The Watershed Erosion Prediction Project Road (WEPP:Road) model (Elliot et al 1999) is a USFS internet-based interface to the Agricultural Research Service’s (ARS) Water Erosion Prediction Project (WEPP) soil erosion model (Flanagan and Livingston 1995). The WEPP:Road model allows the user to predict runoff and sediment yield from a road segment into a nearby stream.

The data inputs for WEPP: Road include weather characteristics, soil texture, road design, road surface, traffic level, and dimensions of the road, fill and buffer. Data are entered into the interface and a report is produced that shows the estimated sediment yield from the road in units of tons/mile/year. It also estimates how much of that sediment will actually reach the stream. The data inputs for WEPP:Road are shown in the internet interface in figure 8. A WEPP: Road Batch tool is also available to run multiple road segments at a time.

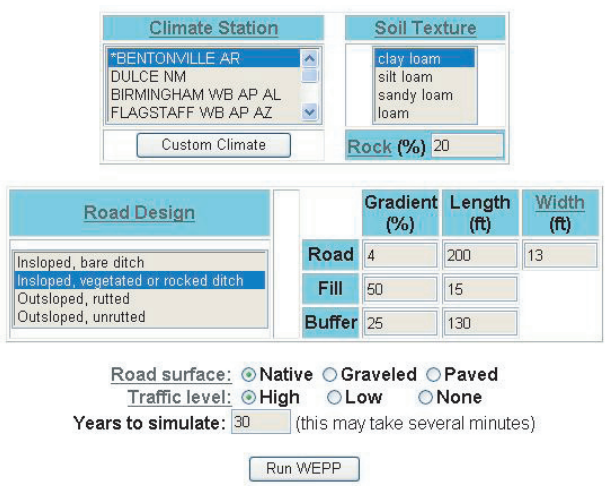



Figure 8. WEPP: Road Internet Interface

*Sampling Design*

In each of the three project areas, about 10% of the inventoried road segments were selected for WEPP: Road modeling. A stratified random sampling design was implemented that would capture the range of inventoried road types. USGS 10-meter and 30-meter digital elevation models (DEM) were used in ArcGIS to assign slope values to all inventoried road segments. SSURGO soils data were incorporated to account for the variations in soil texture across the study areas. Microsoft Excel was used to select random segments across a stratification of slope classes, soil types, road designs and road surface characteristics. The road segments selected for WEPP:Road modeling were plotted on large-format maps and loaded into the Trimble GPS units as background files for navigation to the sites.

*Equipment*

Field measurements of length, width, and slope were made on each road segment. Length was generally collected with a laser range finder. Width was generally collected with a logger’s tape measure. Gradient was made with a clinometer. During early efforts, collected data were entered onto a paper data sheet. In 2006, a Trimble data dictionary was developed to collect and store WEPP:Road field data. The dictionary is shown in figure 9.

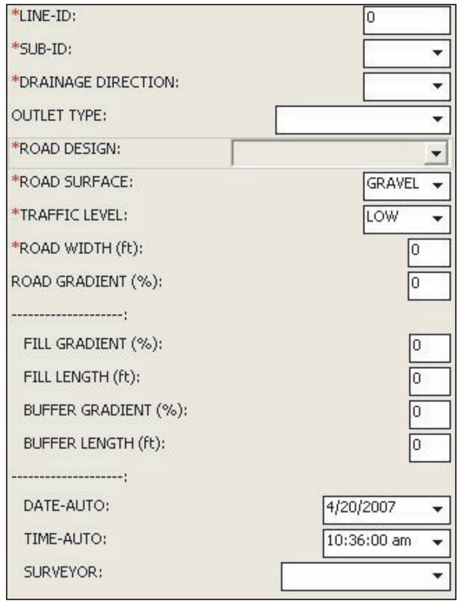

*LINE-ID: 0
*SUB-ID:
*DRAINAGE DIRECTION:
OUTLET TYPE:
*ROAD DESIGN:
*ROAD SURFACE: GRAVEL
*TRAFFIC LEVEL: LOW
*ROAD WIDTH (ft): 0
ROAD GRADIENT (%): 0
--------------------:
FILL GRADIENT (%): 0
FILL LENGTH (ft): 0
BUFFER GRADIENT (%): 0
BUFFER LENGTH (ft): 0
--------------------:
DATE-AUTO: 4/20/2007
TIME-AUTO: 10:36:00 am
SURVEYOR:

Figure 9. Data form for collecting WEPP: Road field data.

*WEPP: Road Field Data Collection*

WEPP: Road data were generally collected with teams of two or three people.  Maps and GPS background files were used to navigate to the selected road segments for field measurements. For WEPP:Road modeling, a road segment was subdivided into individual hydrologic draining surfaces.  For example, a sub-segment of a road might include the road from a local ridge down to a creek crossing where water is leaving the road.  Another example would be a road sub-segment extending from a local topographic high to a wing ditch that routes water off the road.  A third example is a crowned road.  Each half of the road is measured as a distinct sub-segment because the water is exiting the road surface in different directions.   See Figure 10 for a schematic example of road sub-segments.Measurements were taken for the road surface itself, and the fill material.  Buffer characteristics of distance and gradient from the road to the stream were measured in ArcGIS using air photos, NHD streams, topographic streams, and roads data.

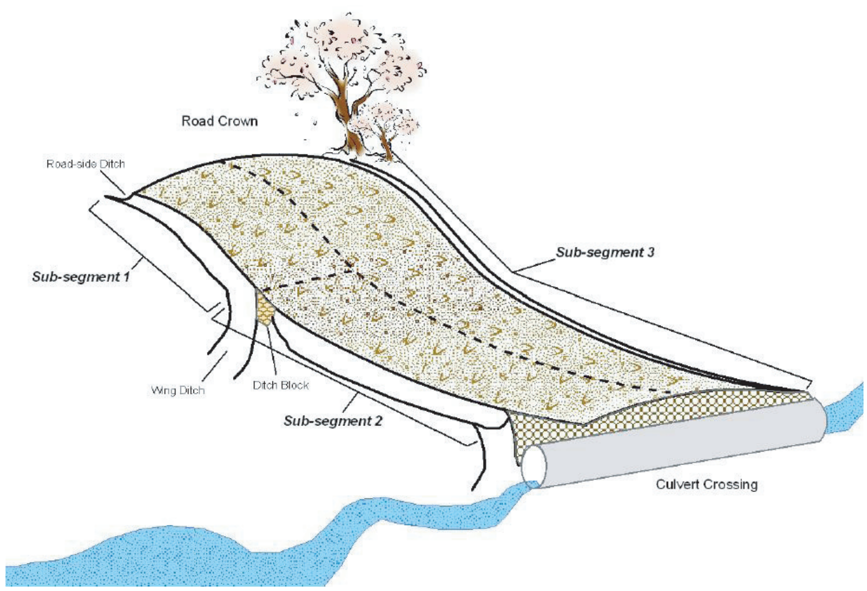



Figure 10. Schematic of road-sub-segments for WEPP: Road modeling.

*WEPP: Road Data Processing and Modeling*

Field data were transferred from paper datasheets or GPS files into Excel spreadsheets in the appropriate format for WEPP: Road Batch. As stated above, buffer characteristics were interpreted in GIS, and added to the Excel spreadsheet. The data were then run through the WEPP: Road Batch internet interface. WEPP: Road sediment yield results from modeled roads were extrapolated to all inventoried roads within the study areas, based on the road characteristics.

## Implementation

*Road Maintenance Workshops*

The primary mechanism for implementing road maintenance improvements to date has been to hold training and demonstration workshops. USFS road engineers, County officials and road crews, other agency personnel, and private landowners were invited to attend these two-day workshops. The first day of the workshop typically included an introduction to unpaved roads as sediments sources, river hydrology and ecology. A presentation of the road inventory and sediment modeling process was also shown. This was fallowed by a discussion of best management practices (BMP) for road construction and maintenance for reducing sediment yields to streams. The second day of workshops generally involved field demonstrations for installing BMP structures and materials at priority sites that were identified through the road inventory process. Recently TNC has received grants to implement road maintenance BMPs in several locations in Arkansas.

## Results

### Road Inventory

From October 2004 to present (April 2007), over 1,200 kilometers of unpaved road and over 5,000 point features have been inventoried in three Ozark watersheds in Arkansas. Table 1 shows the total length of road and the total number of point features inventoried as of December 2006.

Table 1: Summary of Road Inventory through 2006

| Watershed: | Strawberry | | Kings | Mulberry | |
|---|---|---|---|---|---|
| Year: | 2004 | 2006 | 2005 | 2006 | Total |
| **Road Segment** | | | | | |
| Km Mapped | 128 | 667 | 98 | 211 | **1104** |
| **Features** | | | | | |
| Wing Ditch | 379 | 1099 | 679 | 467 | **2624** |
| Crossdrain | 55 | 291 | 40 | 703 | **1089** |
| Bridge (Box) Crossing | 8 | 65 | 10 | 13 | **96** |
| Culvert Crossing | 60 | 223 | 42 | 161 | **486** |
| Ford Crossing | 14 | 106 | 17 | 50 | **187** |
| Slab Crossing | 13 | 94 | 8 | 3 | **118** |
| Road Barrier | | 395 | | 344 | **739** |
| Untraveled Intersection | | 14 | | 190 | **204** |
| **Total** | **529** | **2287** | **796** | **1931** | **5543** |

The geodatabase of edited features for the upper Mulberry River watershed was delivered to the USFS and is being used to update their enterprise road infrastructure database.

### Sediment Modeling

WEPP: Road Analysis was completed for portions of the Strawberry River and Kings River watershed in 2005 (WCRC 2005a, WCRC 2005b). In the Strawberry study, which covered about 10% of the watershed, WEPP: Road data were collected on 18 km of roads. Sediment coefficients were generated for single and double lane roads with various ditch erosion depths. Table 2 shows the results of that study. Results are in tons/mile/year.

Table 2. WEPP: Road Results in the Strawberry Watershed Study Area.

| Road Group (Road Width, Ditch Erosion) | Count | Length Surveyed (mi) | Erosion Coefficient (ton/mi/yr) | Sediment Export Coefficient leaving buffer (ton/mi/yr) | Sediment Export Coefficient entering stream (ton/mi/yr) |
|---|---|---|---|---|---|
| Double, >12" | 2 | 0.8 | 48.5 | 6.9 | 2.4 |
| Double, 1-12" | 6 | 1.8 | 31.1 | 6 | 4.4 |
| Double, none | 1 | 0.1 | 12.2 | 0.6 | 0.6 |
| **Double Average** | **9** | | **32.8** | **5.6** | **3.5** |
| | | | | | |
| Single, >12" | 6 | 1.2 | 83.6 | 35.1 | 35.1 |
| Single, 1-12" | 25 | 5.6 | 48.1 | 28.8 | 24.0 |
| Single, none | 11 | 1.9 | 26.2 | 11.6 | 10.5 |
| **Single Average** | **42** | | **47.4** | **25.2** | **22.1** |
| | | | | | |
| Average All Roads | | | 44.9 | 21.8 | 18.8 |
| **Total** | **51** | **11.4** | | | |

The sediment coefficients were applied out to all unpaved roads in the inventory area.

Table 3: Estimated Yield from all Inventoried Roads Strawberry Watershed Study Area

| Road Group (Road Width, Ditch Erosion) | Sediment Export Coefficient (ton/mi/yr) | Chandler Creek Watershed | | Lick Branch Watershed | | North Big Creek Watershed | | Total Sediment Load (ton/yr) |
|---|---|---|---|---|---|---|---|---|
| | | Miles | Sediment Load (ton/yr) | Miles | Sediment Load (ton/yr) | Miles | Sediment Load (ton/yr) | |
| Double, >12" | 2.4 | 0.1 | 0.2 | -- | -- | 2.3 | 6 | 8 |
| Double, 1-12" | 4.4 | 1.7 | 7 | 0.5 | 2 | 10.3 | 45 | 67 |
| Double, None | 0.6 | -- | -- | -- | -- | 2.1 | 1 | 3 |
| | | | | | | | | |
| Single, >12" | 35.1 | 0.5 | 18 | 0.2 | 6 | 5.6 | 196 | 227 |
| Single, 1-12" | 24 | 4.8 | 116 | 3.8 | 91 | 31.2 | 748 | 995 |
| Single, none | 10.5 | 0.2 | 3 | 0.1 | 1 | 17.0 | 179 | 199 |
| **Public Unpaved Total** | | **7** | **145** | **5** | **100** | **68** | **1175** | **1500** |
| | | | | | | | | |
| Private Roads | 22.1 | 5.3 | 117 | 1.7 | 38 | 56.9 | 1257 | 1412 |
| | | | | | | | | |
| **Total** | | **13** | **262** | **6** | **137** | **125** | **2433** | **2912** |

In the Strawberry River watershed, the remaining portion of the watershed has been inventoried. The WEPP:Road results shown above will be applied to all roads in the watershed in 2007.

In the Dry Fork sub-watershed of the Kings River, WEPP:Road data were collected on about 12 km of roads. The modeling and extrapolation results are presented in tables 4 and 5.

Table 4: WEPP: Road Results in the Kings Watershed Study Area

| Road Group (Road Width, Ditch Erosion) | Count | Length Surveyed (mi) | Erosion Coefficient (ton/mi/yr) | Sediment Export Coefficient leaving buffer (ton/mi/yr) | Sediment Export Coefficient entering stream (ton/mi/yr) |
|---|---|---|---|---|---|
| Double Lane | 2 | 1.2 | 25.1 | 9.2 | 9.2 |
| Single Lane, No Ditch | 6 | 0.4 | 19.5 | 14.6 | 14.6 |
| Single Lane, Ditch Erosion > 12" | 10 | 1.7 | 52.9 | 27.7 | 27.3 |
| Single Lane, Ditch Erosion 1-12" | 17 | 4.0 | 41.8 | 20.7 | 19.4 |
| Single Lane, Ditch Erosion < 1" | 4 | 0.5 | 17.7 | 4.7 | 4.7 |
| | | | | | |
| **Average All Roads** | | | **37.8** | **19.6** | **18.9** |
| **Total** | **39** | **7.7** | | | |

Table 5: Estimated Yield from all Inventoried Roads Kings Watershed Study Area

| Road Group (Road Width, Ditch Erosion) | Sediment Export Coefficient (ton/mi/yr) | Miles | Total Sediment Load (ton/yr) |
|---|---|---|---|
| Double Lane | 9.2 | 3.7 | 34 |
| Single Lane, No Ditch | 14.6 | 8.2 | 119 |
| Single Lane, Ditch Erosion > 12" | 27.3 | 11.5 | 314 |
| Single Lane, Ditch Erosion 1-12" | 19.4 | 30.5 | 590 |
| Single Lane, Ditch Erosion < 1" | 4.7 | 6.7 | 32 |
| | | | |
| **Public Unpaved Total** | | | **1089** |
| | | | |
| Private Roads | 16.5 | 43 | 710 |
| | | | |
| **Total** | | | **1799** |

WEPP: Road data were collected on about 19 km in the upper Mulberry River watershed. These data have been formatted for the WEPP:Road Batch, but have not yet been run.

**Implementation**

Two workshops have been held to date.

**Discussion**

The project presented here is a work in progress. The project has been a success to date, with a large volume of data collected. Large volumes of these data are currently being processed and analyzed. When completed, we will be able to compare results from all three mapped watersheds. The results above show similar erosion coefficients between the Mulberry and Kings watershed.

In current analysis, we are developing WEPP: Road coefficients that are specific to road gradients and soil types, as well as number of lanes and ditch characteristics.  This will allow for more accurate estimates in applying coefficients to all inventoried roads.

We are currently mapping stream bank erosion on the upper Mulberry River using the Bank Erosion Hazard Index (BEHI). Once BEHI data are collected and analyzed, we will be able to identify sediment from roads and stream bank, which will account for the majority of sediment sources in the study area.  We will then be able to prioritize sub-watersheds for sediment-reducing actions. Further prioritization can be accomplished by comparing species records and habitat iformation and focusing on critical areas for species of concern. Road maintenance priorities are already identified through inventory. Stream bank priorities will be identified through BEHI surveys.

**Bigraphical Sketch:** Ethan Inlander has been applying geospatial technologies and physical sciences to conservation issues for over 12 years. He received his undergraduate and master's degrees from the Department of Geography at University of California Santa Barbara, the #1 graduate geography program in the US (NRC, phds.org). His thesis topic was "An Integrated Methodology for the Mapping and Inventory of Riparian Areas in the Upper Santa Ynez Watershed, California ". Before joining The Nature Conservancy, Ethan applied geographical information systems technology to address multiple scale conservation problems in riparian and costal habitats of California. Since joining The Nature Conservancy, Ethan has applied these same techniques to identify and reduce impacts and habitat degradation to freshwater stream ecosystems, conduct local, watershed, and regional threat assessments of subterranean environments, and prioritize and implement karst, terrestrial, and riverine conservation actions at multiple scales.

# Juvenile Salmon Passage in Sloped-Baffled Culverts

**David R. Thurman** (503-780-2456, thurman@u.washington.edu), Graduate Research Assistant, Department of Civil and Environmental Engineering, University of Washington, Box 352700, Seattle, WA, 98195-2700 USA

**Alex R. Horner-Devine** (arhd@u.washington.edu), Assistant Professor, Department of Civil and Environmental Engineering, University of Washington, Box 352700, Seattle, WA, 98195-2700 USA

**Ryan R. Morrison** (rrmorrison@wsu.edu), Graduate Research Assistant, Albrook Hydraulics Laboratory, Department of Civil and Environmental Engineering, Washington State University, Box 642910, Pullman, WA, 99164-2910 USA

**Rollin H. Hotchkiss** (rhh@byu.edu), Professor, Brigham Young University, 370 Clyde Building, Provo, UT 84602 USA

**Abstract:** The connectivity of river drainages has been decreased by the installation of roadway culverts, particularly for the salmonids of the Pacific Northwest. Thousands of culverts within the State of Washington have been designated by the state DOT as fish passage barriers. Though it is well known that the anadromous salmon travel upstream to spawn, recent evidence suggests that juvenile salmon also travel upstream to seek preferred habitats for feeding, which may ultimately improve their survival at sea. Retrofitting culverts is an economical solution that has been initially implemented to improve adult salmon passage. Baffles increase water depth for low flow conditions and reduce velocities for higher flowrates. To determine the effect of baffles on upstream passage of juveniles, sloped-baffles were studied at a culvert test bed near Tenino, Washington. Using an Acoustic Doppler Velocimeter (ADV), 3-D velocity fields were collected in a full-sized 12.2 m (40') long, 1.8 m (6') diameter corrugated culvert. The culvert slope, baffle spacing, and baffle height were varied to observe flow regime trends that describe conditions suitable for fish passage. This project is unique from other hydraulic studies in that biological testing was conducted in conjunction with the hydrodynamic measurements. Biologists randomly selected 100 juvenile Coho salmon from the on-site rearing facility and allowed the fish to ascend the culvert during a three hour period. The movement of the fish was recorded with video cameras and the passage rate was determined.

Results indicate that there is considerable spatial variability in the flow created by the baffles within the culvert. The flow is asymmetric, consisting of a jet traveling over the low side of the baffle and an area of re-circulating water on the high side of the baffle. The asymmetry decreases as the discharge increases and the mean water height surpasses the baffle height. The diversity of flow structures created by this asymmetry is important because it increases the number of reduced velocity paths that fish may travel. The fish passage success rates are also consistent with the trends of asymmetry: as the culvert discharge increases fish are limited to fewer possible paths, and passage rates decrease. The results suggest that both the structure of the flow and the average speed of the flow affect the passage rate. We present a scaling equation that relates the occurrence of flow structures to the independent study parameters in order to provide guidance in baffle implementation. Recommendations for future work include further biological interpretation and testing, so that the hydraulic and biological results may be more closely coupled.

## Introduction

Within the Pacific Northwest, salmon and other anadromous species play an important historical, cultural, and environmental role. Many of these fish populations are suffering and are now listed under the Endangered Species Act. Stream connectivity is a crucial link in the survival and migration of salmonids. Unfortunately, man-made structures such as culverts may be making this more difficult.

### Background

Since 1991, Washington State Department of Transportation (WSDOT) has spent nearly 40 million dollars inventorying stream crossings, conducting habitat studies, and correcting fish passage barriers. There are an estimated 5,853 WSDOT highway crossings. Of the crossings identified as fish bearing, approximately half of those (1,538) are considered fish passage barriers (Wilder *et al.*, 2006). An additional 1,620 culverts have been identified as fish barriers on Washington Bureau of Reclamation and Forest Service lands (Thompson 2002).

Though studies of salmon migration have historically focused on returning spawning adult passage, juvenile salmon are found to travel upstream in search of lower flows, reduced turbidity, preferred water temperature, predator refuge, food, and available habitat (Kahler and Quinn 1998; Kane *et al.*, 2000). The ability for juvenile salmon to access the entire drainage will lead to a stronger and healthier population with a reduced mortality rate. Thereby, juvenile salmon will be better prepared for migration and life in the ocean environment.

### Biological Studies

Retrofitting of culverts is not the ideal solution for remedying fish passage barriers, yet is more economical and sometimes the only practical solution (Gregory *et al.* 2004; Clay 1961). Baffles improve the flow within culverts for fish by increasing water depths at low water conditions and reducing velocities at higher flowrates. A number of field studies have been completed throughout the Pacific Northwest. Kane *et al.*, (2000) studied four culverts across Alaska and determined that a food source was motivation enough for some drainages, and juvenile salmon sought out paths that minimized their energy expenditure. Gregory *et al.*, (2004) looked at seven different retrofitted culverts in Oregon and found that baffles allowed fish to maintain their positions within culverts allowing upstream passage. Several studies concluded that juvenile fish take advantage of culvert corrugation roughness and low velocity zones for passage (Kane et al., 2000; Gregory *et al.*, 2004; Pearson *et al.*, 2006). The majority of biological fish studies, however, have been completed in the absence of hydraulic testing and hence direct hydraulic comparison.

**Hydraulic Studies**

The hydraulics of ribbed roughness or corrugated culverts without baffles have been examined by a number of investigators. Ead *et al.*, (2000) examined the flow regimes in a culvert with corrugations perpendicular to the length of the culvert. They found reduced velocities in the boundary layer and near the surface. Hydraulic measurements have also been collected previously in the spirally corrugated culvert test bed facility used in the present experiments; however, these experiments were without baffles (Richmond 2007; Pearson *et al.*, 2005; Guensch 2004). The results indicated a reduced velocity zone (RVZ) on the right side of the culvert; where, the culverts corrugations slope downstream toward the right side. As we show in the present study, however, this structure does not appear to persist with the addition of baffles.

A series of studies at the University of Alberta in the 1980s and 1990s describe the hydraulics of culvert flow in the presence of different baffle systems. The conclusions from these separate studies are summarized in Ead *et al.*, (2002). They present a discharge scale general to all baffle systems, and show that the dimensionless depth is correlated with this scale for different values of the relative baffle height. Their study does not include sloped baffles such as those considered in the present study, however.

In a separate study, Ead *et al.*, (2004) examined flow regimes, first described by Clay (1961), in a rectangular laboratory flume with baffles and present an expanded description of the transition from plunging to streaming flow. In plunging flow, the cell between subsequent baffles consists of two counter-rotating vertical eddies that are divided by the plunging jet (fig. 1). The upper vertical eddy is a surface roller and the lower vertical eddy is immediately downstream of the baffle (fig. 1a). In streaming flow, on the other hand, a single vertical eddy forms downstream of the baffle that occupies the entire cell. In this case, the water surface is well above the top of the baffle and the flow passes completely above the cell (fig. 1b). There are a number of transitional regimes defined between pure plunging and pure streaming flow. Ead *et al.*, (2004) also describe a third regime, called supercritical jet flow (fig. 1c), in which the plunging flow over the baffle forms a jet along the culvert bottom and a hydraulic jump downstream. They present a regime diagram that describes the transition between these flow states for their rectangular channel.

The regime plot described by Ead *et al.*, (2004) uses a dimensionless discharge $Q_{t*}$ and a ratio of baffle spacing to baffle height to describe the transitions they observed between the different regimes. They concluded that as discharge decreased and/or the ratio of baffle spacing to baffle height increased, regimes transitioned from a streaming flow to a transitional flow before becoming a plunging flow and finally a supercritical jet.

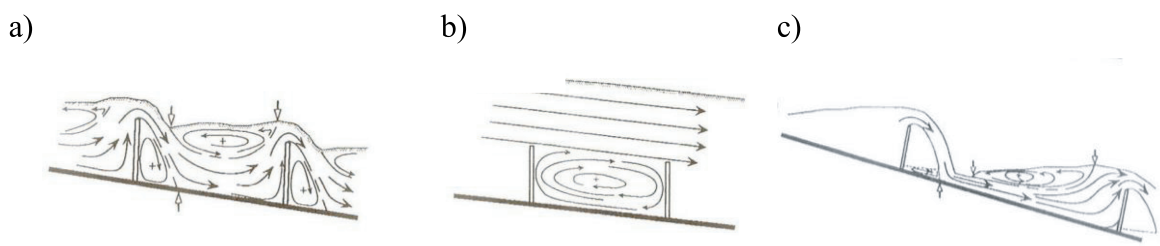



Figure 1. a) Schematics of plunging, b) streaming and c) supercritical jet flow regimes courtesy of Ead *et al.* (2004).

Fish passage in culverts using baffles or weirs has been studied by a number of different groups. However, most of these groups have considered the hydraulics of culvert flow in exclusion of biological testing, or visa-versa. Our study differs from most studies in that biological fish testing was completed in conjunction with the hydraulic testing. The sloped-weir baffles used for our study were found to introduce cross-stream variability and additional flow structures. This observed laterally variability was also created by the spiral culvert corrugations. Scientists and engineers studying fish passage often describe the amount of spatial variability in a flow as the diversity of the stream. The diversity of the flow increases habitat for migration, resting and feeding for fish and other aquatic species (Bates *et el.*, 2003). Baffles increase the flow diversity in culverts by introducing additional flow structures such as eddies, jets, and pools. These structures are important features that break up the symmetry of the flow. By mimicking a river's complex rock and log structures, baffles provide regions for fish to rest and travel. Studies have revealed that fish take advantage of eddies and are able to reduce the amount of energy they expend (Liao 2003).

In the present study we consider the flow in a sloped-baffled culvert to evaluate the structures generated by baffles. The report will also describe flow regimes associated with the variation of hydraulic parameters and their relationship with the biological fish testing results.

## Methods

### Experimental Setup

Hydraulic testing was performed at the Culvert Test Bed (CTB) at the Washington State Department of Wildlife Skookumchuck Fish Rearing Facility near Tenino, Washington. The CTB consists of a 12.2 m (40') long, 1.8 m (6') in diameter metal spirally corrugated culvert connecting a headwater (HW) and tailwater (TW) tanks. The culvert slope was varied with a pulley system on the tailwater side (fig. 2). Hydraulic parameters varied included three culvert slopes, three baffle heights and range of discharges. Discharge was set using magnetic and propeller flowmeters. Baffles were primarily spaced using a multi-agency recommended spacing of 0.06 m (0.2') drop per baffle as to allow for juvenile salmon passage. Baffles were sloped to the right side of the culvert looking upstream (fish perspective) at a 7.5% slope. A list of experiments and experimental parameters is provided in table 1.

### Data Collection/Processing

Experimental data were collected using methodology similar to that used in previous hydraulic testing at the CTB (Pearson *et al.*, 2005). Three-dimensional velocity measurements were acquired using a Sontek micro–acoustic doppler velocimeter (ADV) at a sampling rate of 50 Hz for 120 seconds (6000 data points). The ADV was attached to a gantry system that allowed the device to be lowered and then precisely moved throughout the sampling region via worm gears. Measurements were taken in coarse and fine grid patterns of either 23 or 39 points for 3 to 4 cross-sections spaced between baffles (fig. 3) Velocity data was processed using Matlab coding to filter out data with signal-to-noise ratio (SNR) less than 10 and correlation less than 40%. Further removal of erroneous data was done using a despiking algorithm created by Nobuhito Mori from Osaka City University, Japan (Mori 2007). Spikes occur when acoustic signal return is outside the normal detectable range as resulting from flow aeration, the culvert boundary or other interfering processes. The program incorporates the phase-space thresholding method of Goring and Nikora (2002) and replaces the removed erroneous spikes.

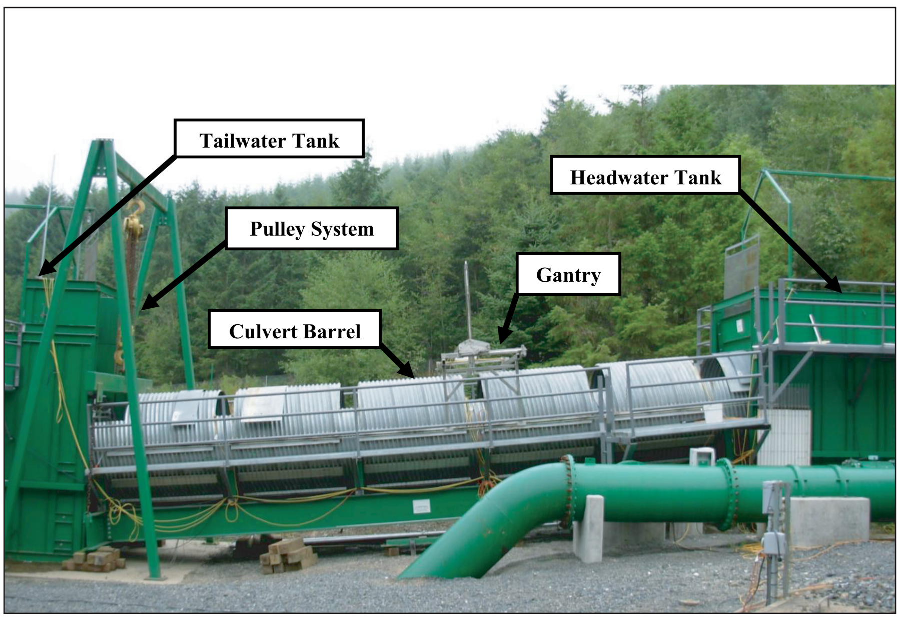



Figure 2. Culvert test bed at skookumchuck fish rearing facility near Tenino, WA.

Table 1: List of Experiments and Parameters Tested

| Slope (%) | Discharge ($l/s-ft^3/s$) | Baffle Spacing (m-ft) | Baffle Height (cm-in) |
|---|---|---|---|
| 1.14 | 42, 57, 85, 113, 227 - 1.5, 2.0, 3.0, 4.0, 8.0 | 4.57 - 15 | 19 - 7.5 |
| | 42, 85 – 1.5, 3.0 | 4.57 - 15 | 27, 34 - 10.5, 13.5 |
| | 42, 85 – 1.5, 3.0 | 2.28 - 7.5 | 19 - 7.5 |
| 4.3 | 42, 85, 113, 170, 227 - 1.5, 3.0, 6.0, 8.0 | 2.28 - 7.5 | 19, 27, 34 - 7.5, 10.5, 13.5 |
| | 42, 85, 113, 170, 227 - 1.5, 3.0, 6.0, 8.0 | 1.37 - 4.5 | 19 - 7.5 |
| | 42, 85 – 1.5, 3.0 | 1.37 - 4.5 | 34 - 13.5 |
| 10.96 | 227 – 8.0 | 1.37 - 4.5 | 19 - 7.5 |
| | 42, 85, 113, 170, 227 - 1.5, 3.0, 6.0, 8.0 | 0.54 - 1.8 | 19, 27, 34 - 7.5, 10.5, 13.5 |

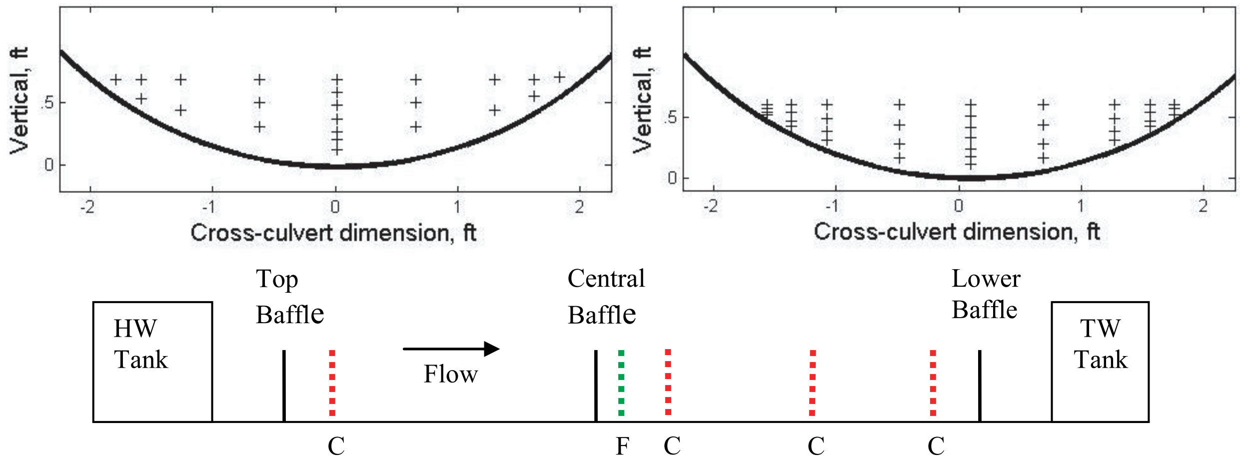



Figure 3. Measurement Grids Coarse (left) Fine (right) locations indicated by (+) signs
Example Measurement Cross-Sections for 4.57 m (15') (bottom).

## Results

Sloped-weir baffles principal effect on flow was an observed cross-stream variability, which introduced flow structures that establish a flow asymmetry. Flow structure formation and asymmetry were determined to be a function of head over the baffle. The influence of the baffle's slope was reduced for higher discharges as the level of baffle submergence became a greater fraction of the laterally varying baffle height.

### Base Flow

A base case was defined for comparison having a 1.14% culvert slope with baffles spaced 4.57 m (15') apart at 42 l/s (1.5 cfs). Under this combination of parameters five separate structures were identified (fig. 4). A jet over the low side of the baffle was observed to propagate down to the next baffle (fig. 4a). The high side of the baffle exhibited a lateral recirculation (fig. 4b) driven by the jet and contraction of water over the outer edges of the baffle (fig. 4c). The high side of the baffle acted as a weir, causing plunging flow to create a plunge line (fig. 4d) that was accentuated by the contraction. Finally, underneath the plunge and below the baffle a vertical recirculating eddy was formed visible through the aeration of the water (fig. 4e). These visual observations were observed by plotting the average velocity fields.

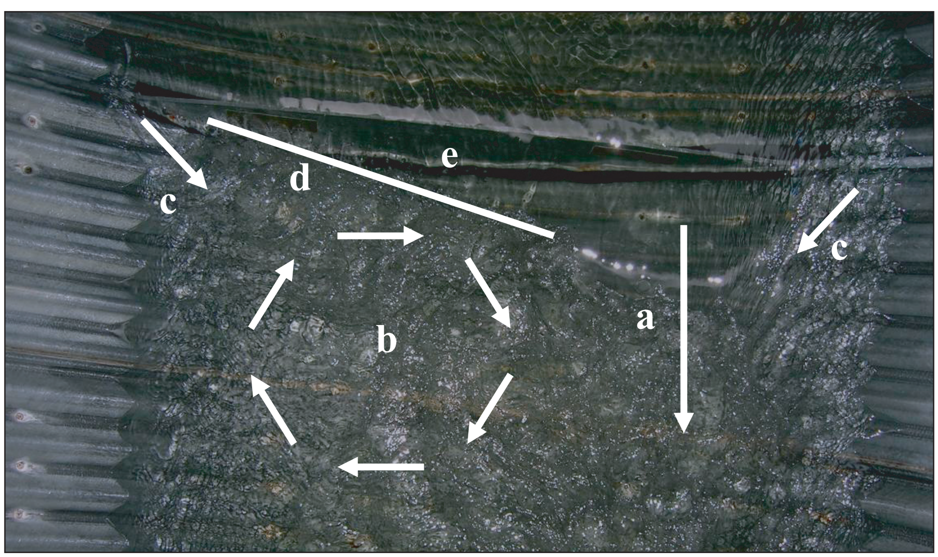
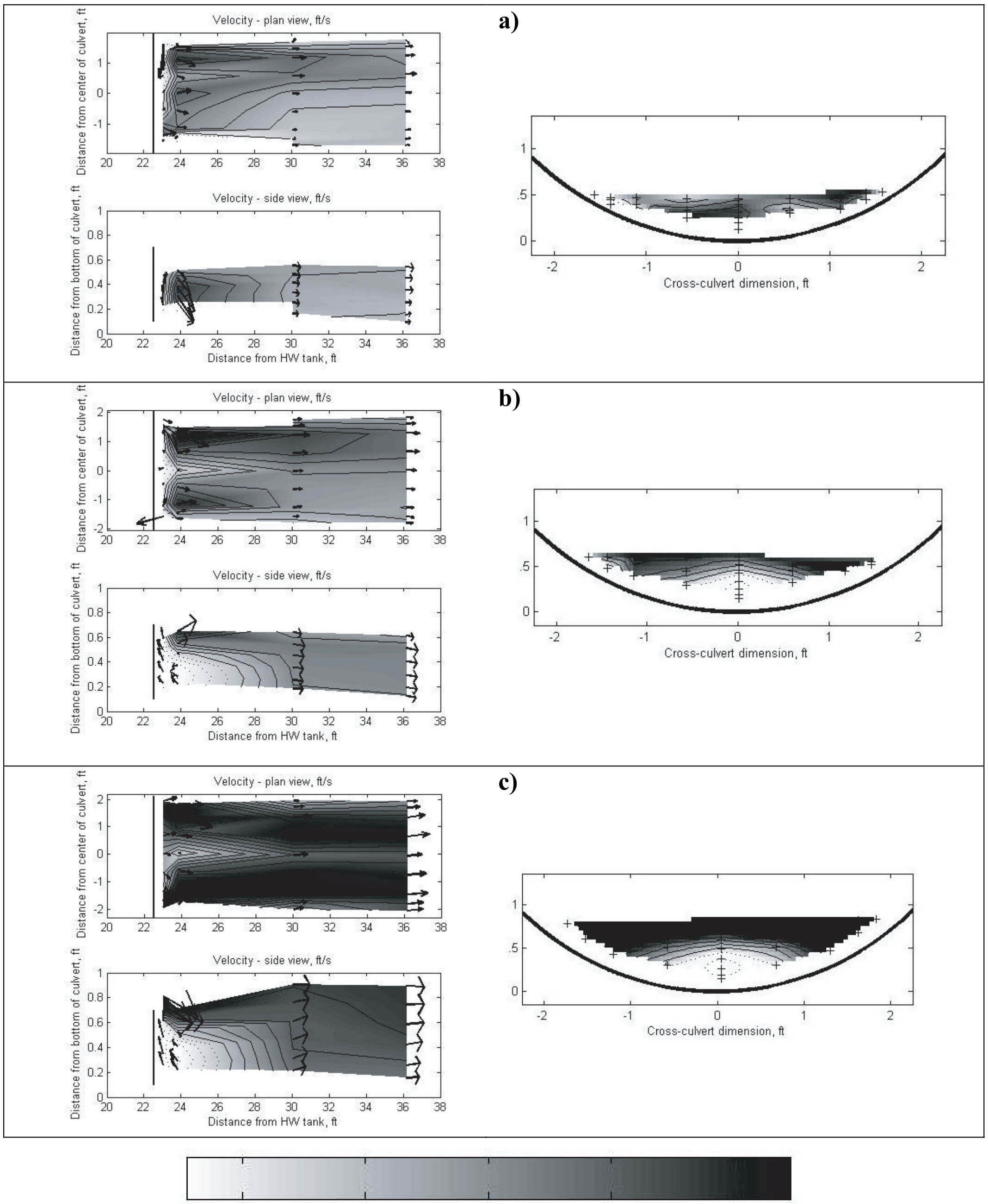



Figure 4. Baseline flow at 42 l/s (1.5 cfs), 1.14% culvert slope, 4.57 m (15') baffle spacing
(a) Dominant Jet (b) Lateral Recirculation (c) Contraction
(d) Plunge line (e) Lateral Recirculation.

### Depth Averaged Velocity

The depth averaged velocity is plotted in fig. 5a for the base case experiments. The flow structures described above are apparent in the velocity fields, including the jet over the low side of the baffle, an upstream return flow on the high side of the baffle indicating the across channel lateral recirculation and a strong across channel flow from the right side.

As the discharge was increased to 85 l/s (3.0 cfs) for the same parameters the head over the baffles grew and the baffles had less of an effect on the flow structures (fig. 5b). The dominant jet on the low side of the baffle grew in magnitude, but the lateral recirculation on the high side of the baffle was replaced by an additional jet. These jets were both accentuated by the contraction that occurred over the outer edges of the baffle. The second jet was significantly smaller in magnitude than the dominant jet and was therefore not able to persist to the downstream baffle. The vertical recirculation between the plunging flow and the baffle intensified and extended further down the culvert with the plunge. The effect of the baffle slope on the flow continued to diminish as the discharge was increased to 8.0 cfs (fig. 5c). At this discharge the jets approached similar magnitudes and the flow became more uniform. The formation of a second jet and the jet increasing in magnitude for increased discharge is similarly described by cross-sections of along-culvert velocity (fig 5). The modification of the jet structure and the elongation of the vertical recirculation region occurred consistently with increasing discharge for all parameters considered in the study.




Figures 5. Velocity fields (ft/s) a) 42 l/s (1.5 cfs) b) 85 l/s (3.0 cfs), and c) 227 l/s (8.0 cfs)
Left: (Top panel) Plan view of depth averaged velocity field
(Bottom panel) Side view of the vertical section of centerline along-culvert velocity
Right: Cross-sections along-culvert velocity contour plots.

### Jet Regimes

To classify the evolution of jets, flow conditions were characterized into three regimes (fig. 6). In regime J1, a dominate jet forms on the right and water begins to travel over the high side of the baffle into the corrugations and is directed toward the culvert center. The second jet regime J2 formed when the water over the left side of the culvert began to form a jet directed down the culvert. Finally, J3 is observed when the jets on either side of the culvert approach similar magnitudes.

In addition to changing with discharge, cross-stream asymmetry was also influenced by baffle height. Higher baffles have greater lengths in order to span the larger culvert width. Since all baffles were installed with the same slope, larger baffle lengths imply larger height differential from the low-side to the high-side of the baffle; hence, higher baffles require larger discharges to obtain the same level of submergence than smaller baffles. Therefore, asymmetry or lateral shear increases for higher baffles. Higher baffles also produce jets with a greater focus directed along the outer culvert wall. Both the increased asymmetry and jet focus were seen by plotting the depth averaged along culvert velocity for all three baffle sizes (fig. 7).

### Average Velocity

Fish passage success is largely dependent on swimming abilities classified into sustained, prolonged or burst speeds. Utilizing these abilities, juvenile salmon must overcome the culvert flows, of which one measure is average culvert velocities. Average velocities were approximated by dividing the discharge by the cross-sectional area of flow. Flow area was geometrically determined using depth of water measurements. Average velocities ranged from about 0.6-1.5 m/s (2-4 ft/s) over the baffle and 0.15- 0.9 m/s (0.5-3 ft/s) just upstream of the baffle. It was observed that baffles acted as elements of roughness reducing velocities for higher baffles. As expected, steeper culvert slopes increase average velocities because velocity is proportional to stream gradient. Though average velocities are an important feature in juvenile salmon's perspective, flow diversity such as lateral shear creates variability that may play an essential role to passage success.

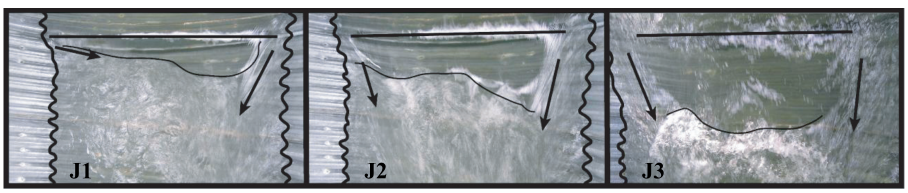



Figure 6. Jet Regimes J1-J3 (left to right), 1.14% culvert slope, 4.57 m (15') baffle spacing
**J1** 42 l/s (1.5 cfs), **J2** 85 l/s (3.0 cfs), **J3** 227 l/s (8.0 cfs).

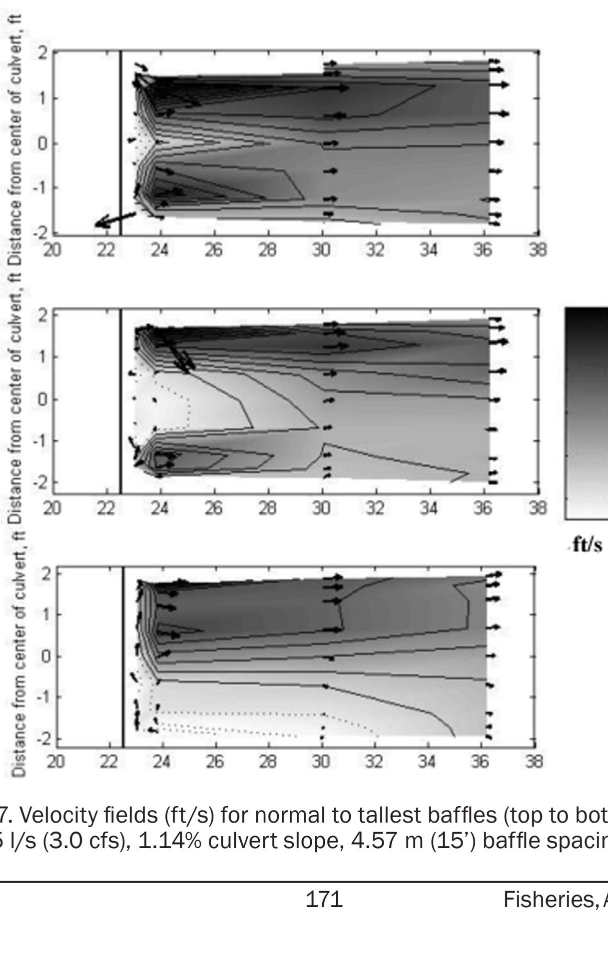



Figure 7. Velocity fields (ft/s) for normal to tallest baffles (top to bottom) at
85 l/s (3.0 cfs), 1.14% culvert slope, 4.57 m (15') baffle spacing.

### Lateral Shear

Lateral shear, previously described as observed jet regimes, is a function of baffle submergence that persists downstream. To create an improved comparison of the asymmetry for all flows a standard measure was defined as:

$$LS = 1 - \frac{1}{R_{avg} / L_{avg}} \quad \text{(Eq. 1)}$$

where $R_{avg}$ is the averaged velocity for flows on the right (fish perspective) side of the culvert and $L_{avg}$ is correspondingly for the left. Lateral Shear (*LS*) was evaluated at the cross-section 0.4 m (2 ft) below the baffle at a location far enough beyond the turbulent plunging and vertical recirculation but close enough to capture jet formation. Shear values greater than 1 correspond with flows forming a clockwise eddy, flow values near 1 are considered highly asymmetric, values nearer 0 are symmetric, and negative values occur when the magnitude of the right jet surpasses that of the left jet. Plotting LS values as a function of discharge confirmed the observed symmetric flows for higher discharges (fig. 8).

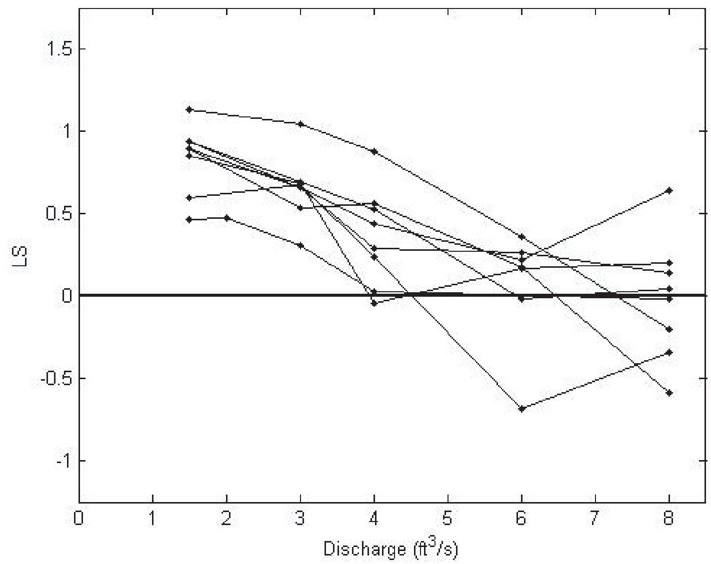



Figure 8. Lateral shear for all experiments.

### Flow Scaling

Regimes, as described in the Ead *et al.*, (2004) and fig 1., are qualitatively observed to vary across the width of the baffle. Each regime is primarily a function of head over the baffle as dictated by discharge. Sloped-weir baffles have different levels of submergence and thus multiple regimes. To describe the relationship between the changing flow regimes and the study parameters Ead *et al.*, (2004) derived a regime diagram using a non-dimensional discharge defined as

$$Q_{t*} = \frac{Q}{\sqrt{g b_o S_o L^{1.5}}} \quad \text{(Eq. 2)}$$

where Q is the discharge, g is gravity, $b_o$ is the baffle width, $S_o$ is the culvert slope, and L is the baffle spacing. They found the regimes to vary with the ratio of baffle spacing (L) to baffle height (P). Plotting our data using this scaling did not result in similar flow regimes because of the occurrence of multiple regimes. When our data are plotted using the Ead *et al.* (2004) scaling, however, we resolve variation in the lateral shear. In fig. 9 all of the experiments are plotted as separate points with darker points representing symmetric flows (*LS* values approaching zero or negative) and lighter points representing asymmetric flows (fig. 9). The scaled plot showed reduced lateral shear for greater discharge and larger lateral shear for higher baffles and smaller baffle spacing.

Separately, definitions of the three jet regimes were used to classify all experiments from photographs and videos. Most regimes were defined as either J1 or J2 regime with very few experiments reaching the J3 regime. From these classifications a unique plot using the same scaling as for the previously described Ead et al., (2004) was made of the three jet regimes. This plot yielded a transitional line between the first J1 regime and the second J2 regime, which is plotted on fig. 9. The transitional line, independently generated, is complimentary to the plot for Lateral Shear Scaling. Thereby, Lateral Shear is strongly associated with these flow structures.

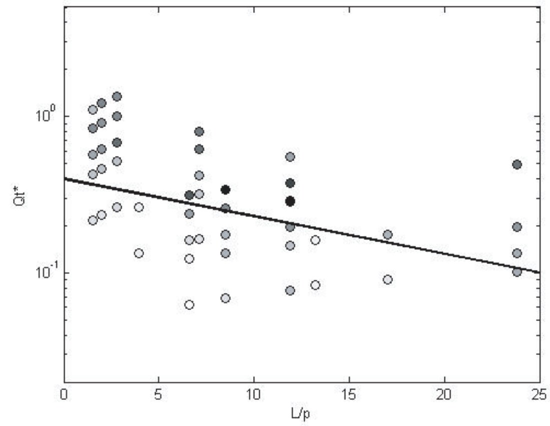



Figure 9. Lateral Shear Scaling, scaling from Ead et al., (2004)
Lateral Shear (LS) Decreases from Lighter to Darker Points
Line Represents Observed Transition between Jet Regime 1 and Jet Regime 2.

## Biological Study

Fish testing was completed by Battelle Memorial Institute, Pacific Northwest Division in which their findings were prepared for WSDOT in the April 2006 Final Report. The following methodology and results are described in detail in Pearson *et al.*, (2006) and summarized here for comparison with the hydraulic measurements.

### Biological Methods

Biological testing was conducted within the same culvert test bed facility at the 1.14% culvert slope, normal baffles spaced 4.57 m (15') for flows 42 l/s (1.5 cfs) to 340 l/s (12 cfs), identical to those described in the initial case and Fig. 5. Tests were conducted by Pearson *et al.*, (2006) at night for a three hour period with 100 test fish. Juvenile coho salmon (Oncorhynchus kisutch) were used from the WDFW Skookumchuck Rearing Facility and placed within a net pen in the tailwater tank initializing the test. At the conclusion of testing, screens were lowered over the culvert ends to capture and count fish within either the headwater tank, culvert barrel or tailwater tank. A successful passage was defined by a fish entering and/or passing through the culvert in to the headwater tank. Real time observations of fish were captured with low-light high resolution cameras positioned above baffles and submerged at the culvert's entrance and exit.

### Biological Results

Fish passage tests were held under three configurations: a standard backwatered condition with and without baffles, or an elevated backwatered condition with baffles. The standard condition had a set backwater elevation as regulated by dam boards in the rear of the tailwater tank. The elevated backwater condition involves setting the level of water on the most downstream baffle to establish an average 0.05 m (0.16') drop over the baffle. Overall, fish passage success resulted in lower fish passage on average 28% passing at 42 l/s (1.5 cfs) that increased significantly at 85 l/s (3.0 cfs) to 53% passing. Passage success declined for increasing discharge with a minimal 6% passage at 340 l/s (12 cfs)(fig. 10). The results of the biological tests also suggest that the same level of passage success may be obtained for less effort with the baffled configuration as compared with the unbaffled configuration. Peak passing at 85 l/s (3.0 cfs) is thought to be explained for larger juvenile salmon by a cue for flows greater than 42 l/s (1.5 cfs) (Pearson *et al.*, 2006).


Figure 10. Percentage of fish passage versus discharge courtesy of Pearson et al. (2006).

Observations of fish traveling over baffles were made to determine if baffles hindered fish passage. At 42 l/s (1.5 cfs) fish crossed the baffle near the center using their burst speed, however at 85 l/s (3.0 cfs) fish traveled over the entire baffle width with a generally equal distribution. For discharges greater than 85 l/s (3.0 cfs) the passage success was reduced; fish that typically used the entire culvert barrel to travel up the culvert were driven primarily toward the outer culvert walls. Fish used the corrugated culvert wall (far right or left) for maintaining resting positions, traveling and crossing over the baffles.

## Conclusions

Comparing the results from both the hydraulic and biological studies indicate that passage was greatest when flows were between an asymmetric and symmetric condition. At a 1.14% culvert slope, normal height baffles spaced 4.57 m (15'), and a discharge of 85 l/s (3.0 cfs), fish ascended the culvert with greatest success. These parameters corresponds to the formation of the second jet regime (J2); where, the entire baffle becomes submerged and the plunging flow over the high left side of the baffle is replaced by a jet. Thus, the plunging weir flow and vertical recirculation, which potentially combine to hinder fish from approaching or crossing over the baffle, is eliminated under these conditions. Observation of fish crossing over baffles also reveals that submergence under these conditions does not limit where fish pass over the baffle. Maximization of the paths by which fish may cross over the baffle is critical; since, it has been observed that juvenile salmon are reluctant to leap or jump over weirs, but instead swim over or around them (Kane *et al.*, 2000; Pearson *et al.*, 2006). To establish an initial prediction for the ideal passage condition for any set of parameters, the transition into J2 regime was plotted with non-dimensional parameters (Fig. 9). However, the fish passage cue and its association with the second jet regime J2 should be verified with additional biological and hydraulic testing. Lastly, the baffle's slope guarantees that plunging flow will not cover the entire culvert width, thus, potentially limiting passage for lower discharges. Instead the baffle slope is fundamental in creating an adequate flow depth and velocity for fish to cross over the baffle.

## References


Bates, K., Barnard R., Heiner B., Klavas P., and Powers P., 2003. Design of Road Culverts for Fish Passage. Washington Department of Fish and Wildlife, Habitat and Lands Program, Environmental Engineering Division. Olympia, Washington.

Clay, C.H. 1961. *Design of fishways and other fish facilities*, The Department of Fisheries of Canada, Ottawa.

Ead, S. A., Rajaratnam, N., and Katopodis, C., 2002. "Generalized Study of Hydraulics of Culvert Fishways" *Journal of Hydraulic Engineering*, Nov. 2002: 1018-1022.

Ead, S. A., Rajaratnam, N., and Katopodis, C., 2004. "Flow regimes and structure in pool weir fishways" *Journal of Environmental Engineering and Science*, Sep. 2004: 379-390.

Goring, Derek A., and Nikora, Vladimir I., 2002. "Despiking Acoustic Doppler Velocimeter Data" *Journal of Hydraulic Engineering*, Jan. 2002: 117-126.

Gregory, S., Klingeman P., McEnroe J., and Wyrick J., 2004. "Final Report: Fish Passage Through Retrofitted Culverts." Oregon Department of Transportation, Portland, Oregon.

Guensch, G.R., Richmond, M.C., Tritico, H. and Pearson, W.H., 2004. "Characterization of Turbulent Open Channel Flow in a Full-Scale Spiral Corrugated Culvert" *World Water and Environmental Resources Congress* June 2004.

Kahler, T.H., and Quinn T.P., 1998. Juvenile and Resident Salmonid Movement and Passage through Culverts. Final Research Report for Project T9903, Task 96. Performed for Washington State Transportation Commission by the University of Washington. (http://www.wsdot.wa.gov/Research/Reports/)

Kane, D.L., Belke C.E., Gieck R.E., and McLean R.F., 2000. "Juvenile Fish Passage Through Culverts in Alaska." INE/WERC 00.05. Water and Environmental Research Center, University of Alaska-Fairbanks. Fairbanks, Alaska.

Liao, J.C., Beal, D.N., Lauder, G.V., and Triantafyllou. 2003. "Fish Exploiting Vorticies Decrease Muscle Activity" Science 302, Nov 2003: 1566–1569.

Mori, N., Suzuki, T., Kakuno, S., 2007. "Noise of Acoustic Doppler Velocimeter Data in Bubbly Flows" Journal of Engineering Mechanics, Jan. 2007: 122-125.

Pearson, W., Richmond, M., Johnson, G., Sargeant, S., Mueller, R., Cullinan, V., Deng, Z., Dibrani, B., Guensch, G., May, C., O'Rourke, L. Sobocinski, K., and Tritico, H., "Protocals for Evaluation of Upstream Passage of Juvenile Salmonids in an Experimental Culvert Test Bed" Final Report, May 2005.

Pearson, W.H., Southard S.L., May C.W., Skalski J.R., Townsend R.L., Horner-Devine A.R., Thurman D.R., Hotchkiss R.H., Morrison R.R., Richmond M.C., Deng D.,"Research on the Upstream Passage of Juvenile Salmon through Culverts: Retrofit Baffles" Final Report, April 2006.

Richmond, M.C., Deng, Z., Guensch, G.R., Tritico, H., Pearson, W.H., 2007. Mean Flow and Turbulence Characteristics of a Full-Scale Spiral Corrugated Culvert with Implications for Fish Passage. Submitted to Ecological Engineering.

Thompson, Tom. Testimony, United States House of Representatives: Concerning Fish Passage Barriers and Pacific Salmon. Washington DC, 10 April 2002. http://www.fs.fed.us/congress/2002_testimony/04102002-3.shtml.

WDFW (Washington Department of Fish and Wildlife).1999. Fish Passage *Design at Road Culverts: A design manual for fish passage at road crossings*. Washington Department of Fish and Wildlife, Habitat and Lands Program, Environmental engineering Division, Olympia, Washington.

Wilder, Eva., Johnson, Greg., Barber Mike., 2006. WSDOT Fish Passage Inventory: Progress Performance Report. Washington State Department of Fish and Wildlife, Habitat and Lands and Technical Applications Division, Olympia Washington.

## Protecting and Enhancing River and Stream Continuity

**Scott Jackson** (413-545-4743, sjackson@umext.umass.edu), Department of Natural Resources Conservation, Holdsworth Hall, University of Massachusetts, Amherst, MA 01003 USA
**Alison Bowden** (617-227-7017, abowden@tnc.org), The Nature Conservancy, 205 Portland Street, Suite 400, Boston, MA 02114 USA
**Brian Graber** (413-585-5896, bgraber@amrivers.org), American Rivers, 37 Phillips Place #2, Northampton, MA 01060 USA

**Abstract:** As long linear ecosystems, rivers and streams are particularly vulnerable to fragmentation. There is growing concern about the role of road crossings – and especially culverts – in altering habitats and disrupting river and stream continuity. The River and Stream Continuity Project began in the year 2000 with a startup grant from the Massachusetts Watershed Initiative. The University of Massachusetts took the lead in convening a group of people from a variety of agencies and organizations who were concerned about the impact of road-stream crossings on fish and other aquatic organism passage. In 2005, three of the organizations/agencies that were key players in initiating and implementing the project joined to create the River and Stream Continuity Partnership. Founding members of the Partnership include:

- UMass Extension ( University of Massachusetts Amherst)
- Massachusetts Riverways Program (MA Department of Fish and Game) and
- The Nature Conservancy

Members of the Partnership have made a commitment to the ongoing implementation of the River and Stream Continuity Project, including updates and revisions to the MA River and Stream Crossing Standards, coordination and implementation of volunteer assessments, management of the Continuity database, and projects to upgrade or replace substandard crossing structures.

Since its beginning, the River and Stream Continuity Project has:

- Developed "Massachusetts River and Stream Crossing Standards" to facilitate river and stream continuity as well as fish and wildlife passage. These standards are referenced in federal and state regulations and policies affecting road-stream crossings.
- Created a field protocol for volunteer assessment of road-stream crossings, including data forms, instructions, and training materials.
- Developed a system for scoring crossing structures for their effects on river and stream continuity and aquatic organism passage based on volunteer assessments.
- Created an online database for data on road-stream crossings collected by volunteers. All crossings are geo-referenced and information from the database can be easily used in a GIS to depict the location and score of all assessed structures in participating states.
- Developed a statewide GIS coverage prioritizing all mapped stream segments in Massachusetts into three categories based on information about their importance for fish and wildlife.
- Conducted volunteer assessments of road-stream crossings in Massachusetts, Connecticut, Rhode Island, Vermont and New Hampshire.
- Initiated demonstration projects to mitigate known barriers to aquatic organism passage on high-priority streams.
- Developed workshops, presentations and other educational material on the subject of river and stream continuity and the Massachusetts River and Stream Crossing Standards.

### Introduction

As long linear ecosystems, rivers and streams are particularly vulnerable to fragmentation. A number of human activities can disrupt the continuity of river and stream ecosystems. The most familiar human-caused barriers are dams. However, there is growing concern about the role of road crossings – and especially culverts – in altering habitats and disrupting river and stream continuity.

Road and highway systems, as long linear elements of the transportation infrastructure, can result in significant fragmentation of river and stream ecosystems. Road systems and river and stream networks frequently intersect, often with significant negative consequences for river and stream ecosystems. Within Massachusetts there are an estimated 30,000-35,000 road-stream crossings, creating a reason for serious concern that the river and stream networks are highly fragmented (figure 1).

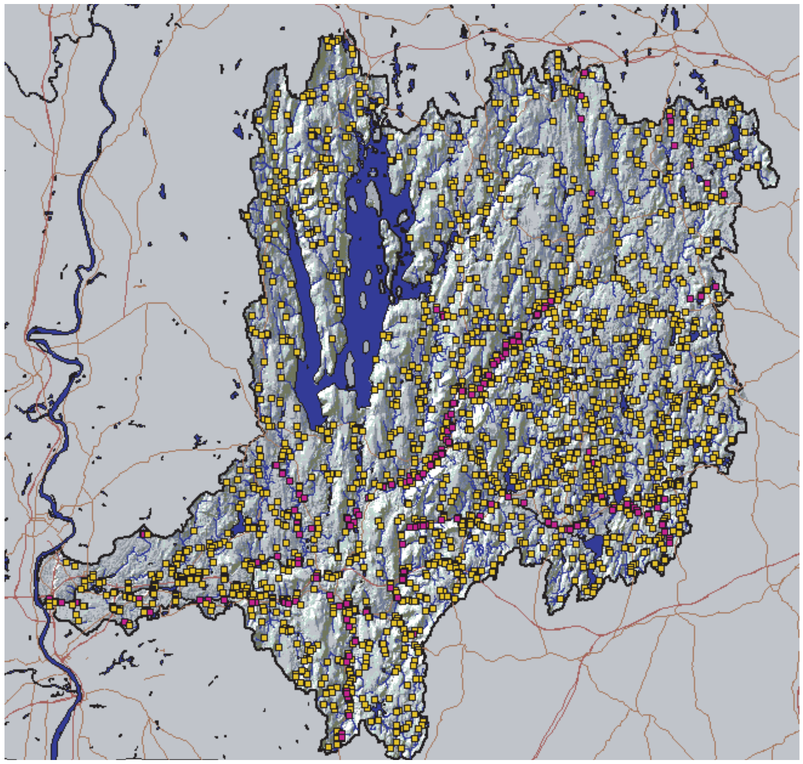


Figure 1. The 721 sq. mi. Chicopee River Watershed is a relatively rural watershed in Central Massachusetts. The watershed contains approximately 2,151 miles of roads and 259 miles of railroad tracks. The intersection of the stream network with roads and railroads results in an estimated 2,230 crossings, raising serious concerns about fragmentation of river and stream ecosystems in this watershed.

Most of the culverts currently in place were designed with the principal objective of moving water across a road alignment. Little consideration was given to ecosystem processes such as the natural hydrology, sediment transport, fish and wildlife passage, or the movement of woody debris. It is not surprising then that many culverts significantly disrupt the movement of aquatic organisms.

Much attention has been focused on passage for migratory fish, especially in the Northwestern U.S. In some cases, considerable resources have been invested in projects addressing fish passage only to find that accommodations made for adults did not address the needs of juvenile fish. Long-term conservation of fish resources will depend not only on passage for both adult and juvenile fish but also on maintenance of healthy stream and river ecosystems. Essential to this approach is a focus on habitat quality and strategies for aquatic organism passage based on communities rather than individual species. Without an ecosystem-based approach to river and stream crossings we will be at risk of facilitating passage for particular fish species while at the same time undermining the ecological integrity of the ecosystems on which these fish depend.

## The River and Stream Continuity Project

The River and Stream Continuity Project began in the year 2000 with a startup grant from the Massachusetts Watershed Initiative. The University of Massachusetts took the lead in convening a group of people from a variety of agencies and organizations who were concerned about the impact of road-stream crossings on fish and other aquatic organism passage. In 2005, three of the organizations that were key players in initiating and implementing the project joined to create the River and Stream Continuity Partnership. Founding members of the Partnership include: University of Massachusetts Extension, the Massachusetts Riverways Program, and The Nature Conservancy (TNC).

Members of the Partnership have made a commitment to the ongoing implementation of the River and Stream Continuity Project, including updates and revisions to the MA River and Stream Crossing Standards, coordination and implementation of volunteer assessments, management of the Crossings database, and projects to upgrade or replace substandard crossing structures. The River and Stream Continuity Project is now operating in five states: Massachusetts, Rhode Island, Connecticut, Vermont and New Hampshire. More information about the project is available from our Web site: www.streamcontinuity.org.

## Program Elements and Accomplishments

### Crossing Standards

Information was compiled about fish and wildlife passage requirements, culvert design standards, and methodologies for evaluating barriers to fish and wildlife passage. This information was then used to develop performance standards for culverts and other stream crossing structures (River and Stream Continuity Partnership 2006). A first draft of the standards was released in 2004. In 2006, the standards were revised and updated. "Massachusetts River and Stream Crossing Standards" is available as a PDF from the stream continuity Web site.

The standards were developed by the River and Stream Continuity Partnership with input from an Advisory Committee that includes representatives from UMass-Amherst, Massachusetts Riverways Program, Massachusetts Watershed Initiative, Trout Unlimited, The Nature Conservancy, the Westfield River Watershed Association, ENSR International, Massachusetts Highway Department (MassHighway), and the Massachusetts Departments of Environmental Protection and Conservation and Recreation. In developing the standards, the Partnership received advice from a Technical Advisory Committee that included representatives of the U.S. Fish and Wildlife Service, USGS BRD, U.S. EPA, U.S. Army Corps of Engineers, MA Division of Fisheries and Wildlife, American Rivers, Connecticut River Watershed Council, Connecticut DEP, a hydraulic engineering consultant, as well as input from people with expertise in Stream Simulation approaches to crossing design. The standards are recommended for new permanent crossings (highways, railways, roads, driveways, bike paths, etc.) and, when possible, for replacing existing permanent crossings.

The MA River and Stream Crossing Standards seek to achieve, to varying degrees, three goals:

1. Fish and other Aquatic Organism Passage: Facilitate movement for fish and other aquatic organisms, including relatively small, resident fish, aquatic amphibians & reptiles, and large invertebrates (e.g. crayfish, mussels).
2. River/Stream Continuity: Maintain continuity of the aquatic and benthic elements of river and stream ecosystems, generally through maintenance of appropriate substrates and hydraulic characteristics (water depths, turbulence, velocities, and flow patterns). Maintenance of river and stream continuity is the most practical strategy for facilitating movement of small, benthic organisms as well as larger, but weak-swimming species such as salamanders and crayfish.
3. Wildlife Passage: Facilitate movement of wildlife species including those primarily associated with river and stream ecosystems and others that may utilize riparian areas as movement corridors. Some species of wildlife such as muskrats and stream salamanders may benefit from river and stream continuity. Other species may require more open structures as well as dry passage along the banks or within the streambed at low flow.

There are two levels of standards (General and Optimum) to balance the cost and logistics of crossing design with the degree of river/stream continuity warranted in areas of different environmental significance. These standards have since been incorporated into federal and state regulations and policies affecting road-stream crossings.

On January 20, 2005, the U.S. Army Corps of Engineers reissued the Programmatic General Permit (PGP) for Massachusetts. The PGP sets terms and conditions that must be met for projects to qualify for Category 1, which doesn't require application to the Corps. In the past, the PGP included general language requiring that crossings of water bodies not "...obstruct the movement of aquatic life indigenous to the waterbody...." The reissued PGP contains more specific language at General Condition 21 to ensure aquatic organism passage and requires that all new permanent crossings meet the general standards contained in the Massachusetts River and Stream Crossing Standards.

By including the Massachusetts River and Stream Crossing Standards as a requirement for all "new" permanent crossings, the reissued PGP will significantly change the way road/stream crossings are designed and permitted in Massachusetts. Structures will generally be larger and will require more careful engineering, design, and construction to ensure that appropriate flow and channel characteristics are maintained over time. Elements of the crossing standards have since been incorporated into the PGP for Maine and it is the stated intention of the Corps to use the standards in the reissue of Programmatic General Permits for all the New England states.

The Massachusetts Department of Environmental Protection has included the crossing standards in its recently released "Massachusetts Wildlife Habitat Protection Guidance for Inland Wetlands" (DEP 2006) and is in the process of requiring that road-stream crossings adhere to the standards as part of the state's water quality standards. There has been a great deal of interest in the Massachusetts River and Stream Crossing Standards and other New England states are developing their own standards (Maine has crossing standards that predate those developed for Massachusetts).

### Assessment of Road-Stream Crossing Structures

The River and Stream Continuity Partnership has developed a program for volunteer assessment of river and stream crossings. A simple data form has been developed for assessing crossing structures in the field along with instructions and training materials for collecting data and completing the form. Volunteer groups that receive training may enter data into the River and Stream Continuity Crossings Database, an online database available at www.streamcontinuity.org/cdb.

The River and Stream Continuity Crossings Database allows cooperators to input data from volunteer surveys directly into an online database. An algorithm within the database automatically calculates scores for each road-stream crossing based on a scale of 0 (severe barrier) to 10 (meets optimum standards). Data and computed scores from the database are available for viewing and download from the web site. All crossings are geo-referenced and information from the database can be easily used in a GIS to depict the location and score of all assessed structures in participating states. The online database ensures timely availability of data for researchers and volunteers and creates a cost-effective method for gathering information about road-stream crossings throughout New England.

Under the leadership of The Nature Conservancy, the Rhode Island Office of the USDA Natural Resource Conservation Service and the Massachusetts Riverways Program trained volunteers have now assessed over 2600 crossing structures. In particular, The Nature Conservancy has been focusing their efforts to get comprehensive assessment of crossings in key watersheds of the Connecticut River. They are using information from these assessments to establish priorities and create action plans for protecting and enhancing river and stream continuity in these target watersheds.

**Prioritizing Crossing Structures for Replacement**

In order to help prioritize crossing structures for replacement or retrofits we developed a stream classification system for Massachusetts based on existing GIS data. Three levels of standards were applied, Class A (Highest quality), Class B (High quality), and Class C (General).

Class "A" designations were applied in areas where crossings might adversely impact:

- A select number of BioMap Core habitats for riverine species, or
- Living Waters Core habitats.

Class "B" designations were applied to areas that fell within:

- Areas of Critical Environmental Concern (ACEC),
- BioMap cores (other than select cores used for Class A),
- Known anadromous fish runs,
- Streams that supported coldwater fisheries, or
- Designated federal or state wild and scenic rivers.

Class "C" designations were applied to all other stream segments. The GIS coverage, available as a shapefile, can be downloaded from the stream continuity Web site.

Work is underway at the University of Massachusetts to create more sophisticated methods for prioritizing stream segments for protection. An approach piloted in the Westfield River Watershed used the Conservation Assessment and Prioritization System (CAPS) to apply rigorous landscape-based models and predict gains in ecological integrity that could be achieve via the replacement of sub-standard crossing structures (for more information about CAPS go to www.masscaps.org). The Nature Conservancy is developing its own, more detailed system for prioritizing stream and river segments for protection or restoration.

**Demonstration Projects**

The Massachusetts Riverways Program has taken the lead in providing technical assistance to municipalities on a number of demonstration projects to enhance river and stream continuity. These include Tower Brook in Chesterfield, Bronson Brook in Worthington, and Labor in Vain Brook, Somerset, MA.

**Education and Training**

Partners in the River and Stream Continuity Project have engaged in extensive education and training programs raising awareness of the ecological issues associated with road-stream crossings, standards and regulations, volunteer assessment protocols, crossing design and construction, and strategies for protecting and enhancing river and stream continuity. Training workshops on crossing design and associated regulations and policy have been developed and implemented for state and federal agency personnel, municipal conservation commissioners, civil engineers and environmental consultants. Volunteer training and support programs have been developed and implemented. Information has been presented at the Northeastern Wildlife and Transportation Conference, American Fisheries Society annual conference, and International Conference on Ecology and Transportation.

Project personnel also served on an interdisciplinary team organized and coordinated by the USDA Forest Service to develop and implement training programs and a technical guidance document on the "Stream Simulation" approach to road-stream crossing design. Stream Simulation is a design approach that avoids flow constriction during normal conditions and creates a stream channel that maintains the diversity and complexity of the streambed through the crossing. The goal is to create crossings that are essentially "invisible" to aquatic organisms by making them no more of an obstacle to movement than the natural channel. Detailed information about "Stream Simulation" will soon be available in an USDA Forest Service guidance document currently in the final stages of development (USDA in preparation).

## Conclusion

Road networks and river systems share several things in common. Both are long, linear features of the landscape. Transporting materials (and organisms) is fundamental to how they function. Connectivity is key to the continued functioning of both systems. Ultimately, our goal should be to create a transportation infrastructure that does not fragment or undermine the essential ecological infrastructure of the land. The River and Stream Continuity Project is an effort to inventory and more effectively address barriers to fish movement and river and stream continuity.

**Acknowledgements:** Funding for the River and Stream Continuity Project was provided by: the Massachusetts Watershed Initiative (Executive Office of Environmental Affairs), Massachusetts Riverways Program (Department of Fish and Game), the Sweetwater Trust, and The Nature Conservancy. The River and Stream Continuity Project is part of the New England Regional Water Program supported by the USDA Cooperative State Research, Education and Extension Service.

## References

Massachusetts Department of Environmental Protection. 2006. Massachusetts Wildlife Habitat Protection Guidance for Inland Wetlands. MA DEP, Boston MA. 64+v pp.

River and Stream Continuity Partnership. 2006. Massachusetts River and Stream Crossing Standards. University of Massachusetts, Amherst MA. 18 pp.

U.S. Army Corps of Engineers. 2005. Department of the Army Programmatic General Permit: Commonwealth of Massachusetts. USACOE, Concord MA. 30 pp.

USDA Forest Service. [In preparation]. Stream Simulation: an Ecological Approach to Road-Stream Crossings. San Dimas CA: USDA Forest Service National Technology and Development Center.

# A Review of the Influences of Road Crossings on Warmwater Fishes in Ouachita Mountain Streams, Ouachita National Forest

**Richard W. Standage** (501-321-5247, rstandage@fs.fed.us), U.S. Department of Agriculture, Ouachita National Forest, P.O. Box 1270, 100 Reserve Street, Hot Springs, AR 71902, Fax: 501-321-5353 USA

**Charles J. Gagen** (479-964-0814, cgagen@atu.edu), Fisheries and Wildlife Science Program, Arkansas Tech University, 1701 N. Boulder Avenue Russellville, AR 72801, Fax: 479-964-0837 USA

**Abstract:** Several studies have measured the influence of road crossings on fish movement and on fish communities within the Ouachita National Forest. In an initial study, passage of more than a hundred darters through a baffled pipe and over a grouted rip-rap ramp was documented over nine weeks. A broader study of fish movements associated with nine crossings ranging from natural-bottomed fords to piped crossings showed that natural ford and box culverts allowed unrestricted fish passage, but other designs were associated with reduced passage or none at all. Six piped crossings were examined in more detail including three that were modified in an attempt to improve fish passage. Fish were less likely to move across reaches with these low-water bridges compared to nearby natural reaches without low-water bridges. Average species richness was higher for fish communities downstream of the crossings compared to upstream (12.5 versus 6.3). Two rip-rapped low-water crossings were the only ones where upstream fish passage was detected. In a study of leopard darters, only one individual was detected moving downstream through a low-water crossing and none were found moving upstream. In an extensive study of twenty-one randomly selected low-water crossings, species richness was greater downstream versus upstream (9.4 versus 7.1, respectively). Total abundance (total number of all individuals of all species) was also significantly lower in the combined upstream reaches versus the combined downstream reaches. New box culvert installations indicated limited success in upstream passage, though detection of marked fish was quite low. Watershed-scale road and crossing densities were not significantly related to diversity and abundance of warmwater fishes or smallmouth bass density and biomass. Another study looking strictly at the effects of low-water crossings on stream geomorphology found stream widening upstream, stream incision downstream and changes in substrates when compared to a representative reach without a crossing. Work continues in designing, constructing and monitoring crossings that will pass fish.

## Introduction

While dams have long been acknowledged as barriers to fish movements (Yeager 1993), published studies of road crossing impacts were scarce through the 1980's and the few exceptions were limited primarily to migrating adult salmon and steelhead trout (Anderson and Bryant 1980). It was not until the mid 1990's that research on road crossing impacts and fish passage needs for warmwater fish species began to receive much notice (USDA Forest Service 1998, Newbrey et al. 2001). In 1991, when confronted with a newly acquired tract of land containing a multi-culvert road crossing apparently blocking access to a historic spawning site for the Ouachita Mountains endemic, paleback darter (*Etheostoma pallididorsum*), we completed a literature search for relevant information and possible solutions. Relevant publications appeared limited to a single paper on the critical swimming speed of two warmwater darter species (Matthews 1985). Thus began the Ouachita National Forest's studies of various aspects of fish passage at road crossings, mostly with university cooperators, which have continued to date.

## Physiography of the Study Area

The Ouachita National Forest is located in western Arkansas and southeastern Oklahoma and includes nearly 741,000 ha (1.83 million acres) of federally managed land. The Ouachita National Forest lies within the Subtropical Division of the Humid Temperate Domain. Most of the Forest is within the Ouachita Mountains Section of the Ouachita Mixed Forest-Meadow Province. The study areas contain high to mid-elevation mountains to hills with wide valleys and east-west trending ridges with very steep to moderately steep north facing slopes and moderately sloping south-facing slopes. Elevations range from 122 meters (400 feet) in the valleys to 701 meters (2,300 feet) above sea level in the mountains. Arkansas study sites were within the Ouachita River drainage and Oklahoma sites were within the Little River drainage, both tributaries of the Red River and eventually the Mississippi River. Maximum mean monthly temperatures range from 9.4°C (49°F) in January to 34.2°C (93.5°F) in July for the Forest. Mean annual precipitation ranges from 100 centimeters (39.4 inches) per year to 141 centimeters (55.5 inches) per year across the Forest. (USDA Forest Service 2005).

## Case Studies

### Jessieville Culvert Repair Study

In an effort to improve fish passage at a culvert barrier less critical than the one mentioned for the paleback darters, a 1.8 meter diameter (70 inch) corrugated metal pipe with a nearly 36 centimeter (14 inch) drop (figure 1) was paved inside with depressions and small rocks inserted as fish cover and to break up velocities. A grouted riprap ramp was added to eliminate the drop (figure 2).

Figure 1. Rusted out pipe with drop. Figure 2. Grouted pipe and riprap ramp.

Prior to culvert modification, the lead author (Standage et al. 1993) electrofished upstream of the culvert and found no fish. After modification, the ramp, the culvert and 60 meters upstream of the culvert (to a natural fish barrier) was electrofished weekly for nine weeks from February through early April of 1992. Captured orangebelly darters (*E. radiosum*) from each section received a batch fin-clip, by section and were released downstream of the ramp at the creek's confluence with a larger stream. Significant numbers of these darters were captured and recaptured upstream of the culvert where none had been captured prior to the modifications (figure 3). These darters were also captured and recaptured on the ramp and in the culvert. However, no other species were found upstream of the modified culvert even though green sunfish (*Lepomis cyanellus*), central stonerollers (*Campostoma anomalum*) and longear sunfish (*Lepomis megalotis*) were common downstream of the study tributary.

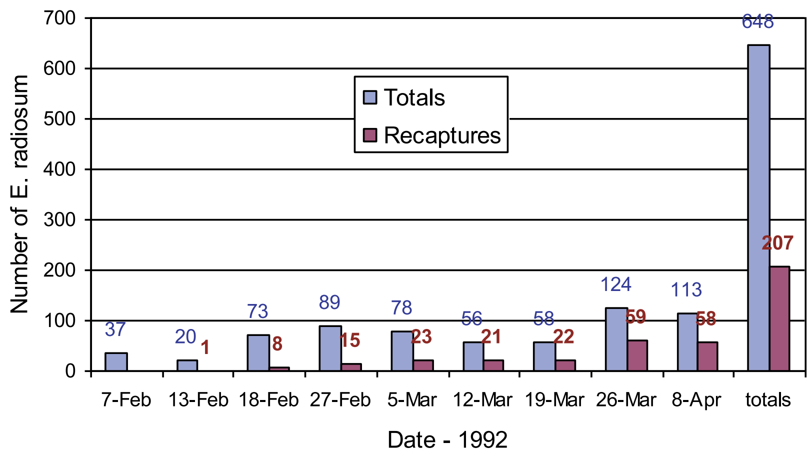



Figure 3. Captures and recaptures of orangebelly darters upstream of the modified ramp and culvert.

*Swimming speed studies*

In searching for guidance in designing the culvert and ramp modifications for the previous project, the paucity of literature for warmwater fish swimming speeds justified the need for study of local species. A cooperative study by Layher and Ralston (1997a-h) was initiated with the newly formed US Fish and Wildlife Service Research Project at the University of Arkansas, Pine Bluff to assess swimming characteristics of Ouachita drainage species (table 1).

Table 1: Sustained and Burst Swimming Speeds of Selected Warmwater Species (Layher and Ralston 1997a-h)

| Species | Sustained swimming speed | Burst swimming speed |
|---|---|---|
| Central stoneroller (*Campostoma anomalum*) | | 36.6-54.6 cm/s |
| Bigeye shiner (*Notropis boops*) | 19.8 cm/s | 39.6 cm/s |
| Golden shiner (*Notemigonous crysoleucas*) | 48 cm/s | 58 cm/s |
| Greenside darter (*Etheostoma blennioides*) | | 22.9 cm/s |
| Orangebelly darter (*Etheostoma radiosum*) | | 18.7 cm/s |
| Redfin darter (*Etheostoma whipplei*) | | 16.7 cm/s |
| Longear sunfish (*Lepomis megalotis*) | 19 cm/s | 33.5 cm/s |

These data were incorporated into a fish passage modeling software package developed by the Forest Service called FishXing (http://stream.fs.fed.us/fishxing/index.html) (Love et al. 1999).

*Fish movements relative to crossing types*

Warren and Pardew (1998) conducted an electrofishing mark-recapture study utilizing a three segment design to detect individual fish movements upstream or downstream through various stream crossing types and between the downstream and further downstream similar-sized segments to detect natural movements unencumbered by a crossing. The natural-bottomed ford and the box-culvert crossings had movements of marked fish through the crossings comparable with or higher than marked fish movements detected for natural reaches. The vented low-water crossings with smooth concrete or corrugated plastic pipes had significantly reduced fish passage and there was no fish passage at an unvented, slab low-water crossing that functioned as a low-head dam. They hypothesized that the increased water velocity through the vented crossings constituted a major mechanism by which the crossings restricted fish movements.

*Fish movements focusing on low-water vented crossings*

To further explore the impacts of vented low-water fords on the Forest, six of the more than 300 such crossings on the Forest were examined by Gagen and Landrum (2000) utilizing the same study design as Warren and Pardew (1998). After one year of sampling (1997), three of the crossings were modified by backfilling with riprap to eliminate drops from the structures' aprons into plunge pools (1998) (figures 4 & 5). The same study design was repeated following these modifications (Rajput, 2003).

Figure 4. Vented low-water ford fish barrier.

Figure 5. Vented low-water ford modified.

Prior to modification, species richness upstream of the crossings was found to be only half that found downstream (6.3 species upstream versus 12.5 species downstream and 10.0 species further downstream at the natural/reference reach). Recapture of marked fish that had moved across reaches with low-water fords was less than half that of marked fish found to have moved across the natural/reference reaches. Marked fish found to have moved were twice as likely to move downstream than upstream. After the three crossings were modified to eliminate the jump, two of the modified crossings had improved fish passage as detected by marked fish. For the two years of mark-recapture efforts at the three modified and three unmodified low water vented fords, 27 fish moved upstream across the modified crossings and 35 moved downstream across them. At the unmodified crossings, no upstream fish movements were detected and only 6 downstream movements were detected through the crossings. Fish moving across low-water crossings included creek chubs (*Semotilus atromaculatus*), green sunfish and longear sunfish. Fewer fish were found to have moved through the culverts of the low-water crossings than across natural reaches in either direction, leading to the conclusion that these crossings constituted various degrees of filter barriers relative to movements of warmwater fishes.

**Leopard Darter Movement Studies**

In 1995, the Ouachita National Forest completed a land trade with Weyerhaeuser in which the Forest acquired over 44,400 hectares (110,000 acres) of land in the Glover River tract of Southeastern Oklahoma including nearly 23 kilometers (14 miles) of the Glover River which is designated as Critical Habitat for the threatened leopard darter (*Percina pantherina*). Within this acquisition were six, man-made low-water crossings. To assess the fish barrier potential of the six crossings, a study was developed with Oklahoma University researchers to compare leopard darter movements at one of the low-water crossings to movements across a natural shallow riffle that was occasionally used as a natural low-water ford. In addition, laboratory trials were conducted to provide guidance in crossing design for replacement river crossings. The constructed crossing had two round culverts, each roughly 60 centimeters in diameter, and four box-culverts, each approximately 3 meters wide. Schaefer et al. (2001) implemented a mark-resight study on these two sites in 1998 and 1999 with two study sections upstream and two downstream for each site. Leopard darters from the nearest section on each side of the natural riffle and the low-water crossing were marked but all four sections were surveyed for marked leopard darters to detect upstream or downstream movements.

They found few leopard darters moved from their original capture sites at either location. At the natural riffle site, two to three leopard darters moved downstream across the riffle and leopard darters also moved upstream into deeper water when water temperatures exceeded 29˚C (84˚F). At the low-water crossing, only movement of one to two leopard darters downstream through the structure was detected (batch marking precluded determination of whether it was the same darter that had moved on two resight occasions). Leopard darter movements into deeper (4-5 meter deep) pools from shallower areas (1 meter or less deep) corresponding with 3-4˚C (5-7˚F) cooler temperatures when their preferred shallower habitats warmed to 29˚C had not been previously documented (Schaefer et al. 2001).

In laboratory trials examining leopard darter movements between clusters of preferred habitats, Schaefer et al. (2001) found that imposing a simulated crossing structure into the artificial stream channel not only reduced movement through the crossing structure but also overall movements between the habitat clusters either side of the structure. Square wide openings appeared less disruptive than square narrow and small smooth or ribbed round openings.  The researchers recommended that replacement crossings be positioned to avoid precluding access to thermal refugia and that openings in the crossing be as large as possible.

*Community-level impacts of low-water vented crossings*

More extensive surveys were implemented to assess the extent to which reduced movement due to vented crossings might influence fish diversity and abundance (Rajput 2003). The rationale for these concerns was based on the observation that relatively long segments of relatively large streams in the Ouachita Mountains experience discontinuous surface flow during summer (e.g. Homan et al., 2005a). The resulting widespread mortality of associated fishes produces ecosystems that can be highly influenced by extinction-recolonization dynamics, thus pointing to the importance of movement in determining community structure (Gagen et al., 1998).  The survey included 28 randomly selected low-water vented fords over a range of stream orders/sizes. The approach included two upstream and two downstream segments to balance a one-time sampling effort (without the follow-up mark-recapture movement phase). Field measurements of the stream crossing velocity, slope, drop, etc. from each site were applied to the FishXing program (Love et al. 1999) to predict the barrier potential and to the then-draft National Inventory and Assessment Procedure for Identifying Barriers to Aquatic Organism Movement at Road-Stream Crossings (USDA Forest Service 2000). Model predictions were compared to observed patterns of fish occurrence where presence downstream, but not upstream of a crossing was defined as a "loss" to the community.

The low-water crossings averaged a two species loss in diversity from downstream to upstream and fish were less abundant upstream with an average loss of thirty individuals. As expected, fewer species were captured at sites farther upstream in watersheds. In 67% of the 21 study streams sampled for fish, fewer species were found upstream of the crossings which had spring baseflow velocities ranging from 16 to 85 cm/s (0.5-2.8 ft/sec). Species losses occurred upstream of all crossings with a spring baseflow equal to or greater than 60 cm/s (1.9 ft/sec). Bluegill (*L. macrochirus*), northern hogsucker (*Hypentelium nigricans*) and pirate perch (*Aphredoderus sayanus*) were never found upstream of low-water crossings.

FishXing software provided a slightly greater percentage of congruence with species loss than did the draft Assessment Procedure guide. The FishXing software utilized Layher and Ralston's (1997 a-h) swimming speed data for Ouachita species; whereas, the Assessment Procedure employed an example matrix for trout. An assessment matrix for local species and sizes of fish was not developed as recommended.  Seventy-one percent of the predictions from FishXing were congruent with the empirical data for species losses. Forty-eight percent of the Assessment Procedure guide results were congruent with the empirical data for losses with twenty-four percent of the guide results placed in an indeterminate passage category requiring additional study. Based on recommendations from this study, the Assessment Procedure guide was modified prior to finalizing to change the measurement of drop at the invert of the pipe to the measurement of any drop at the outlet, specifically including a drop from the crossing's apron to the stream below the structure. Crossing/culvert aprons in the Ouachita National Forest were typically designed without a drop at the pipe(s). Consequently, a drop measurement at that point would result in a spurious assessment of no drop; whereas, apron drops often emerged as crossings age.

**Latest Study of Fish Passage Through Box-Culverts**

Based on the results of the early fish passage studies, particularly Warren and Pardew (1998) and Gagen and Landrum (2000), the Ouachita National Forest abandoned the vented low-water crossing design and began replacing failing low-water crossings with either on-grade slabs or low-water box-culverts where traffic conditions dictated a higher standard crossing. With these concrete cast-in-place box-culverts costing a minimum of $100,000 and upwards of $150,000 or more, the concern is whether these crossings are in fact better for fish passage than their predecessors. Three recent box-culvert replacements were sampled in the spring of 2003 with fish marked separately in two downstream segments and two upstream segments (Homan et al. 2005b). Two of the streams with box-culverts were electrofished and the fish were marked in June, sampled twice during their driest times and then sampled once after fall flows resumed. The third crossing was on the Cossatot River which is double to triple the size of the other two streams.  There, approximately 2,500 fish were electrofished and marked on three occasions between September 29 and October 12 during low flows with nearly equal numbers upstream and downstream of the crossing.  Unfortunately, just prior to what would have been the last Cossatot sampling under renewed fall baseflow, the drainage received a large storm event with resultant flows too high to safely resample for the remainder of the season. Thus, this site had to be dropped from the analysis of results. The recently installed Muddy Gibbs crossing (designed to be "fish friendly"), had a marked fish population of 102 fish and a recapture rate of 11%. Five of the 11 recaptures had moved, with four having moved from downstream to upstream across the box culvert. These included two redfin pickerel (*Esox americanus*; formerly grass pickerel), and two central stonerollers. The Bear Creek crossing had a total of 785 marked fish with a recapture rate of 15%, but none of the recaptured fish indicated any movement from the study sections in which they were originally captured. The Bear Creek structure has a drop from the concrete apron into a plunge pool that likely constituted a barrier to upstream fish movements (figure 6). The Muddy Gibbs crossing's apron was designed to prevent plunge pool creation (figure 7).

Figure 6. Bear Creek box culvert with drop.

Figure 7. Muddy Gibbs crossing without a drop.

*Search for watershed-scale relationships between road networks and fish communities*

In 2004, Homan et al. selected three matched-size watersheds representing a gradient of road densities and road crossings to search for relationships between fish communities and the respective road measures. The Caney Creek watershed was within the Caney Creek Wilderness thus there were no roads or road crossings. Interestingly, it had the lowest species richness and lowest mean fish density based on bankfull areas and linear stream distance relative to adjacent roaded watersheds with crossings. However, Caney Creek also had the lowest conductivity, alkalinity and calcium concentrations which might have overridden effects of road density and crossing abundance. Ultimately, no clear relationship was found between road density or abundance of road crossings and the fish communities. Also as part of the study, smallmouth bass productivity was measured at similar points in the watersheds of Brushy Creek and the Cossatot River headwaters in the spring, summer and fall of 2004. While road density was similar for both watersheds, the total number of road crossings was higher in the Cossatot River headwaters which surprisingly had higher smallmouth bass production. Thus, this attempted watershed-scale approach did not indicate clear negative effects of roads on fish communities or smallmouth production. However, the small sample size, effects of a pre-fall flood event, possible spurious differences in angler induced smallmouth bass mortality, and inability to control or accurately measure smallmouth bass ingress and egress render conclusions quite tenuous at this time.

**Oklahoma Department of Wildlife Conservation's Glover River Stream Morphology Study**

Due to the results from the Schaefer et al. study (2001), the need to replace low-water crossings on the Glover River was evident in order to restore fish passage, particularly for the threatened leopard darter. In a cooperative study with the Oklahoma Department of Wildlife Conservation, Vincent et al. (2005) examined the road 53000 low-water crossing of the Glover River (figure 8), and compared it to a representative natural reach to assess the impacts of the current crossing and provide appropriate design criteria relative to streambed slope, elevation and wetted width for a new crossing. They used the Rosgen (1996) Level II assessment protocol measuring longitudinal profile, cross-section surveys, pebble counts and subsequent calculations of entrenchment ratio, and width/depth ratios relative to bankfull flows.

Figure 8. Glover River 53000 low-water crossing.

They found bankfull stage to occur near the 1.25 year flood interval for this hydrophysiographic province. The longitudinal baseflow slope at the Glover site was 0.015% upstream of the crossing and 6.13% downstream; whereas, the reference reach exhibited a mean baseflow slope of 0.25%. The median grain diameter was 109 millimeters (4.3 inches) in the reference reach versus 69 millimeters (2.7 inches) upstream of the Glover crossing and 237 millimeters (9.3 inches) downstream. Cross sections upstream of the crossing have widened as smaller aggregates were not transported and filled interstitial gravel spaces. Streambed scouring downstream of the crossing, presumably associated with excessive shear strength, has incised the stream and coarsened the substrate. Average natural stream width at the Glover Crossing should be approximately 24.5 meters (80 feet); however, it is nearly double that now. The pool habitat, width:depth ratio for the Glover crossing was 43.24 versus 18.96 at the reference site. For riffles, the width: depth ratios were 29.84 and 42.30 for the crossing and the reference sites, respectively. Thus it appears clear that the current crossing configuration profoundly affects all channel parameters measured and consequently affects habitat quality/availability for associated fishes.

## Conclusion

Fifteen years of fish passage studies on the Ouachita National Forest clearly indicate that road crossings not only impact fish diversity, community composition and population abundance but also the physical characteristics of the stream channel/habitat upstream and downstream the crossings. While engineered crossings may consider swimming speeds of targeted species, there also appear to be behavioral considerations that are subtle to us but important to fishes (e.g. longear sunfish are within the group of species found to have moved upstream through low-water vented-fords; whereas, closely-related and morphologically similar bluegill were not found upstream of these structures). Even when design considerations are made for fish passage at new or replacement road crossings, if bottom elevations are incorrectly set either at the planning or the construction phase and/or sediment balances and scour potentials are not adequately addressed, large sums of money can be spent on a very long-lived structure that limits fish passage. The Weyerhaeuser Bear Creek box culvert installation pictured above (figure 6) is a prime example of such.

Tools, most developed in the western states, are available for designing and assessing fish passage at crossings; however, these models need to be fine-tuned to meet local environmental conditions and fish species. While mark-recapture or mark-resight surveys can detect fish movements through crossings or the lack thereof, logistics and expenses may be prohibitive to conduct this level of work at a very broad scale. One-time sampling for fish species diversity, while less labor intensive, may not be precise enough for some applications; thus, results are likely seasonally influenced and the practice is probably most appropriate for small streams high in watersheds and without extensive species diversity. We see a need for new approaches to detect fish movements in unsecured remote sites (e.g. passive monitoring equipment). The most useful approaches must be effective during a wide range of water flows to best advance our understanding of how associated environmental conditions affect species and size-specific timing of fish movements. These issues must be addressed to fully evaluate the importance of movements to natural ecosystem functions and to protect those ecosystem functions.

The Ouachita National Forest will continue to examine its efforts in restoring aquatic organism passage at newly constructed crossings to further its understanding of how to reconnect fragmented aquatic habitats.

**Biographical Sketch:** Richard Standage received his B.S. degree in fisheries management from Utah State University in 1973. He worked five years for the Kansas Fish and Game Commission, three years of that as a District fisheries biologist and two years as biologist and project leader for their water quality assessment team. Beginning in 1978 he moved to the USDA Forest Service as fisheries biologist for the Sequoia National Forest in California working on the recovery of the Little Kern golden trout. In 1984 he moved to Virginia as the Forest Fisheries Biologist/Program Manager for the George Washington National Forest and also covered the Jefferson National Forest. In 1990 he transferred to the Ouachita National Forest as the Forest Fisheries Biologist/Program Manager also with responsibility for the aquatic threatened and endangered species program and he is the Forest's hydropower coordinator. He has been working with fish passage restoration research and design applications since the early '90's and initiated some of the first studies on warmwater stream fish passage issues and swimming speed studies for warm water fish species through cooperative efforts with university researchers in Arkansas and Oklahoma.

Charles J. Gagen received his B.S. degree in Wildlife Biology from the University of Tennessee, and M.S. and Ph.D. in Ecology from Penn State University in 1991. Since that time, he has been a professor of fisheries science at Arkansas Tech University, where he currently serves as the Head of the Biology Department. His research has focused on determining the effects of environmental variables on fish populations and communities, especially in streams. Early studies documented direct effects of acid rain on coldwater fishes; whereas, more recent studies have looked at warmwater fish responses when sections of streams go dry in summer. In both cases, movement and mortality have emerged as important aspects of the population dynamics involved. Thus, tendencies for road crossings to affect fish movement patterns are viewed as potential impacts on community structure.

## References


Anderson, L. and M. Bryant. 1980. Fish passage at road crossings: an annotated bibliography. Gen. Tech. Rep. PNW-117. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 10 p.

Gagen, C.J. and C. Landrum. 2000. Response of warm-water fish to road crossings on Ouachita mountain streams. Report to USDA Forest Service, Ouachita National Forest, Hot Springs, AR. 8 pp.

Gagen, C.J., R.W. Standage, and J.N. Stoeckel. 1998. Ouachita madtom (*Noturus lachneri*) metapopulation dynamics in intermittent Ouachita Mountain streams. Copeia 1998: 874-882.

Homan, J.M., N.M. Girondo, and C.J. Gagen. 2005a. Quantification and prediction of stream dryness in the Interior Highlands. Journal of the Arkansas Academy of Sciences.59:95-100.

Homan, J.M., N. M. Girondo and C.J. Gagen. 2005b. Relationships between roads and fish communities of the Ouachita National Forest. Report to USDA Forest Service, Ouachita National Forest, Hot Springs, AR. 28 pp.

Layher, W.G. and A.O.Ralston. 1997a. Differences between electrofished and seined golden shiners as related to swimming performance. Final report to USDA Forest Service, Ouachita National Forest, Hot Springs, AR. 16 pp.

Layher, W.G. and A.O.Ralston. 1997b. Notes on the swimming ability of a large central stoneroller. Final report to USDA Forest Service, Ouachita National Forest, Hot Springs, AR. 3 pp.

Layher, W.G. and A.O.Ralston. 1997c. Swimming performance of juvenile bighead carp (*Hypophthalmichthys nobilis*). Final report to USDA Forest Service, Ouachita National Forest, Hot Springs, AR. 5 pp.

Layher, W.G. and A.O.Ralston. 1997d. Swimming speed performance of the bigeye shiner from the Ouachita River drainage. Final report to USDA Forest Service, Ouachita National Forest, Hot Springs, AR. 13 pp.

Layher, W.G. and A.O.Ralston. 1997e. Swimming speed performance of the longear sunfish. Final report to USDA Forest Service, Ouachita National Forest, Hot Springs, AR. 10 pp.

Layher, W.G. and A.O.Ralston. 1997f. Swimming speeds of the central stoneroller. Final report to USDA Forest Service, Ouachita National Forest, Hot Springs, AR. 11 pp.

Layher, W.G. and A.O.Ralston. 1997g. A comparison of swimming performance of orangebelly darters collected by kick-seining and backpack electrofishing. Final report to USDA Forest Service, Ouachita National Forest, Hot Springs, AR. 9 pp.

Layher, W.G. and A.O.Ralston. 1997h. Critical current speeds of several darter species of the genus Etheostoma. Final report to USDA Forest Service, Ouachita National Forest, Hot Springs, AR. 9 pp.

Love, M., S. Firor, N. Furniss, R. Gubernick, T. Dunklin, and R. Quarles. 1999. FixhXing (version 2.2). USDA Forest Service, San Dimas Technology and Development Center, San Dimas CA. http://www.stream.fs.fed.us/fishxing/ downloadpage.html.

Matthews, W.J. 1985. Critical current speeds and microhabitats of the benthic fishes Percina roanoka and Etheostoma flabellare. Envir. Biol. Fishes 12(4):303-308.

Newbrey, M.G., M.A. Bozek and C.E. Edwards. 2001. Effects of stream barriers as impediments to warmwater fish movement with an emphasis on culverts and siltation: an annotated bibliography. Final report to USDA Forest Service, North Central Station, Grand Rapids, MX. 52 pp.

Rajput, S. 2003. The effects of low-water bridges on movement, community structure, and abundance of fishes in streams of the Ouachita Mountains. Master's Thesis. Arknsas Tech University, Russellville, AR. 94 pp.

Rosgen, D.L. 1996. Applied River Morphology. Wildlife Hydrology, Pagosa Spring, CO.

Schaefer, J.F., E. Marsh-Matthews, D.E. Spooner, K.B. Gido, and W.J. Matthews. 2003. Effects of barriers and thermal refugia on local movement of the threatened leopard darter, *Percina pantherina*. Envir. Biol. Fishes 66:391-400.

Standage, R.W., H.L. Mansbridge, and K.M. Hartman. 1993. Culvert modification to provide passage for orangebelly darters. File report of USDA Forest Service, Ouachita National Forest, Hot Springs, AR. 8 pp.

U.S. Department of Agriculture, Forest Service. 1998. Water/Road interaction: an annotated bibliography. Compilers: R.L. Copstead, K. Moore, T. Ledwith, and M. Furniss. San Dimas Technology and Development Center, San Dimas, CA. 160 pp. http://www.stream.fs.fed.us/water-road/w-r-pdf/bibliography.pdf.

U.S. Department of Agriculture, Forest Service. 2002. DRAFT-National inventory and assessment procedure for identifying barriers to aquatic organism movement at road-stream crossings. USDA Forest Service, San Dimas Technology and Development Center, San Dimas, California. http://fsweb.sdtdc.wo.fs.fed.us/ programs/eng/aopxing/Products/NIAP.pdf (final publication).

U.S. Department of Agriculture, Forest Service, Ouachita National Forest. 2005. Final Environmental Impact Statement for the Revised Land and Resource Management Plan, Ouachita National Forest, Arkansas and Oklahoma.. Hot Springs AR. 385 pp.

Vincent, J.R., P.E. Balkenbush, and C. Whisenhunt. 2005. Assessment of road crossing impacts on local stream bed morphology and fish movement potential using applied fluvial geomorphology techniques. Final report to USDA Forest Service, Ouachita National Forest, Hot Springs, AR. 11 pp.

Warren, M.L. Jr. and M.G. Pardew. 1998. Road crossings as barriers to small-stream fish movement. Transactions of the American Fisheries Society. 127:637-644.

Yeager, B.L. 1993. Dams. Pages 57-113. In C.F. Bryan and D.A. Rutherford, editors. Impacts on warmwater streams: Guidelines for evaluation. Southern Division, American Fisheries Society, Little Rock, AR.

# A Strategic Approach for the Identification and Correction of Fish Passage on National Forest Lands for the Pacific Northwest

**David Heller** (503-808-2994, daheller@aol.com), Regional Fisheries Program Leader, USDA Forest Service, PNW Region, 3335 NE 32nd Ave., Portland, OR 97212 USA

**Abstract**

A multi-year, cooperative program for the identification, prioritization and correction of fish passage at road- stream crossings (more than 4,000 sites on a land base of 24 million acres) sites has been developed and is being implemented over the last five years.

A comprehensive assessment of fish passage, at road-stream crossings, was completed for all 17 of the National Forests in the states of Oregon and Washington. The assessment took 3 years to plan and complete. More than 5,100 crossings, representing 82% of all crossings on fish bearing streams, were evaluated in the field. Initial determinations were made to identify which crossings would pass all species and life stages of fish found in the respective streams. Juvenile coho salmon were used as the target species for evaluation and a matrix integrating a variety of crossing characteristics including crossing type, crossing structure gradient, outlet drop height, a ratio of crossing structure width to bank full width, etc. was utilized to categorize sites into three categories (passable, not passable and need further investigation). Results indicate that 68% of all road-stream crossings (bridges included) impair, to some degree, upstream passage for at least one species/life stage of fish. Considering only culvert crossing structures, about 90% are impassable. It is estimated that more than 3,000 miles of habitat for fish is affected. This represents about 15% of the total miles of fish bearing streams on National Forest System lands of the Pacific Northwest Region. The assessment has provided the foundation for a more systematic and strategic approach to improve fish passage as part of the Regional Aquatic Restoration Program.

A cooperative process to prioritize river basins and treatment sites is being used to guide selection of sites for remediation. Regional design standards have been established for replacement crossings and 2 design assistance teams have been created to improve the effectiveness and cost efficiency of new structures. More than 250 sites have been treated over the last 5 years. Increasingly, cooperative funding is being used to increase the number of sites being treated.

A basic protocol for monitoring post treatment effectiveness is currently being revised to provide more quantitative results for post project monitoring. Additional research on the biological response of aquatic organisms, including non game and juvenile fish, during a full range of flows, is needed.

# Supporting Water, Ecological, and Transportation Systems in the Great Lakes Basin Ecosystem

**Judy Beck** (312-353-3849, Beck.Judy@epamail.epa.gov), Lake Michigan Manager, and
**Sherry Kamke** (312-353-5794, Kamke.Sherry@epamail.epa.gov), Environmental Specialist, Great Lakes National Program Office, U.S. Environmental Protection Agency (USEPA), Region 5, 77 W. Jackson Blvd., Chicago, IL 60604 USA
**Kimberly Majerus** (708-283-4346, Kimberly.Majerus@.dot.gov), Ecologist and GIS Analyst, Environmental Team, Resource Center, Federal Highway Administration (FHWA), 19900 Governors Drive, #301, Olympia Fields, IL 60461 USA

**Abstract:** The North American Great Lakes Basin ecosystem is globally significant. A unique, bi-national Great Lakes Water Quality Agreement (GLWQA) between Canada and the United States is the backbone for cooperative efforts within the Basin. The Agreement establishes a basis for implementing a systems approach "to restore and maintain the physical, chemical and biological integrity of the waters of the Great Lakes Basin Ecosystem,"… as…"the interacting components of air, land, water and living organisms, including humans, within the drainage basin" (GLWQA 1987). This paper introduces the interacting systems of the Great Lakes Basin ecosystem. Lessons learned and the shortfalls of approaches that divide an ecosystem into individualized compartments are also summarized. Discussion includes advancements in practices and partnerships to improve ecosystem health. The purpose of this paper is to highlight activities within the Great Lakes Basin and to discuss a systems approach to sustaining multiple economic, community, and environmental benefits.

## Introduction

The Great Lakes Water Quality Agreement can be viewed as a model of international management and protection for a shared natural resource. A process for implementation of the Agreement includes periodic public reviews and revisions. Amendments to the 1972 Agreement in 1978, 1983, and 1987 provided several advancements that are discussed in this paper. Currently, public review of the Agreement is underway. The purpose of the review is to identify if any changes are needed to help ensure that the Agreement can continue to serve as a bi-national, visionary document that drives cooperative efforts for emerging, new, and long-standing Great Lakes priorities.

Activities to implement the Great Lakes Water Quality Agreement include cooperative efforts between an International Joint Commission (IJC) as a single entity representing Canada and the United States, the two governments of Canada and the United States, eight states within the U.S. (Illinois, Indiana, Michigan, Minnesota, Ohio, New York, Pennsylvania, and Wisconsin), and the Canadian Province of Ontario. Participation extends to federal, Tribal, regional, state, county, and local levels of government and agencies and the private sector, including private citizens. Partnering toward shared goals and objectives is an ongoing process for the Great Lakes. Other examples of activities and cooperative efforts underway at a national level and for the Great Lakes region are discussed in this paper.

Several United States environmental and transportation laws, requirements, and initiatives are complementary to the activities discussed in this paper. A few examples include the National Environmental Policy Act, the Clean Water Act, the National Historic Preservation Act, and the Endangered Species Act. Other examples exist at the national, Tribal, regional, state, and local levels. Transportation legislation and regulations support interdisciplinary approaches to transportation decision-making for planning and project delivery. As one example, the 2005 transportation legislation more fully links together environmental and transportation practitioners to accomplish long-range transportation planning. Provisions for environmental reviews and project level requirements are also included. The 2005 transportation legislation is the Safe Accountable Flexible Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU 2005). Many complimentary efforts are also underway in Ontario, Canada.

Several existing reports and references are available as summaries about the systems and the cooperative efforts within the Great Lakes Basin ecosystem. One example of a compilation of materials and web links is supported by the U.S. Environmental Protection Agency, Great Lakes National Program Office (USEPA GLNPO) at: http://www.epa.gov/glnpo/. Further details are available from this source as well as other sources. An overview of the Great Lakes Basin ecosystem and a systems approach to ecosystem management is provided below.

## Overview: Systems and Benefits of the Great Lakes Basin Ecosystem

The water system of the Great Lakes Basin is a source of drinking water for more than 40 million people in Canada and the United States (IJC 2005). Drinking water is provided by both surface water and ground water. The Great Lakes contain 18 percent of the fresh surface water in the entire world (Canada and USEPA, GLNPO 1995). The Basin is a broad landscape of 290,000 square miles (750,000 square kilometers) (TNC 2000). This expansive watershed has a diversity of climate, soils, ecology, hydrology, topography, and cultures. The Great Lakes Basin ecosystem is a diversity of prairies, savannahs, fens, bogs, forests, alvars, dunes, beaches, streams, shorelines, and lakes with an abundance of flora and fauna and various rural and urban land uses. More than 30 unique natural communities that occur within the Basin are rarely found on earth and might not exist in any other locations (TNC 1997).

The Great Lakes Basin extends across the international boundary of the United States and Canada encompassing 2 provinces and 8 states "and includes the lakes, connecting channels, tributaries, and groundwater that drain through the international section of the Saint Lawrence River" (IJC 2000). Glacial and natural processes shaped the drainage patterns and the landscape of the Basin after the retreat of the last glacier 10,000 years ago (Canada and USEPA, GLNPO 1995). The maps in figure 1 show the natural watershed boundary that shapes the Basin and its position in North America. The 5 Great Lakes of Superior, Michigan, Huron, Erie, and Ontario are also shown.

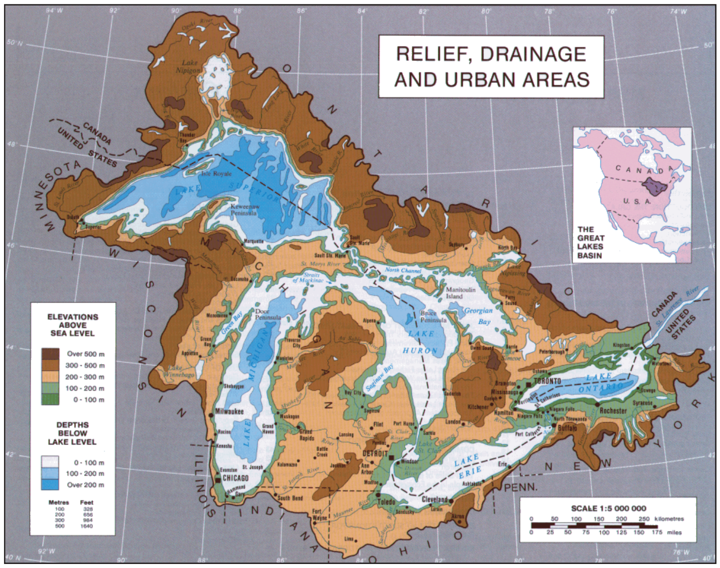



Figure 1. Great Lakes Atlas: Relief, Drainage, and Urban Areas, showing the natural watershed boundary of the Basin. (Source: Canada and USEPA, GLNPO 1995).

A basin/watershed can be described as a region or area from which water drains into a single stream, lake, water body, or ocean. Topography and terrain are the foundation for natural drainage patterns and natural watershed/basin and sub-watershed/sub-basin boundaries. The Great Lakes Basin boundary defines a natural geographic area that is used as a focus for bi-national, ecosystem-based management (Canada and USEPA, GLNPO 1995).

An ecosystem is comprised of interacting systems. Figure 2 illustrates this concept. A balance within and between systems is ideal for sustaining multiple benefits through time.

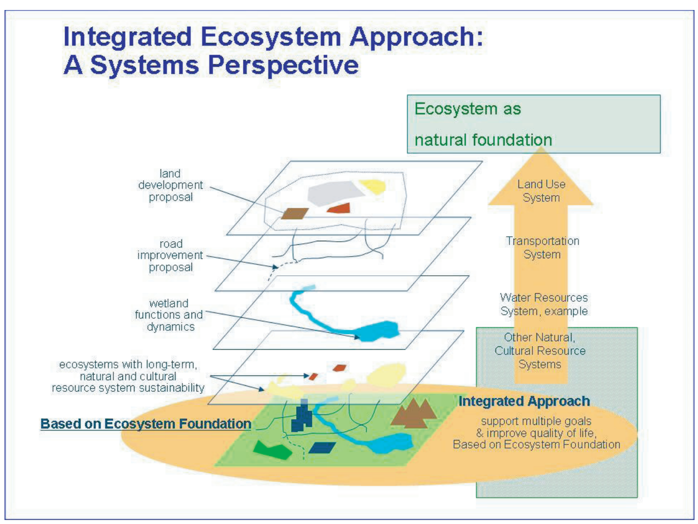



Figure 2. An ecosystem foundation can provide multiple benefits sustained by an effective interaction between systems, independent of jurisdiction or political boundaries (Source: Available within the public domain).

The integrated systems shown at the bottom of figure 2 is the foundation of a systems approach. An understanding of systems and their interactions has advanced over many years. With changes to systems, natural processes occur in response as homeostasis. A few highlights about systems within the Great Lakes Basin ecosystem are discussed below.

## Interacting Systems Within the Great Lakes Basin Ecosystem

A systems approach for the Great Lakes Basin ecosystem is cooperatively agreed upon within the bi-national Great Lakes Water Quality Agreement for “the interacting components of air, land, water and living organisms, including humans, within the drainage basin of the St. Lawrence River at or upstream from the point at which this river becomes the international boundary between Canada and the United States” (GLWQA 1987).

Figure 3 shows some interacting processes including surface and groundwater storage and flows as well as precipitation, water infiltration into soil, surface runoff, transpiration, evaporation, and flow through connecting channels between the Great Lakes (Canada and USEPA, GLNPO 1995). Under natural conditions, the Great Lakes are at low elevations in the landscape and are receiving waters within the Basin (Grannemann and Weaver 1998).

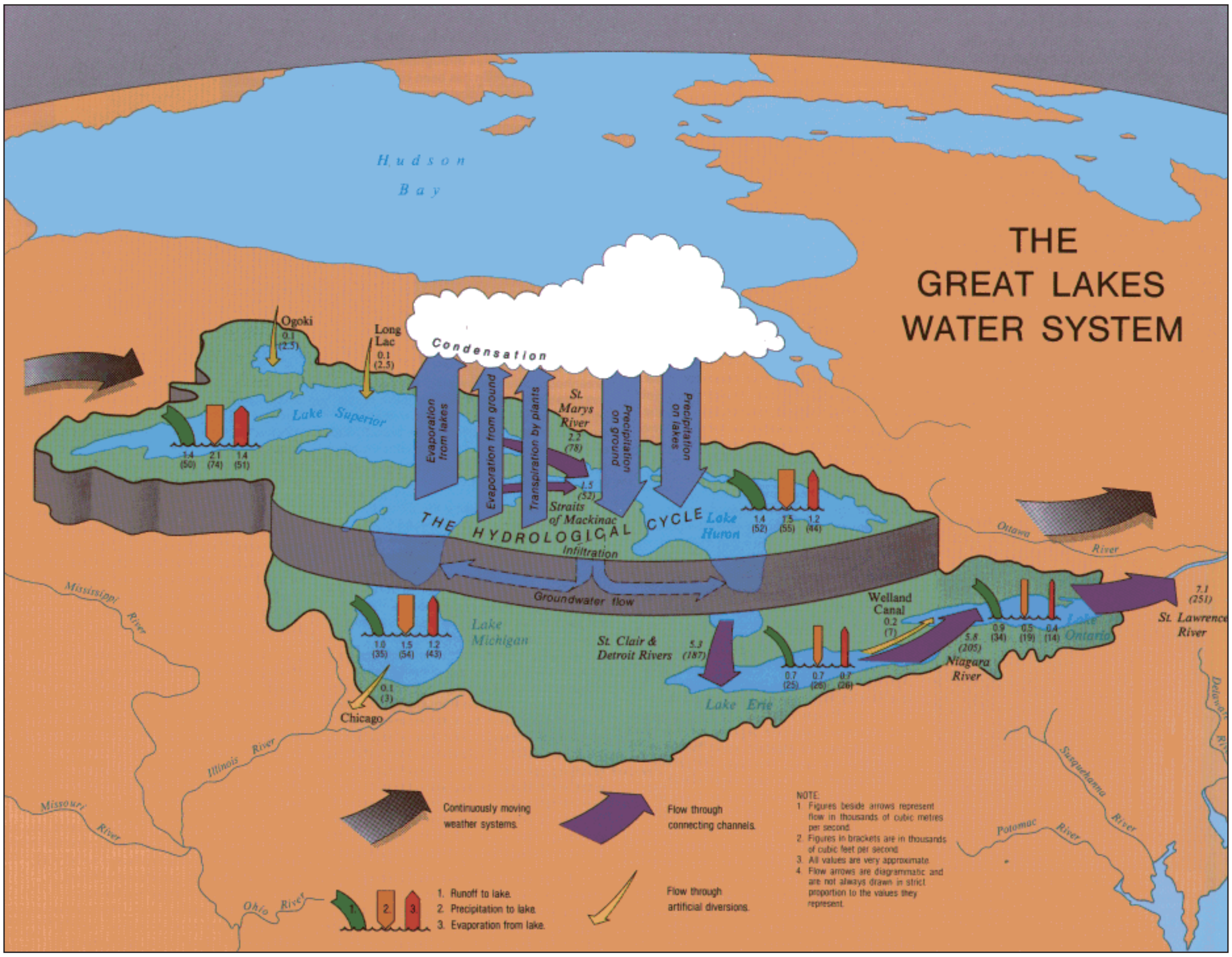



Figure 3. The natural drainage boundary of the Great Lakes Basin watershed and the cycling processes between water, land, and atmospheric systems within the Basin. (Source: Canada and USEPA, GLNPO 1995).

The Great Lakes Basin ecosystem has supported Native American Indians and their cultures for millennia. "The first Europeans found a relatively stable ecosystem, which had evolved during the 10,000 years since the retreat of the last glacier" (Canada and USEPA, GLNPO 1995). Expansion of human settlement continued through time. "In the United States, transcontinental movement of population and industry"..."fostered a dynamic" in land use and development of infrastructure"... to support new settlements and new economic activity" (IJC 2000). Population changes in the Basin from 1900 to 1990 are shown in figure 4.

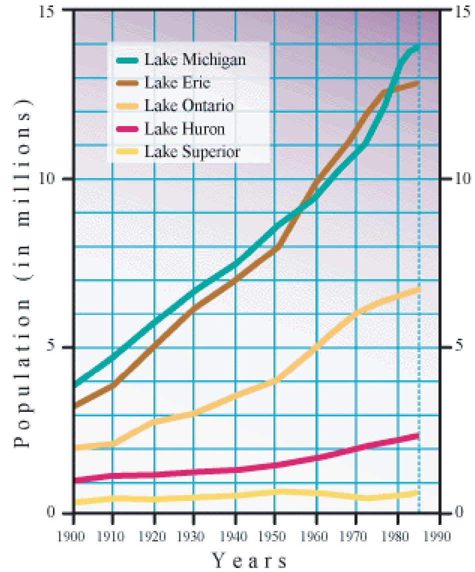



Figure 4. Human population in the Great Lakes Basin 1900 to 1990 by sub-basin for each of the Great Lakes. (Source: Canada and USEPA, GLNPO 1995).

Today, the largest population centers in the Basin are along the shorelines of the Great Lakes as Chicago, Illinois; Detroit, Michigan; and the city of Toronto in Ontario, Canada. Currently, the Great Lakes Basin supports more than 10 percent of the United States population and 25 percent of the Canadian population as a total of more than 37 million people (Canada and USEPA, GLNPO 1995; IJC 2005).

Through settlement, original wetlands, prairies, savannas, and forests were converted to other land uses and purposes. Natural landscapes were converted to production agriculture, forest industry, and rural and urban uses. Waters were fished commercially. These changes altered the ecosystem and its balance (Canada and USEPA, GLNPO 1995). Currently, land uses are distributed in the Basin as shown in the map in figure 5. Changes in commercial fisheries are also shown. An estimated 7 percent of agricultural production in the United States and almost 25 percent of agricultural production in Canada is supported within the Great Lakes Basin (Canada and USEPA, GLNPO 1995).

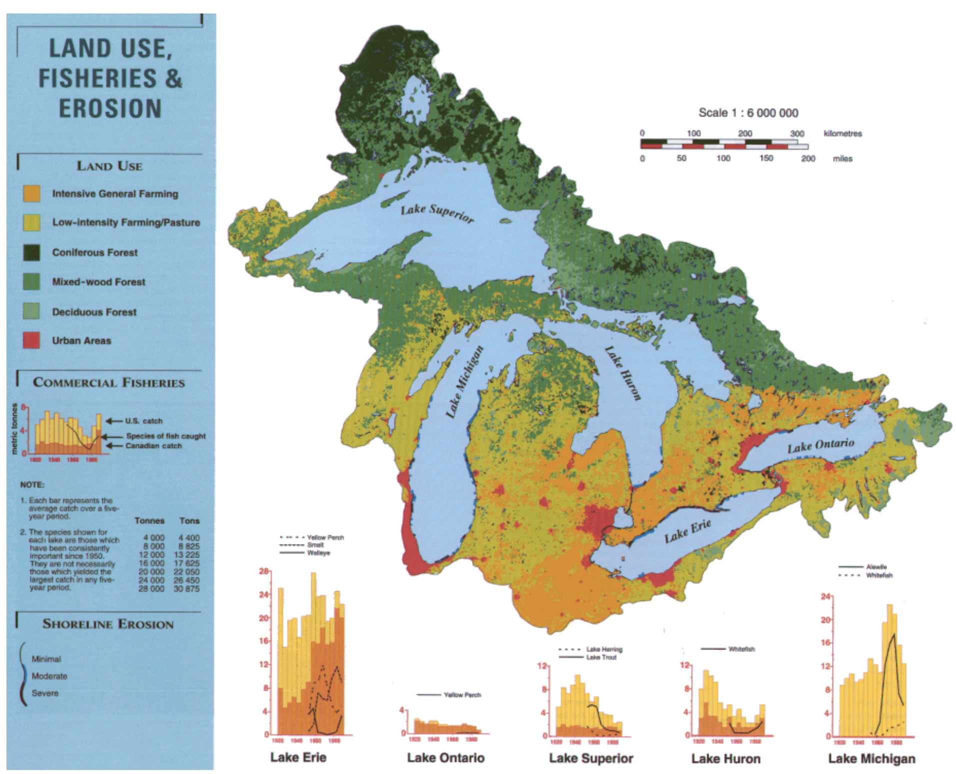



Figure 5. Land uses for agricultural, forest, rural, and urban purposes; and changes in commercial fisheries catch and shoreline erosion in the Great Lakes Basin (Source: Canada and USEPA, GLNPO 1995).

Changes in land use were observed to cause runoff of water and erosion from land surfaces including transport of dissolved chemicals and nutrients and sediment as water flowed across the landscape and drained to lower elevations and water bodies.  Based on these observations, in 1972, the IJC was asked to investigate pollution from land use activities.  New studies investigated both urban and rural land uses and interactions between systems.  The original focus on point sources of pollution was expanded to include pollution from non-point sources.  For example, key non-point urban sources were identified and categorized as nutrients, toxic substances, pathogens, and sediments within runoff (GLSAB 2000).

Priorities for improved ecosystem management for land and water interactions and point and non-point sources of pollution were identified and promoted for these types of practices (FHWA 1996a, FHWA 1996b, FHWA 2006, GLSAB 2000, GLWQA 1987, Grannemman 2004):

- Watershed planning and approaches
- Control and treatment of runoff from land surfaces
- Land use planning and evaluations
- Land management and conservation
- Conservation tillage for agriculture
- Stream and wetland vegetative buffers
- Site selection and design
- Prevention of soil erosion and displacement
- Control of sediment deposition
- Management of non-stormwater sources (e.g. septic systems)
- Control and management of combined and sanitary sewer systems and overflows
- Methods that include changes in impervious surfaces and development in analyses
- Evaluations of alterations in hydrology and corresponding impacts
- Incorporating chemical and pollutant and sediment loading into methods
- Virtual elimination and zero discharge of persistent toxic substances into the Great Lakes
- Stormwater best management practices (BMPs)
- Use of education programs

The benefits of land use planning and selection of land use practices and infrastructure development to match landscape and site conditions became apparent.  Examples of methods for selecting land uses based on soil characteristics and economic analyses have been developed for the Great Lakes region (Campbell and Majerus 1986). Conservation tillage on agricultural lands has reduced soil erosion and sediment loading into wetlands and waterways.

For transportation, highway hydrology methods can incorporate knowledge of how land use changes affect watershed changes. "Deforestation and urbanization change the runoff processes that control watershed response to rainfall" (FHWA 1996a). Systems planning for highway drainage systems can integrate hydrology, land use, soil types, topography, and watershed characteristics and size as well as the "expected level of development in the upstream watershed over the anticipated life of the facility" (FHWA 1996b). Advancements in understanding and improved practices toward integrated approaches continue to be applied to managing the systems within the Great Lakes Basin (GLSAB 2000).

Changes in land use systems and the needs of a growing population also affected changes in transportation systems. For the Great Lakes region, the water system is essential within the transportation system as an intermodal system that links together rail, air, transit, road/highway, bicycle, pedestrian, and marine/water transportation.  As a broad overview of transportation in the Basin, figure 6 depicts waterborne commerce for major commodities and figure 7 shows other transportation modes and major types of infrastructure.  It is important to recognize that the waterborne transportation in the Great Lakes is taking place in the drinking water source.

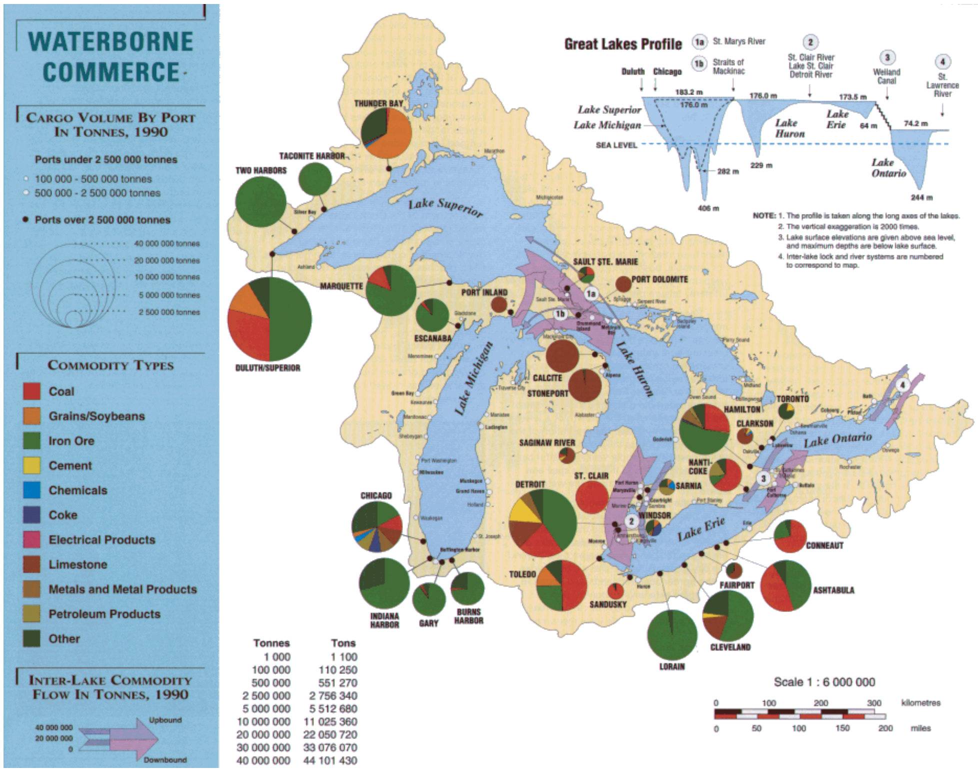



Figure 6. Waterborne commerce in the Great Lakes Basin ecosystem as of 1990. (Source: Canada and USEPA, GLNPO 1995).

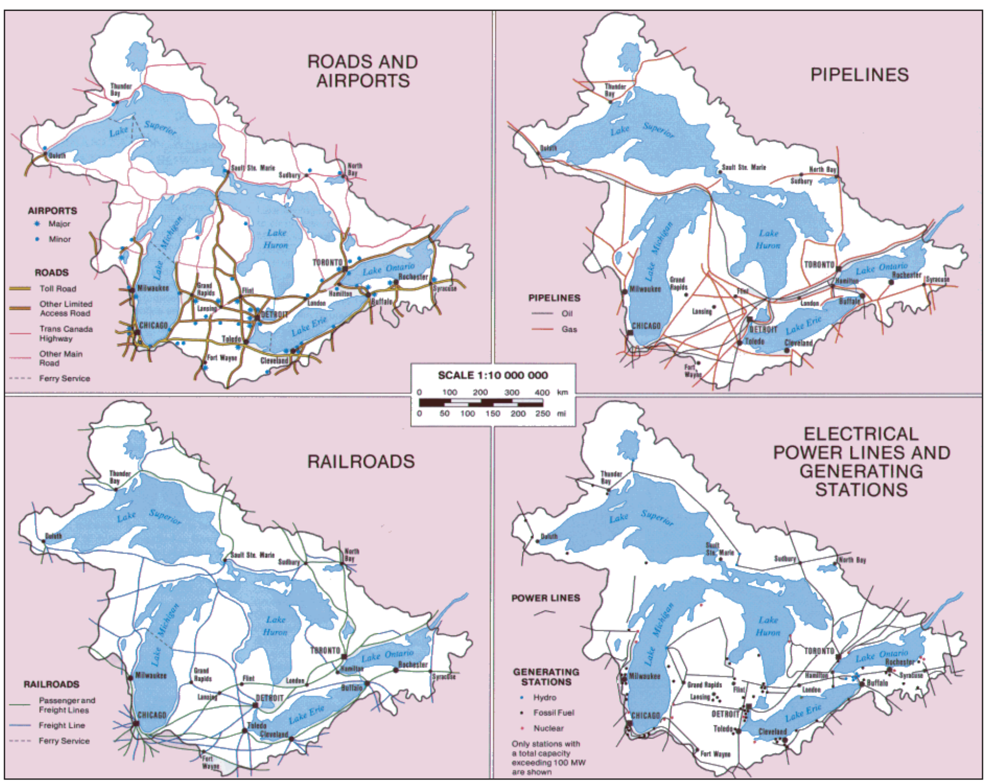



Figure 7. Transportation systems and major infrastructure in the Great Lakes Basin ecosystem (Source: Canada and USEPA, GLNPO 1995).

The transportation system expanded to support international enterprises and trade. Some ecosystem changes happened unknowingly and the implications only became understood later with observation and monitoring through time. One example occurred with the movement of transoceanic ships into the Great Lakes water system. More than 20 years ago, discharges of ballast water from transoceanic ships introduced a new, non-native species into the Great Lakes system, the zebra mussel (Dreissena polymorpha). The zebra mussel expanded in numbers in the freshwater habitat of the Great Lakes. In 20 years, the location of zebra mussels extended and "invaded" into the freshwaters of the Great Lakes, as well as the Ohio River Basin and the Mississippi River Basin as shown in the map in figure 8.

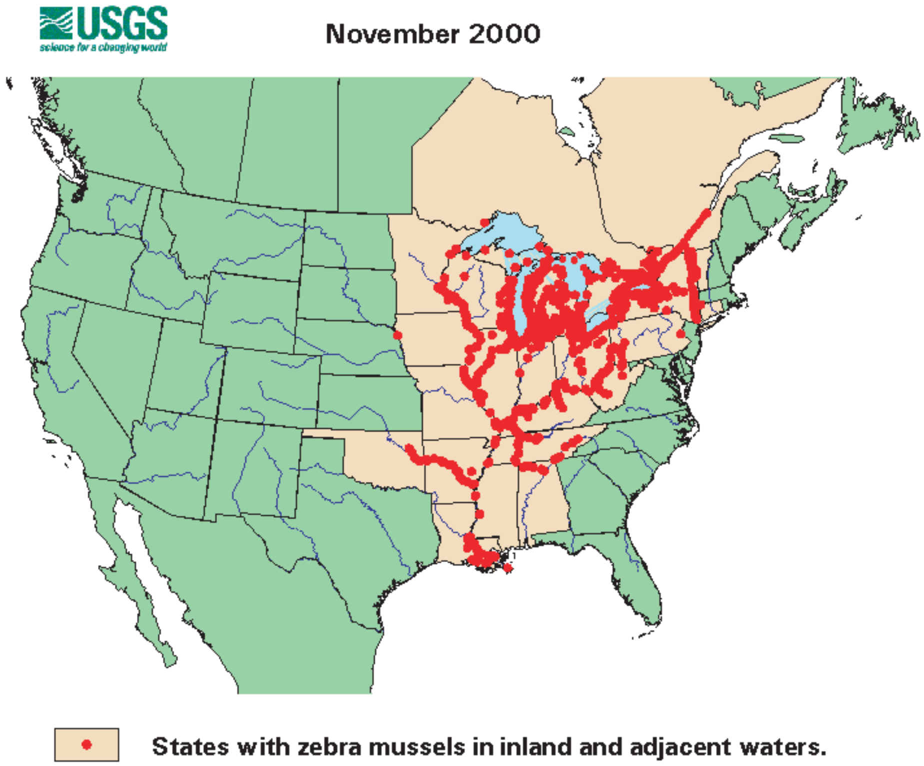



Figure 8. Extent of location of zebra mussels in the U.S. water systems 20 years after their initial introduction into the Great Lakes (Source: USGS 2000). The zebra mussel is considered an "invasive" species.

The arrival of the zebra mussel and its effect on the Great Lakes ecosystem emerged as a prime example of the interdependencies between biological, chemical, and physical processes. Zebra mussels impacted Great Lakes biological integrity by disrupting the established food web. They impacted the chemical integrity by clearing the water as filter feeders. Changes in water clarity allowed sunlight to reach further into the depths of the lakes and promoted the growth of plants and algae. Zebra mussels also impacted physical integrity by clogging water intake pipes and as a source of mounds of shells on the shoreline beaches. Research also seems to indicate the potential that zebra mussel fecal matter can act as fertilizer, contributing nutrients to the lake chemistry. This nutrient control problem of the 1960s and 1970s was thought by many to have been solved but has recently returned to areas near the shorelines. As filter feeders, zebra mussels build up toxins in their tissues. This causes bioaccumulation of toxins because zebra mussels are a food source for higher trophic levels in the food web. This toxicity alters chemical processes (Beck 2007).

There are many other examples of how the introduction of non-native species into the Great Lakes Basin can trigger disruption in the health of the ecosystem. Control of invasive species and prevention of their introduction into the ecosystem remain as ongoing challenges. In concert with ecosystem management, there are ongoing priorities to nurture and sustain species native to the Basin, such as native mussels. Priorities also include sustaining water quality and quantity for the long-term.

Changes in population and land use also triggered changes in the use and consumption of water. The IJC states that "water uses" … can be… "presented in two categories: (1) consumptive uses estimated from water withdrawal data and (2) removals. Close to 90 percent of withdrawals are taken from the lakes themselves, with the remaining 10 percent coming from tributary streams and groundwater sources." The IJC summarized consumptive use in the Great Lakes Basin by type of water use as: "irrigation, 29 percent; public water supply, 28 percent; industrial use, 24 percent; fossil fuel thermoelectric and nuclear uses, 6 percent each; self-supplied domestic, 4 percent; and livestock watering, 3 percent," based on 1993 data (IJC 2000).

The International Joint Commission also presented the following discussion of water use to support the economy and land uses within the Basin (IJC 2000):

> "The Commission has developed insights into trends in water use and their impact on potential future water demands. These insights were derived from a simple extension of trends established over the previous decade. ... All predictions are heavily dependent on the assumptions underlying them and on an accurate understanding of the present starting point. Factors such as climate change could encourage the increased use of water for irrigation and other purposes. On the other hand, continued improvement in water demand management as well as in water conservation might help to slow any increase in withdrawals for consumptive use within the Basin. Because population will increase, there is a greater probability of increasing use in the future than there is of decreasing use. Projections presented below extend to 2020. The Commission believes that water use is likely to increase modestly by 2020 and that projections beyond this point should be considered highly speculative.
>
> *Thermoelectric Power Use*. At thermoelectric power plants, water is used principally for condenser and reactor cooling. In the United States, thermoelectric withdrawals have remained relatively constant since 1985 and are expected to remain near their current levels for the next few decades. In Canada, modest increases are expected to continue along with population and economic growth.
>
> *Industrial and Commercial Use*. In the United States, industrial and commercial water use has declined in response to environmental pollution legislation, technological advances, and a change in the industrial mix from heavy metal production to more service-oriented sectors. A similar trend is evident in Ontario, so combined use is expected to gradually decline through 2020.
>
> *Domestic and Public Use*. In the United States, water use for domestic and public purposes in the Great Lakes Basin generally increased from 1960 to 1995 and is expected to climb gradually through 2020. In Ontario, however, the modest downward trend established in recent years because water conservation efforts is expected to continue.
>
> *Agriculture*. In the United States, water use for agriculture in the Great Lakes region increased fairly steadily from 1960 to 1995 and is expected to continue to grow. In Canada, the rate of increase was somewhat greater, so that combined projections indicate a significant increase by 2020...
>
> *Total Water Use*. There is agreement that water withdrawal will increase in the future, although it is impossible to say with confidence just how much the increase will be. There is, however, no such agreement on consumptive use...
>
> ... The above figures" ... "represent a range of possibilities. What is clear is that water managers will need to manage the resource carefully"

This information supports decision-making for water demand management and water conservation and the use of advisories and restrictions on water withdrawals and consumption, water diversion, uses of water, swimming, and fish consumption.

Additional efforts for water management were launched in December 2005 when the Great Lakes Governor's and Premiers signed an agreement that will provide protection for the Great Lakes-St. Lawrence River basin. This agreement will have to be approved by the state legislatures in order to be implemented. The agreement bans new diversions with limited exceptions based on a consistent standard for review. The agreement also provides for data collection and sharing, development of water conservation goals, and efficiency measures. The agreement recognizes that the waters of the basin are a shared public treasure and includes a strong commitment to continued public involvement in the implementation of the agreement. Information is available at: http://www.cglg.org/projects/water/annex2001Implementing.asp (Council of Great Lakes Governors 2005).

Studies of water and hydrology can provide baseline information for existing conditions and monitoring changes through time to assess impacts to water quantity and quality and ecosystem response. The previous diagram shown in Figure 3 includes approximations of quantities for some of the water inputs and outputs for the Great Lakes water system (Canada and USEPA, GLNPO 1995). The groundwater system connects to streams that flow into the Great Lakes so that "groundwater indirectly contributes more than 50 percent of the stream discharge to the Great Lakes" (Grannemman et al. 2000). These approximations provide an example of the types of water supply studies that are conducted within the Basin.

Systems respond to changes and stressors through homeostasis as ongoing natural processes. However, it is now known that thresholds and limits exist in system capabilities to respond to changes to regain ecosystem health and it is possible that ecosystem balance could collapse. For the Basin, it was "later in time, when the watershed was more intensively settled...," that it was ... "learned that abuse of the waters and the basin could result in great damage to the entire system" (Canada and USEPA, GLNPO 1995). Monitoring showed the existence of problems and sometimes pointed out unexpected interactions.

For example, contaminated groundwater was discovered to be a source of pollutants for the Great Lakes. The deposition of toxic chemicals from the air was also found to be detrimental to the waters of the Great Lakes. Deposition of contaminated sediments also influenced the ecosystem. Through time, it was also found that …"in spite of their large size, the Great Lakes are sensitive to the effects of a wide range of pollutants. The sources of pollution include "… the runoff" that transports soil particles "… and farm chemicals from agricultural lands, the waste from cities, discharges from industrial areas and leachate from disposal sites. The large surface area of the lakes also makes them vulnerable to direct atmospheric pollutants that fall with rain or snow and as dust on the lake surface." … "Outflows from the Great Lakes are relatively small (less than 1 percent per year) in comparison with the total volume of water. Pollutants that enter the lakes - whether by direct discharge along the shores, through tributaries, from land use or from the atmosphere - are retained in the system and become more concentrated with time. Also, pollutants remain in the system because of resuspension (or mixing back into the water) of sediment and cycling through biological food chains." (Canada and USEPA, GLNPO 1995). This knowledge and the results of monitoring were applied to advancements in partnering and management efforts for the Great Lakes Basin.

## Bi-National Partnerships and Agreements for the Great Lakes

Canada and the United States formalized a bi-national partnership to define and implement priorities for the Basin. Specifically, the 1909 Boundary Waters Treaty created the International Joint Commission as a single body to act in concert toward shared benefits for Canada and the United States. In addition, "the Treaty created a unique process for cooperation in the use of all the waterways that cross the border between the two nations, including the Great Lakes" (Canada and USEPA, GLNPO 1995). Under the Boundary Waters Treaty of 1909, the Great Lakes Water Quality Agreement was created in 1972 and modified in 1978, 1983, and 1987. The Great Lakes Water Quality Agreement became a bi-national agreement and in many ways can be considered a model for addressing environmental priorities and resources across an international boundary (IJC 2006). The content of the bi-national agreement as of 1987 serves as the foundation to implement activities "to restore and maintain the physical, chemical and biological integrity of the waters of the Great Lakes Basin Ecosystem," … as" the interacting components of air, land, water and living organisms, including humans, within the drainage basin" (GLWQA 1987).

## Advancements in Bi-National Agreements and Approaches

An understanding of inter-dependencies and ecosystem changes can be viewed as the basis for changes in the Great Lakes Water Quality Agreement from 1972 to 1987. These changes can be highlighted as the following advancements.

- Broadening of the original focus on the Great Lakes as individual water bodies, toward a Great Lakes water system, and then toward a definition of the Great Lakes Basin ecosystem as "the interacting components of air, land, water and living organisms, including humans, within the drainage basin of the St. Lawrence River at or upstream from the point at which this river becomes the international boundary between Canada and the United States" (Canada and USEPA, GLNPO 1995; GLWQA 1978).
- Chemical water quality objectives were expanded to more comprehensive goals that seek "to restore and sustain the chemical, physical, and biological integrity of the waters of Great Lakes Basin Ecosystem" (GLWQA 1987).
- Inclusion of ecosystem objectives and indicators to complement the chemical objectives already mentioned in the Agreement (Canada and USEPA, GLNPO 1995).
- Approaches based on an understanding that watersheds, basins, and drainage areas occur within and are part of ecosystems (Canada and USEPA, GLNPO 1995).
- Activities for monitoring as "a scientifically designed system of continuing standardized measurements and observations and the evaluation thereof…" (GLWQA 1987).
- Implementation of continued monitoring as a basis for improved management practices (Canada and USEPA, GLNPO 1995).
- Use of indicators within monitoring methods. An indicator has been defined as a measurable feature, or one derivable from measurements, which singly or in combination provides managerially and scientifically useful evidence of ecosystem integrity, or reliable evidence of progress toward one or more ecosystem objective (DePinto 2005).
- Advancements from an early focus on point source pollution to include both point and non-point sources of pollution (GLWQA 1987).
- Strengthened management provisions to achieve defined and desired future conditions (GLWQA 1987).
- Application of new knowledge to solutions that embrace relationships of water systems to land systems to atmospheric systems, specific to impacts of deposition of airborne toxic substances into waters, contaminated sediments, and pollution from contaminated groundwater and both point and non-point sources of pollution (Canada and USEPA, GLNPO; GLWQA 1987).
- Creation of specific water quality planning and restoration programs, such as Remedial Action Plans (RAPs) for geographically defined Areas of Concern (AOCs) and Lakewide Management Plans (LaMPs) for critical pollut-

ants and goals to improve the health of the Great Lakes ecosystem. (Finger Lakes-Lake Ontario Watershed Protection Alliance 2000, Lake Michigan LaMP 2000).

- Implementation of Lakewide Area Management Plans using adaptive management approaches including the identification and use of biological, chemical, and physical indicators to monitor the health and response of the ecosystem to changes and management efforts (Lake MI LaMP 2000).
- Identification of 14 impairments to beneficial uses for the Great Lakes, as defined by the International Joint Commission (GLWQA 1987).
- Creation and participation of Great Lakes Advisory Boards to include a variety of expertise and scientific approaches. For example, one advisory board will "… consist of managers of Great Lakes research programs and recognized experts on Great Lakes water quality problems and related fields…" (GLWQA 1987).

Further details are provided below.

Specifically, the Great Lakes Water Quality Agreement advanced to establish an expanded advisory committee structure for the International Joint Commission that brings together experts in the Water Quality Board, Air Quality Board and the Science Advisory Board. The parties to the agreement, the United States and Canada, work jointly through the Bi-national Executive Committee (BEC). The following efforts report to the BEC: Lakewide Management Plans (LaMPs), Area of Concern Remedial Action Plans, State of the Lakes Ecosystem Conference and the Bi-national Toxic Strategy. All of the efforts produce plans and reports for the public, hold conferences, and support on-going public stakeholder groups. The Lakewide Area Management Plans are developed collaboratively and focus on the sub-basin/sub-watershed of each of the Great Lakes.

Another aspect of the implementation process for the Great Lakes Water Quality Agreement is periodic public reviews. The IJC conducted public hearings and public reviews during 2005 and 2006 (IJC 2006). Many of the changes suggested in review comments support the concepts of systems alignment now underway in various Great Lakes efforts. The review process is still underway.

Regarding this review of the Agreement, the International Joint Commission offered the following advice to the Governments of Canada and the United States as they undertake their review of the Agreement (IJC 2006):

> "Since 1972, the Great Lakes Water Quality Agreement between Canada and the United States … has provided a vital framework for bi-national cooperation, consultation and action to restore and maintain Great Lakes water quality and the ecological health of the Great Lakes basin. Much has worked well over the past three decades and there have been many achievements. Threats to water quality persist, however, and new ones have emerged. Scientific advances have yielded new understandings of problems which, in turn, point to different solutions than in the past. What once was judged far-sighted and robust enough to protect vulnerable populations of humans, fish and wildlife is no longer sufficient. … Key principles and concepts from the current Agreement, such as virtual elimination and zero discharge of persistent toxic substances, should be retained." … Changes to the agreement to include "other concepts that could underpin and strengthen the Agreement, such as the ecosystem approach," and "adaptive management" … "should also be clearly enunciated in the new Agreement"

## Ecosystem Approach and Collaborative Implementation

An ecosystem approach for the Great Lakes "is a departure from an earlier focus on localized pollution" … and from … "management of separate components of the ecosystem in isolation"… and it … "assumes a more comprehensive and interdisciplinary attitude…" (Canada and USEPA, GLNPO 1995). "This approach calls for creative partnerships that look at natural boundaries… as the unit of management" (GLIN 2006). The State of the Lakes Ecosystem Conference (SOLEC) 2006 discussed the ecosystem management concepts illustrated in figure 8.

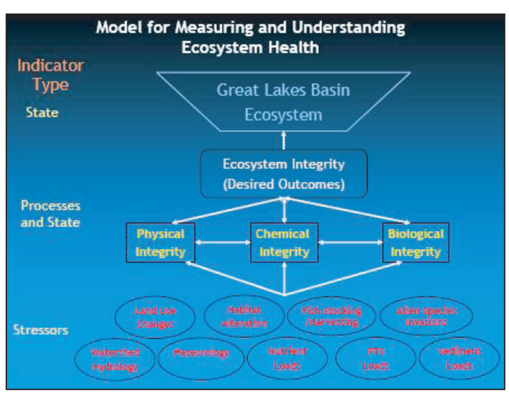



Figure 8. Model for ecosystem health, including physical, chemical, and biological integrity; indicators; and monitoring of ecosystem integrity and outcomes. (Source: DePinto 2005)

Examples for implementation include the Lakewide Management Plans that have been developed for each Great Lake sub-basin/sub-watershed.  Participation includes an array of federal, Tribal, regional, local, state and provincial agencies and stakeholders to develop and implement the management plan.

As a specific example, the Lake Michigan Lakewide Management Plan (LaMP) seeks multiple benefits for people and communities as (Lake MI LaMP 2000):

- "*Moderating natural events and human activities*. Healthy landscapes can make communities safer and more livable by tempering the effects of natural events and human activity. For example, wetland systems can absorb and store storm waters and thereby aid in flood control and ensure more routine flows and water levels in streams.
- *Enhancing social well-being*. Healthy landscapes provide services that make communities more enjoyable and rewarding. For example, they provide opportunities for outdoor recreation. To many, they also serve as a source of civic pride and personal and spiritual well-being.
- *Supporting local economies*. In sustainable landscapes, people meet the needs of the present without compromising the ability of future generations to meet their needs"

The Lake Michigan LaMP 2000 incorporates 3 components of ecosystem sustainability including: environmental integrity, economic vitality, and socio-cultural well being. A shift in focus from resource programs to resource systems is considered necessary.  Humans and communities are considered part of an ecosystem and its management and are affected by ecosystem health (Lake MI LaMP 2000).

Regarding an example approach to adaptive management, the Lake Michigan LaMP 2000 quotes the Keystone Report of 1996 which states, "adaptive management encourages active participation by all stakeholders in the planning, implementation, monitoring, and redirection of ecosystem management initiatives. Social and economic values and expectations are routinely considered, along with ecological objectives, in continually correcting the course of management.  Results from the monitoring of ecological, economic, and social variables are used to track management outcomes" (Keystone Report 1996).

In addition to the Great Lakes Water Quality Agreement and the International Joint Commission, several other partnerships and multi-agency initiatives are moving forward to support ecosystem approaches to sustain multiple benefits across systems, including transportation and infrastructure.  A few examples of these supporting partnerships and initiatives are discussed below.

### Executive Order Expands Collaboration for the Great Lakes

In 2004, the collaboration for the Great Lakes took another major step.  "In May 2004, President Bush signed Executive Order 13340 creating a cabinet-level Task Force to bring an unprecedented level of collaboration and coordination to accelerate protection and restoration of this national and internationally significant resource.  Recognizing that efforts to protect and enhance the ecosystem must go beyond the federal government, the Executive Order" … calls for … "the convening of a Regional Collaboration of National Significance to facilitate collaboration among the federal government, the Great Lakes states, local communities, Tribes, and other interests in the Great Lakes region as well as Canada" (GLRC 2004).  The title of this Executive Order is:  Establishment of a Great Lakes Interagency Task Force and Promotion of a Regional Collaboration of National Significance for the Great Lakes (EO 13340 2004).

This Executive Order set up a Federal Interagency Task Force and a Regional Working Group for the Great Lakes. Several efforts are related to this Executive Order.  One example is a U.S. Department of Transportation (USDOT)/FHWA Great Lakes stormwater workshop that brought together representatives from 8 Great Lakes states including state transportation agencies, FHWA headquarters, FHWA state Division Offices, and the USEPA Region 5 office. Participants included transportation and environmental professionals involved with stormwater management in the Great Lakes region (FHWA 2006).

The USDOT/FHWA workshop presentations and discussions included several topics such as the Clean Water Act (Sections 401 and 402), the National Pollutant Discharge Elimination System (NPDES) and permitting, prevention of soil erosion, control of sediment, pollution prevention plans (PPPs), drainage studies and drainage plans, and use of stormwater Best Management Practices as part of transportation project delivery.  FHWA distributed a written summary of various resources and sources of information on stormwater that is included in the final workshop report (FHWA 2006).

The workshop discussions highlighted examples from a cooperative effort that is a compilation of information and a database and website for stormwater BMPs. The overall purpose of the cooperative effort is to provide scientifically sound information to improve the design, selection and performance of BMPs. This "International Stormwater Best Management Practices" (BMPs) website is located at: http://www.bmpdatabase.org/ (International Stormwater BMPs 2007). Adoption and use of stormwater BMPs is one example of how to improve practices for transportation within the Great Lakes Basin.

Another partnership is underway within a nationwide, multi-agency initiative for integrated and ecosystem approaches to developing infrastructure. This initiative can be implemented in the Great Lakes region as well as through local, state, regional, Tribal, and national level efforts. A summary is provided below.

**Multi-Agency Initiative – Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects**

*Eco-Logical* is a multi-agency initiative and guide that encourages federal, Tribal, state, and local partners to integrate environmental solutions and goals into planning and delivery of infrastructure projects. *Eco-Logical* offers a conceptual framework for integrating environmental and transportation plans and projects across agency and geographical boundaries, and endorses ecosystem-based mitigation approaches to compensate for unavoidable impacts caused by infrastructure projects. The framework is useful for practitioners in both the public and private sectors. *Eco-Logical* meets all existing U.S. regulatory requirements while offering improved practices within an ecosystem approach (Eco-Logical 2006). *Eco-Logical* also supports the requirements of U.S. transportation legislation, the Safe Accountable Flexible Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU 2005).

The *Eco-Logical* approach shifts the U.S. federal government's traditional focus from individual jurisdictions and actions to a larger focus across multiple agencies within a larger natural ecosystem. An *Eco-Logical* guide was developed as a multi-agency, collaborative effort and was agreed upon and signed by the headquarters offices of 8 U.S. federal agencies including:

- Federal Highway Administration, U.S. Department of Transportation
- U.S. Environmental Protection Agency, (Office of Federal Activities)
- U.S. Environmental Protection Agency, (Office of Wetlands, Oceans, and Watersheds)
- U.S. Fish and Wildlife Service, U.S. Department of Interior
- U.S. Forest Service, U.S. Department of Agriculture
- Bureau of Land Management, U.S. Department of Interior
- U.S. Department of the Army; Department of Defense
- National Park Service, Department of Interior
- National Marine Fisheries Service, National Oceanic and Atmospheric Administration

Participants on the multi-agency *Eco-Logical* Steering Team also included two state transportation agencies and a toll highway authority (Eco-Logical 2006).

The *Eco-Logical* framework includes an agreed upon definition of an ecosystem as: "an interconnected community of living things and the physical environment they depend upon (humans included)" (Eco-Logical Guide 2006). *Eco-Logical* recommends a non-prescriptive framework for ecosystem-based mitigation and sequencing to avoid adverse impacts, then minimize impacts, and then compensate for unavoidable adverse impacts. The overall goals of the ecosystem approach to mitigation and Eco-Logical are: conserve larger, scarce, multi-resource ecosystems; increase habitat and system connectivity; improve predictability in environmental review and regulatory processes; provide better public involvement to improve transparency and establish greater credibility; and streamline infrastructure planning and project delivery (Eco-Logical 2006).

The *Eco-Logical* framework can facilitate ongoing future refinements in planning and project delivery using the elements shown in figure 9. It is important to recognize that any part of the *Eco-Logical* cycle of elements shown in Figure 9 can be implemented at any stage during planning and project delivery.

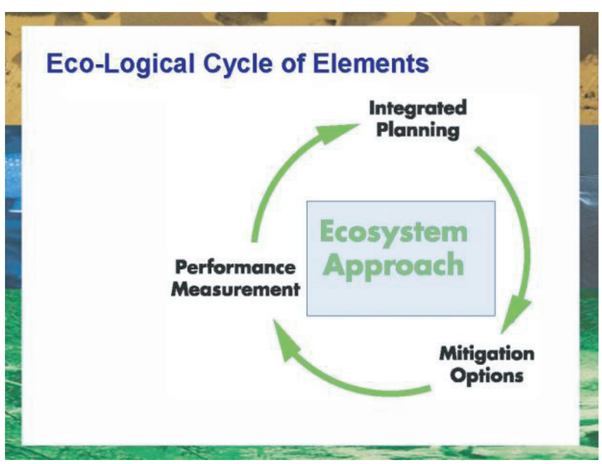



Figure 9. Elements within the *Eco-Logical* framework (Source: Eco-Logical 2006).

Details are provided in the multi-agency guide available as "Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects," downloadable at: http://www.environment.fhwa.dot.gov/ecological/eco_index.asp (Eco-Logical 2006).

**Implementation of *Eco-Logical* via Funding and an FHWA Grant Solicitation**

Across the United States, several efforts that implement Eco-Logical are already underway within long-range planning, mid-range planning, and project delivery. To further advance implementation of Eco-Logical, the Federal Highway Administration (FHWA) is providing funding and currently soliciting grant applications. Eligible applicants can be from all levels of the U.S. government, Tribes, non-profit organizations, colleges/universities, and private entities. Information about the U.S. Eco-Logical grant solicitation is posted at: http://www.grants.gov/search.do?oppId=13223&mode=VIEW

*Eco-Logical* supports several initiatives and U.S. Executive Orders such as: Cooperative Conservation, Integrated Planning, and Environmental Streamlining and Stewardship for Transportation. *Eco-Logical* also supports existing agreements and Executive Order 13340 for the Great Lakes. Within the *Eco-Logical* ecosystem approach, infrastructure and environmental planning and project delivery can be integrated to support economic, environmental, and social needs and achieve multi-purpose goals and community benefits.

## Recommendations and Future Activities

This paper has highlighted findings and activities that can be applied to sustain ecosystem health for multiple benefits. Based on this discussion, the following recommendations are offered for planning and project delivery and activities at the international, national, provincial, state, regional, and local levels.

- Implement and promote the *Eco-Logical* multi-agency initiative and guide (Eco-Logical 2006).
- Participate in the FHWA *Eco-Logical* grant solicitation underway (Integrating Transportation and Resource Planning to Develop Ecosystem Based Infrastructure Projects) as posted at: http://www.grants.gov/search/search.do?oppId=13223&mode=VIEW.
- Utilize a systems approach rather than compartmentalizing systems and efforts into separate, individual pieces.
- Pursue and use best available science and technology and expertise and interdisciplinary approaches.
- Implement ecosystem-based approaches with a focus on natural boundaries rather than jurisdictional or political boundaries.
- Use adaptive management and methods that measure and monitor results and outcomes as a basis for adapting and refining plans and activities.
- Recognizing that land use can affect either a positive or a negative response within an ecosystem, implement practices for land use planning and land management that help sustain ecosystem health.
- Coordinate and develop partnerships with the public and private sectors, as relevant.
- Coordinate with relevant activities of the International Joint Commission within the transboundary watershed area shared by Canada and the U.S. extending from the west to east coasts of North America.
- Participate in the public review of the Great Lakes Water Quality Agreement currently underway.

The following section provides a brief biography for each author.

**Biographical Sketch:** Judy Beck has managed the Lake Michigan team in the Great Lakes National Program Office of USEPA since 1995. Prior to this position, she served as State Relation's Manager in the USEPA Region 5 Regional Administrator's Office. She began her career at EPA working in what was then the "new" Superfund Program. Judy Beck has also held non-partisan public office in Illinois, being re-elected 5 times as Commissioner of the Glenview Park District. She has also served as President of the Illinois Association of Park Districts and represents them on the Northeastern Illinois Planning Commission (NIPC). Judy graduated from Old Dominion University and did graduate work at George Washington University.

Sherry Kamke is an Environmental Specialist with the USEPA, Region 5 office. Sherry's responsibilities include implementation of the National Environmental Policy Act (NEPA). Sherry conducts environmental reviews for proposed infrastructure and transportation projects. Some of these projects involve a level of NEPA processing as environmental assessment and environmental impact statements. Sherry has also supported long-range transportation and regional planning. Sherry has a B.S. degree in Chemistry from Saint Xaiver University and a M.S. in Environmental Engineering from the Illinois Institute of Technology.

Kimberly Majerus is a natural resource and GIS analyst with the Environmental Team of the FHWA-Resource Center in Olympia Fields, IL. She supports FHWA Divisions and Headquarters to deliver technical assistance and customized sessions to transportation and environmental practitioners nationwide. A 20 year career includes the Illinois Department of Transportation and Corps of Engineers and University of Illinois as project manager, environmental unit head, and GIS lab coordinator as well as President of the Illinois Environmental Council (IEC). As a Project Manager, Kimberly has implemented projects through all stages from planning to design, to construction, operations, and maintenance. Kimberly's experience includes participation in nationwide, multi-agency programs and projects. Her B.S. and M.S. degrees were earned at the University of Illinois at Urbana-Champaign.

## References


Beck, Judy 2007. Email prepared by Judy Beck summarizing changes in the Great Lakes ecosystem from the introduction of the non-native zebra mussel (Dreissena polymorpha). April 18, 2007.

Boundary Waters Treaty of 1909. Treaty between the United States and Great Britain relating to Boundary Waters, and Questions Arising between the United States and Canada. United States and Great Britain.

Campbell, Gene E. and Kimberly A. Majerus 1986. Final Report: An Economic Assessment of Short-Rotation Forestry and Herbaceous Crop Production for Energy Feedstocks on Marginal Land in the Great Lakes Region. Research conducted by the University of Illinois at Urbana-Champaign for the Council of Great Lakes Governors and U.S. Department of Energy (DOE). DOE Contract Number: FG05-83OR21390. Report Number: DOE/OR/21390-T19. 100 pages.

Canada and U.S. Environmental Protection Agency (USEPA), Great Lakes National Program Office (GLNPO) 1995. The Great Lakes: An Environmental Atlas and Resource Book. Jointly produced by: Government of Canada, Toronto, Ontario and USEPA, GLNPO, Chicago, Illinois. Third Edition 1995. Available online at: http://www.epa.gov/glnpo/. Individual maps are compiled from several sources listed in the Great Lakes Environmental Atlas and Resource Book.

Council of Great Lakes Governors 2005. Annex 2001 Implementing Agreements: The Great Lakes-St. Lawrence River Basin Sustainable Water Resources Agreement-December 13, 2005, and The Great Lakes-St. Lawrence River Basin Water Resources Compact-December 13, 2005. Great Lakes Water Management Initiative. Council of Great Lakes Governors. Available at: http://www.cglg.org/projects/water/annex2001Implementing.asp

DePinto, Joseph V. 2005. Chemical Integrity of Naturally-Occurring Substances in the Great Lakes. Content of Presentation for a State of the Lakes Ecosystem Conference (SOLEC) Pre-conference Workshop for SOLEC 2006. Windsor, Ontario –November 29-30, 2005. Presentation developed by J. DePinto, Limno-Tech, Inc., Ann Arbor, MI.

Executive Order (EO) 13340 2004. Establishment of a Great Lakes Interagency Task Force and Promotion of a Regional Collaboration of National Significance for the Great Lakes. Signed by U.S. President G.W. Bush.

Eco-Logical 2006. Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects. Multi-agency initiative and guide. DOT-VNTSC-FHWA-0601. FHWA-HEP-06-011. 83 pages. Available at: http://www.environment.fhwa.dot.gov/ecological/eco_index.asp

Federal Highway Administration (FHWA) 1996a. By: Richard H. McCuen, Peggy A. Johnson, and Robert M. Ragan 1996. Highway Hydrology, Hydraulic Design Series Number 2. Performed by: Department of Civil Engineering, University of Maryland, College Park, MD. Sponsored by: USDOT, FHWA Office of Technology Applications and Office of Engineering. Report Number FHWA-SA-96-067. 357 pages.

Federal Highway Administration (FHWA) 1996b. By: S.A. Brown, S.M. Stein, and J.C. Warner 1996. Urban Drainage Design Manual, Hydraulic Engineering Circular Number 22. November 1996. Performed by: TVGA Engineering, Surveying, P.C., Lanse, PA. Sponsored by: USDOT, FHWA Office of Technology Application; and Office of Engineering. Report Number FHWA-SA-96-078. 478 pages.

Federal Highway Administration (FHWA) 2006. Great Lakes Stormwater Workshop Final Report: Summary and Strategic Directions. August 10, 2006. Cleveland, Ohio.

Finger Lakes-Lake Ontario Watershed Protection Alliance 2000. The State of the New York Lake Ontario Basin: A Report on Water Resources and Local Watershed Management Programs 2000.

Grannemann, Norman G. and Thomas L. Weaver, 1998. An Annotated Bibliography of Selected References on the Estimated Rates of Direct Ground-Water Discharge to the Great Lakes: U.S. Geological Survey Water-Resources Investigations Report 98-4039, 22 pages.

Grannemann, Norman G., Randall J. Hunt, James R. Nicholas, Thomas E. Reilly, Thomas C. Winter 2000. The Importance of Groundwater in the Great Lakes Region. U.S. Department of the Interior (USDOI), U.S. Geological Survey (USGS), Water-Resources Investigations Report 00–4008. Cooperatively funded by the International Joint Commission and the USDOI, USGS. 14 pages.

Grannemann, Norman G. 2004. Summary of USGS Remarks on Pesticides/Chemicals,

Great Lakes Nonpoint Source Pollution from Land Use Workshop. November 8-9, 2004. Ann Arbor, Michigan.

Great Lakes Information Network (GLIN) 2006. Information available at: http://www.great-lakes.net/envt/.

Great Lakes Science Advisory Board (GLSAB) 2000. Nonpoint Sources of Pollution in the Great Lakes Basin. Workgroup on Parties Implementation. Based on the Findings of a Workshop to Assess the Status of Nonpoint Source Pollution Control in the Great Lakes Basin. ISBN 1-894280-14-8. 24 pages.

Great Lakes Water Quality Agreement (GLWQA) 1987. Under the Boundary Waters Treaty of 1909 emerged an agreement between Canada and the United States of America on Great Lakes Water Quality (including modifications from 1972 to 1978, 1983, and 1987). The Government of Canada and the Government of the United States of America. Full text of Great Lakes Water Quality Agreement available at: http://www.ijc.org/rel/agree/quality.html.

Great Lakes Regional Collaboration (GLRC) 2004. Framework for the Great Lakes Regional Collaboration. 13 pages.

Great Lakes Science Advisory Board (GLSAB) 2000. Non-Point Sources of Pollution in the Great Lakes Basin. Workgroup on Parties Implementation. Based on the Findings of a Workshop to Assess the Status of Nonpoint Source Pollution Control in the Great Lakes Basin. ISBN 1-894280-14-8. 24 pages.

International Joint Commission (IJC) 1999. Protection of the waters of the Great Lakes, Interim Report to the Governments of Canada and the United States, 40 pages.

International Joint Commission (IJC) 2000. Protection of the Waters of the Great Lakes, Final Report to the Governments of Canada and the United States.

International Joint Commission (IJC) 2005. A Guide to the Great Lakes Water Quality Agreement: Background for the 2006 Governmental Review. International Joint Commission. ISBN 1-894280-53-9.

International Joint Commission (IJC) 2006. Advice to Governments on their Review of the Great Lakes Water Quality Agreement: A Special Report to the Governments of Canada and the United States. August 2006. IJC Special Report. ISBN 1-894280-67-9. 34 pages.

International Stormwater BMPs 2007. International Stormwater Best Management Practices (BMPs) Summary of cooperative effort and Web site is available at: http://www.bmpdatabase.org/

Keystone Report 1996. Final Report. The Keystone National Policy Dialogue on Ecosystem Management. Final Report October 1996. Keystone, Colorado.

Lake Michigan (MI) Lakewide Management Plan (LaMP) 2000. U.S. Environmental Protection Agency (USEPA), Great Lakes National Program Office (GLNPO) Lake Michigan Lakewide Management Plan (LaMP) 2000.

Lake Michigan (MI) Lakewide Management Plan (LaMP) 2006. U.S. Environmental Protection Agency (USEPA), Great Lakes National Program Office (GLNPO) Lake Michigan Lakewide Management Plan (LaMP) 2006.

Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) 2005. Links to information on SAFETEA-LU Sections 6001 and 6002: http://www.environment.fhwa.dot.gov/integ/related.asp.

The Nature Conservancy (TNC), Great Lakes Program 1997. Great Lakes in the Balance - Protecting Our Ecosystem's Rich Natural Legacy. Support for its production was made possible through a grant from the U.S. Environmental Protection Agency, Great Lakes National Program Office (GL995819-02-0) and a contribution by Newman's Own Organics. 28 pages.

The Nature Conservancy (TNC), Great Lakes Program 2000. Toward a New Conservation Vision for the Great Lakes Region: A Second Iteration (Revised September 2000). Copyright 2000. 47 pages.

U.S. Geological Survey (USGS) 2000. Zebra mussel U.S. Distribution Map 2000. USGS Nonindigenous Aquatic Species. Zebra mussel page. Available at: http://nas.er.usgs.gov/taxgroup/mollusks/zebramussel/.

# Conservation Management of Historic Road Reserves in Australia

**Peter G. Spooner** (02 6051 9620, pspooner@csu.edu.au), Professor, Institute of Land, Water and Society, Charles Sturt University, P.O. Box 789, Albury NSW 2640 Australia

**Abstract:** Road reserves have a rich history of human impacts, and are important social, economic and ecological component of agricultural landscapes in Australia. Road verge, or roadside environments are gaining greater recognition for their role in nature conservation. In Australia, road reserves are areas of public land retained for the development of future roads. Many road reserves were originally surveyed at one-chain (20.12m) width, however many historic roads, such as early Traveling Stock Routes (TSRs), were surveyed at widths of up to 1 mile wide. As a result, roadsides often constitute a significant proportion of native vegetation remaining in many agriculture areas.

Many local government authorities have now completed an assessment of the conservation values of road reserves in their municipality. Each roadside has been surveyed using a rapid bio-assessment methodology, and given a conservation ranking (High, Medium or Low). These rankings are then used to determine appropriate management actions for each road category, as described in local roadside management plans. However as local governments authorities have few funds for conservation management of roadsides, resources are often directed towards the maintenance of the better high conservation roads.

Recent research has shown that in many cases, roadside conservation values are a direct legacy of 19th century land policies, and decisions by administrators and surveyors, whose imprint remains on the landscape today. Each road has a unique story to tell, and as such, many high conservation roads with important natural and heritage values could be considered as 'historic roads'. Understanding the development history of roads can provide an important tool to gain new awareness of their cultural and environmental values, and facilitate greater community investment in their ongoing management.

## Introduction

The road network is an important social component of agricultural landscapes worldwide; it facilitates transport of people, is an infrastructure corridor and is important for movements of outputs and inputs of agricultural production (Pauwels & Gulinck 2000; Broomham 2001). In the early settlement of rural areas of Australia, roads were vital for communication between isolated homesteads and the nearest towns or supply points (NSW DMR 1971). In recent years there has been growing recognition of the environmental values of historic road reserves (Forman et al. 2003; Spooner & Lunt 2004). The environmental values of roads are often undervalued, perhaps due to the ubiquitous nature of roads in most landscapes (Cooper 1991). It is important to recognise that road reserves often contain a significant proportion of remnant native vegetation in cleared agricultural areas of south-eastern Australia (Bennett 1991), Similarly in Europe, the USA and New Zealand, hedgerows and green lanes are gaining greater recognition for their importance in providing agronomic functions and refugia for biodiversity (e.g. Dover *et al.* 2000; Viles and Rosier 2001; Marshall and Moonen 2002; Forman *et al.* 2003).

In managing roadside environments, it is important to recognise that roads have developed for human use, and often have a long history of human inputs (Spooner et al. 2004). Despite this, roadside vegetation is often regarded as temporally inert and devoid of human impacts, as some relic of past conditions. As Fensham (1989) states, it is short sighted to assume that the makeup of remnant vegetation can automatically be interpreted as being representative of the historical condition of a site. Remnant vegetation in human altered ecosystems such as roadsides may be vastly different from the original ecosystems from which it developed (Foster *et al.* 2003).

In New South Wales, most attention on the historical value of roads has focussed on major arterial roads emanating from Sydney (e.g. Newell 1938; NSW DMR 1971; 1976). In regards to rural roads, although there is extensive literature regarding patterns of historical settlement (e.g. Buxton 1967; Carnegie 1973; Gammage 1986), these tend to ignore or only superficially detail aspects of the development of associated roads. The aim of this paper is to synthesise information on the historical development of road reserves in southern NSW, Australia, and discuss the implications for conservation management of roadside reserves.

## Background: Land Settlement History of Southern NSW

In the 1830-40s, early European pastoralists took up most of the unsettled districts of southern NSW in large leasehold arrangements in 'runs' of up to 100 000 acres (Roberts 1935). The pastoral era continued until 1861, when legislation was enacted in NSW to allow new settlers to purchase leasehold crown lands. To maintain control of 'their' land, pastoralists could exercise pre-emptive rights by way of 'improvements' to purchase the land, and clearing of woodlands and forests by way of ringbarking was a popular and cost-effective choice. But despite their wealth, early pastoralists could still not afford to purchase runs outright, and instead used influence with government land inspectors and surveyors to request that certain areas be reserved as road, stock, water, timber or gold mining reserves. Many such reserves were often revoked later and shrewdly purchased by squatters when funding permitted (Gammage 1986). In the 1870–1890s, pastoralists cleared the land at a feverish pace to gain pre-emptive rights of purchase. During this time, thousands of new settlers also arrived to stake out claims, and promptly cleared the land for cropping. By the late 1890s, apart from road and some public land reserves, most of the land had been cleared for agriculture (Buxton 1967).

During this period of rapid land settlement, surveys were completed to subdivide southern NSW into a system of counties and parishes. Each parish was designed as a support for the Church of England, with land allocations for a church, cemetery, town commons and school site in each parish (Jeans, 1972; Winston-Gregson 1985; Broomham). The original intent was to divide parishes and counties in a grid-based system similarly to that in the United States. However due to government squabbling, and chaotic state of the NSW Survey and Land Departments (which had few resources to survey the vast extent of land being rapidly settled), survey of counties and parishes proceeded in a rather ad-hoc fashion as land was purchased (Hallman 1973). Boundary data annotated on maps of former pastoral 'runs' were used as templates for succeeding parish and county maps, which were then updated as land was claimed or changed ownership (Read 2003). It wasn't until later trigonometric surveys were completed in the early 1900s that many boundary anomalies were corrected. In this context, the first road reserves were surveyed:

**Survey of Road Reserves**

Throughout the 1800s, the Survey Department of NSW issued survey instructions for roads as a series of notices or circulars, or as more formal statutes or regulations which were gazetted in government parliamentary proceedings of NSW (Hallman 1973; Marshall 1999). The first formal instructions to surveyors regarding road design in rural areas appears to be a Circular dated in 1848. It states (Clause 6):

> In laying out a series of country or suburban lots, a way of access must be preserved to each, by marking roads of a **chain wide** (20.12m) at the back of any range of allotments fronting a river…(Williamson 1982; Marshall 1999).

Instructions issued in 1848 detailed the marking of portion boundaries with blazed trees 'with a broad arrow at least 6 inches long….and the portion number' (fig. 1), though the practice of marking corners with numbers and a broad arrow was considered tedious, and limited to the principal points. The mark mainly used was a shovel shaped blaze, and corner trees were often blazed on four sides (Beaver 1953; Marshall 1999). Other methods for marking boundaries included using piles of stones or simple plough lines (Beaver 1953; 1980; Williamson 1982).

In this way, a vast network of narrow 1-chain road reserves was surveyed across the landscape in the 1870s to provide access to allotments. However problems with road usage and construction evidently led to changes in survey design regulations for road reserves. It was initially hoped that newly formed parishes would pay for the upkeep of minor 'parish roads' as in England. But as road construction was a low priority in the late 1800s, as compared to rail (Broomham 2001), most 'roads' of the time were no more than a boggy collection of tracks. The 1872 *Regulations for the Guidance of Licensed Surveyors* detailed these problems. Clause 24 states:

> Very serious interruption to traffic in the interior of the Colony has resulted from the fencing in of lands by proprietors either side of projected or reserved roads, previously to the construction and drainage of such roads, and it is considered expedient that… roads according to the nature of the ground and probable traffic may be **100 or 150 links wide (1 – 1.5 chains; 20-30m)**, or even more in cases where materials for road making are scarce.

It appears that the fencing in of one-chain road reserves was causing major problems in road usage and construction. Many roads were in such a deplorable state, 'ploughed up into such a slough by bullock teams', that travellers were forced to take rails out of adjoining paddock fences to circumnavigate problems areas, much to the consternation of neighbouring landholders (Howitt 1855, p. 40).

By 1900, the 'road' network in most local government areas was nothing more than an ad-hoc collection of narrow 1-chain wide vegetation corridors, allocated by surveyors for road access to various land titles as described above, in which travellers navigated their way through the trees along rough bush tracks. As Prichard (1991, p. 19) states:

> When Lockhart Shire was formed most of the access roads consisted of unformed tracks wandering through a mass of trees. Frequently it was necessary for the farmer to remove some trees to make it trafficable for vehicles.

In the early 1900s, a major task of rural councils was to identify and declare all road reserves currently in-use (or projected) as 'public roads', to secure vital funds from State government authorities for upkeep (Prichard 1991). This process was the first major step in constructing some semblance of a useable road network from the hundreds of one-chain road reserves and TSRs (see below) surveyed across the landscape. This would not have been an easy task, as property boundaries were still in flux. These actions were in part instigated by the *Public Roads Act* (1902), which provided for the resumption and dedication of land for roads, the payment of compensation and the closing of unnecessary roads (NSW DMR, 1976). As a result, many road reserves that were not utilised would later be closed or resumed into adjacent private land. Many of these can be observed today as linear patches of remnant vegetation.

By the 1920s there were still few constructed roads in most parts of southern NSW, except for main routes (NSW DMR, 1976). Road construction was initially carried out in scattered locations with no specific plan, where in many cases, roadworks were carried out by landholders at their own expense (Prichard, 1991; Lockhart Shire Council, 2003). During the depression in the 1930s, councils received unemployment relief grants which were provided for labour intensive work (NSW DMR, 1976). Most men were employed ‘on clearing timber from unformed roads’. In the postwar period of the 1940s, there was rapid development of the road network, due to greater external funding and purchase of heavy machinery. Works included realignment of numerous ‘dog-leg’ corners, a legacy of previous ad-hoc land subdivision. By the 1970s, road networks had developed into a modern network to transport people and agricultural production.

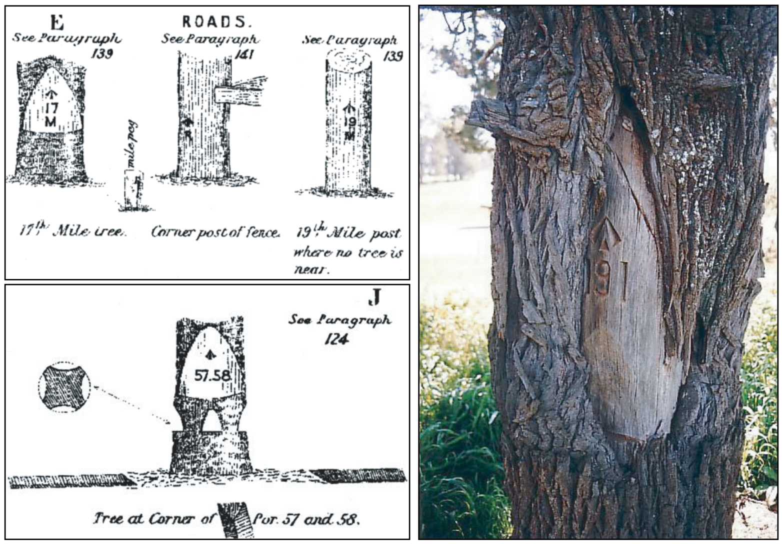



Figure 1. (a) Diagram showing survey regulations for roads and boundary markers in 1882 (Marshall 1999). (b) A rare example of an original survey boundary, tree circa 1890, in good condition (Photo: P. Spooner).

**Historic Roads: Travelling Stock Routes (TSRs)**

During early settlement, Travelling Stock Routes (TSRs) and reserves were informally developed by squatters to move stock from their runs to principle markets in major cities or the goldfields (Figure 3). This complex network of crown road and land reserves was estimated to cover 2.27 million hectares, or 2.8% of NSW (McKnight 1977). During the 1850-90s, TSRs became the first road transport routes in many parts of southern NSW, particularly those linking towns and railway stations. Many TSRs are up to **1 mile wide**, and therefore are important landscape components across south-east Australia.

So how did TSRs originate? The first government references to Travelling Stock Routes or Reserves originated in 1874. Records suggest that TSRs were formally developed due to concerns by District stock inspectors, who expressed some urgency to gazette the existing network of informal stock routes and reserves before hungry land settlers took up the land (NSW LA 1875a,b). As an early government report states:

> These reserves (Reserves for Travelling Stock) are very far from being in a satisfactory state. A great deal too few have been proclaimed, and the most suitable land for them is being fast taken up by selectors along the main droving roads; while those that have been proclaimed are rendered comparatively valueless to drovers (stock herdsmen) by the occupants of the adjoining land consuming the grass… (NSW LA 1875b).

In response, the Chief Inspector of Stock requested district stock inspectors to supply details of ‘droving roads’ as they were called at the time, including descriptions, usage by stock, and also requested suggestions for **sufficient stock route widths**, to ensure there were no difficulties in ‘bringing stock to markets’ (NSW LA 1875b). In reply, district stock inspectors reported details of stock routes in use, and recommended varying widths from **five chains to a 1 mile wide**, depending on stock usage at the time (NSW LA 1876). This correspondence explains why the width of stock routes is quite variable across NSW (fig. 2a).

Information supplied by district stock inspectors and surveyors was used to produce what appears to be the first official ‘Map of New South Wales Stock Routes” in 1880 (NSW LA 1881). In later years, TSRs were re-surveyed 3 chains wide and previous land sold to adjacent landholders (fig. 2b). In this fashion, it is clear that for many TSRs, government authorities merely surveyed and administered pathways *already in existence*. The origins of TSRs are therefore of great historical interest, as they are a lasting imprint of people and transport patterns long ago. It has been suggested that many may have started as trails of the indigenous people, tracks of native animals, early explorers, or as routes between early settlers homes, water-points and townships (Gammage 1986; Anderson 1994). For example, there is evidence that trails of previous indigenous inhabitants were utilised to great advantage in the early pastoral settlement of many regions of south-eastern Australia (Reynolds 1990; Harrison 2004). Not surprisingly, TSRs are now gaining new attention as historic roads in many rural areas of Australia.

In this way, for many road networks in Australia, each road often contains sections surveyed at different periods in the past. More by necessity than design, road reserves that were surveyed during the period of rapid land development of the late 1800s, were put into use as settlement patterns dictated. In the early 1900s, local councils were then left with the enormous task of creating a trafficable road network from a myriad of road reserves surveyed across the landscape. Simply due to lack of resources, only the immediate road surface area was cleared of vegetation. Today, roadside verges now provide important refuge for native vegetation.

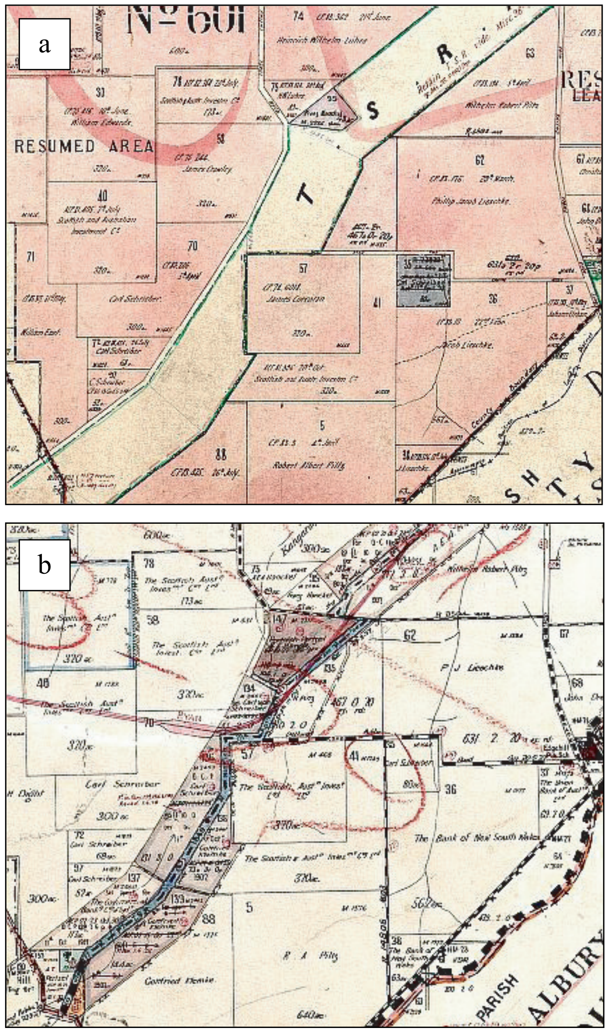



Figure 2. Reduction and alteration of a Travelling Stock Route, Parish of Edgehill, County of Mitchell (1888-1899, and 1913-1928). The first map (a) shows a ½ mile wide TSR gazetted in 1878, and evidence of early settlers claiming parts of the route (see Portion 57) before survey and marking. The second map (b) shows that by 1928, this TSR was reduced to its present-day width of 3 chains (NSW LPI 2001).

## **Present-day Roadside Conservation Values**

In much of south-eastern Australia, local government authorities have completed assessments of the conservation values of road reserves in their municipality. Each roadside has been surveyed using a rapid bio-assessment methodology, and given a conservation ranking (High, Medium or Low) based on attributes such as the width of the road reserve, proportion of remnant native vegetation, percentage of weed cover, degree of site disturbance, potential habitat value, and presence of any threatened species of flora or fauna. These rankings are used to determine appropriate management actions for each road category, as described in local roadside management plans. These plans vary from one council area to the next, depending on local conditions and funding, but the following general principles apply:

1. To ensure that high conservation value vegetation and special management areas (historic roads, heritage sites, locations for rare and threatened species) are able to continue as self maintaining weed and pest free environments, protected from disturbance from road or utilities works, and supplied with appropriate grazing and fire regimes (fig. 3)
2. To improve medium conservation value areas towards high conservation value, self sustaining areas;
3. To minimize threats to ecosystems within reserves to ensure that low conservation value areas are maintained so as to ensure safety of road users, avoid weed spread, assure fire control and retain their aesthetic values. In these areas, limited firewood collection and grazing is permitted (NSW REC 1996).

As many local governments have few funds for conservation management of roadside habitats, resources are often directed towards the maintenance of high conservation value roads (fig. 3). For example in southern NSW, Catchments Management Authorities (CMAs) and local government agencies are developing management plans for roads of high conservation value, many of which have important heritage values as 'historic roads'. Plans consider the unique nature of each road (e.g. species present, land-use history, current disturbance regimes) and road characteristics (width, road category & traffic volume).

## Influence of Land-use History on Roadside Conservation Values

So why is the structure and composition of individual segments of roadside vegetation often so variable? Are roadsides a legacy of past conditions as often assumed? In recent work by Spooner & Lunt (2004), historical information on the development of road reserves was collated from recently digitised 19th and 20th century pastoral and parish maps, such as road reserve age, road width, as well as data relating to locations of old pastoral fencelines, county or parish boundaries, previous reserves, stock routes and road re-alignments.

Regression analyses showed that road reserve width and road age were important predictors of roadside conservation rankings. There was a significant difference ($P < 0.001$) in mean road reserve width and age between road segments of different conservation ranking (Table 1). In general, wide road reserves had a higher percentage of roads segments classified as high conservation status (> 300 links/ 3 chains: 43%) than narrow roads (100 links: 15%) (fig. 4).

Further analysis with individual Mann-Whitney U tests showed that mean road reserve width and age were significantly greater on historic roads and travelling stock routes (Spooner & Lunt 2004).

Figure 3. Picture of a high conservation road in southern NSW, which is a placed along a parish boundary, and is 2-chains (40.1m wide). The large tree in the left foreground has a survey blaze from the 1870s on its trunk (Photos: L. Smallbone).

Table 1: Comparisons of mean road width and road survey age for road segments of different roadside conservation rankings ($P < 0.01$; Kruskal-Wallace tests)

| Roadside conservation value | Road width (m) | Road survey age (years) |
|---|---|---|
| 1 (High) | 46.3 | 121.9 |
| 2 (Medium) | 37.7 | 117.9 |
| 3 (Low) | 31.9 | 113.3 |

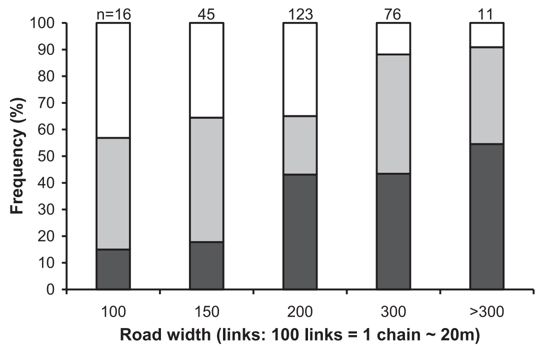



Figure 4. Frequency distribution of roadside conservation ranking's in five road width categories (original empirical units shown), showing road segments scored as High (black bars), Medium(grey bars) and Low (white bars) conservation value.

In this study, most wide roads were past or present Travelling Stock Routes (TSRs), and some rail reserves. As described, TSRs were surveyed at various widths up to one mile wide to provide enough fodder for stock travelling to markets. This highlights the important, albeit unintended, role of early surveyors in conserving native biota in roadside environments today. The work by Spooner & Lunt (2004) has shown that road reserve age was also important in predicting roadside conservation values. Variability in roadside conservation values is usually attributed not to road reserve age, but to internal processes such as grazing by stock, or external processes such as edge effects, weed invasions, roadworks and nutrient transfers from the agricultural matrix (e.g. Foreman et al. 2003, Spooner et al. 2004). As this study has demonstrated, an explicit understanding of road development history can explain much of the variability in roadside conservation values. More specifically, this study has identified that many road reserves of high conservation value are old roads – and in that sense have important heritage values to consider as 'historic roads'.

## Identification and Management of Historic Roads

It is important to identify and preserve historic roads, not just for heritage values, but also for their aesthetic, natural and conservation values. Formal listing on State and National registers may result in opportunities in gaining funding for management from sources otherwise not considered. However what criterion constitutes an historic road is not well understood in Australia. The term immediately evokes thoughts of famous roads such as Route 66 and the Columbia River Highway in the United States, or the Great Ocean Road in Australia. In New South Wales, the **Old Great North Road** (north of Sydney) is the only historic road listed on the NSW State Heritage Registry, and is significant because:

> ".. it is associated with several notable figures in colonial administration, surveying and engineering including Governor Darling, Surveyor General Thomas Mitchell and Percy Simpson, one of Australia's earliest scientific road engineers. ..The Old Great North Road physically demonstrates the work patterns, skills and organisation of convict work gangs...It has technological value in that it demonstrates the standards and practice of road engineering in the colony during the 'Great Roads' period of the late 1820s and 1830s. (NSW Heritage Office 2007)

Further inspection of the State Heritage Register shows that in relation to historic roads, the focus of heritage assessments is more on the built environment (e.g. old trestle bridges, early convict constructions, associated infrastructure) rather the natural values of the route. An historic road can be listed on the NSW State Registry if it meets one of the following criteria:

(a) an item is important in the course, or pattern, of NSW's cultural or natural history;
(b) an item is important in demonstrating aesthetic characteristics, or
(c) an item possesses uncommon, rare or endangered aspects of NSW's cultural or natural history; e.g. plants (NSW Heritage Act 1977, Amended 1998).

The latter criterion (c) suggests that suitable assessment mechanisms are in place to identify historic roads in NSW for their conservation (natural) values, however few are listed. A similarly inspection of the register of the Register of the National Estate (Australian Commonwealth) reveals two roads are listed:

- **Bala Travelling Stock Route - Remnant Vegetation Site**, Boorowa NSW
- **Somerton Road Travelling Stock Route**, Lower Somerton Rd, NSW.

In contrast to the NSW register, these historic roads (or routes) have been listed for "**..possession of uncommon, rare or endangered aspects of Australia's natural or cultural history**", as they contain 'intact' remnants of endangered White box woodlands, and provide refuge for a number of rare or endangered plant species (Australian Heritage Council 2007). Similar criteria exist in the United States (Historic Roads 2007) to identify historic roads.

Therefore as 'historic roads' often contain endangered remnant ecosystems, which make a significant contribution to conservation targets in many cleared landscapes of Australia, there is considerable scope and opportunities for road management authorities, land managers, and local communities to formally identify 'historic roads'. In particular, components of the Travelling Stock Route network, which represent important aspects of Australia's natural and cultural history. But why go to the trouble?

As stated in Historic Roads (2007), the benefits of identifying, preserving and managing an historic road are diverse. They may include opportunities for tourism and economic development, and assistance for restoration of historic structures and features such as bridges, survey trees, indigenous camp sites etc. Preservation of certain road sections may result in improved road safety and traffic flow. Furthermore, such a process may foster community pride associated with a more comprehensive understanding of their cultural and transportation heritage. Importantly, understanding the development history of historic roads can provide an important tool to gain new awareness of roadside environmental values, and facilitate greater community investment in their ongoing management.

## Conclusion

The present day road networks of south-eastern Australia are a historical vestige of past land-use decisions; a collection of TSRs, former pastoral run boundaries, county and parish boundaries, overlaid onto an uncoordinated collection of mostly one-chain roads, some of which were given 'character' by 19th century surveying errors. More by necessity than design, road reserves that were surveyed during rapid land development in the late 1800s, were later put into use as settlement patterns dictated. Many road reserves still contain important evidence of past land-use history in the form of historic survey trees, indigenous scar trees, stock ramps, camps, old tree stumps, bridges, rail sidings, post and rail fences and old wells, to name a few. In this way, each road reserve has a unique story to tell, often containing sections surveyed at different times with different histories, some with important historical and cultural values to the region.

An historical perspective of roads can greatly assist our interpretation of associated roadside and remnant ecosystems. As described, the conservation values of many roadside environments can be attributed to past land-use decisions. Many roads of high conservation status are often older roads, and in turn, many of these have important heritage values as historic roads. Understanding the land-use history of agricultural and other landscapes, and associated development of road networks, can provide new insights of the social and cultural values of roadside environments; a key issue to the successful conservation of these unusual landscape elements. Recognition of regional land-use and transportation histories, its legacies, and human relationships can only enrich our understanding of roadside environments.

**Acknowledgements:** This paper uses some edited material originally published as:

(a) Spooner, P.G. 2005. On squatters, settlers and early surveyors: historical development of road reserves in southern New South Wales. Australian Geographer 36, 55-73. It is produced courtesy of Taylor & Francis Ltd. http://www.tandf.co.uk/journals/titles/00049182.asp

(b) Spooner, P. G. and Lunt, I. D. 2004. The influence of land-use history on roadside conservation values in an Australian agricultural landscape. Australian Journal of Botany 52, 445-458. It is produced courtesy of CSIRO publishing. http://www.publish.csiro.au/paper/BT04008.htm

## References

Anderson, W. K. 1994. *Roads for the people: A history of Victorias roads*. South Melbourne: Hyland House.

Australian Heritage Council. 2007. The Register of the National Estate. http://www.ahc.gov.au/register/ (accessed 19 April 2007)

Beaver, P. W. 1953. The history of surveying in NSW. *The Australian Surveyor* 14(6 & 7): 182-96.

Beaver, P. W. 1980. An outline of the development of reference and permanent marks in New South Wales. *The Australian Surveyor* 30 (3): 189-96.

Bennett, A. F. 1991. Roads, roadsides and wildlife conservation: A review. In *Nature Conservation 2: The Role of Corridors* (eds D. A. Saunders, and R. J. Hobbs), 99-118. Chipping Norton NSW: Surrey Beatty & Sons.

Broomham, R. 2001. *Vital Connections: A History of NSW Roads From 1788*. Alexandria, NSW: Hale & Iremonger.

Buxton, G. L. 1967. *The Riverina 1861-1891*. Carlton: Melbourne University Press.

Carnegie, M. 1973. *Friday Mount: First Settlement at Holbrook and the South-Western Slopes of New South Wales*. Melbourne: Hawthorn Press.

Cooper, M. A. 1991. Too many users: the tragedy of the commons in rural roadsides. In *Nature Conservation 2: The Role of Corridors* (eds D. A. Saunders and R. J. Hobbs), 363-69. Chipping Norton, NSW: Surrey Beatty & Sons.

Dover, J., T. Sparks, S. Clarke, K. Gobbett, and S. Glossop. 2000. Linear Features and Butterflies: the Importance of Green Lanes. *Agriculture Ecosystems & Environment* 80(3): 227-42.

Fensham, R. J. 1989. The pre-European vegetation of the Midlands, Tasmania: a floristic and historical analysis of vegetation patterns. *Journal of Biogeography* 16: 29-45.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. 2003. Winter. 2003. *Road Ecology: Science and Solutions*. Washington: Island Press.

Foster, D., F. Swanson, J. Aber, I. Burke, N. Brokaw, D. Tilman, and A. Knapp. 2003. The importance of land-use legacies to ecology and conservation. *Bioscience* 53 (1): 77-89.

Gammage, B. 1986. *Narrandera Shire*. Narrandera, NSW: Narrandera Shire Council.

Hallman, F. M. 1973. *Legal aspects of boundary surveying as apply in New South Wales*. Sydney: New Century Press.

Harrison, R. 2004. Shared Landscapes: Archaeologies of Attachment and the Pastoral Industry in New South Wales. Sydney: University of NSW Press

Historic Roads (2007) Identification of Historic Roads. http://www.historicroads.org (accessed 18 April 2007).

Howitt, W. 1855. *Land, labour and gold; or two years in Victoria with visits to Sydney and Van Diemen's land*. Kilmore, Victoria, Australia: Lowden.

Jeans, D. N. 1972. *An historical geography of New South Wales to 1901*. Sydney: Reed Education.

Lockhart Shire Council. 2003. Shire History. http://lockhart.local-e.nsw.gov.au: Accessed 09 Oct 2003.

Marshall, E. J. R., and A. C. Moonen. 2002. Field Margins in Northern Europe: Their Functions and Interactions With Agriculture. *Agriculture Ecosystems & Environment* 89(1): 5-21.

McKnight, T. L. 1977. *The long paddock : Australia's travelling stock routes*. Armidale NSW: University of New England, Dept. of Geography.

Newell, H. H. 1938. Road engineering and its development in Australia: 1788-1938 (Pt 1 & 2). *Journal of the Institute of Engineers* 10(2 & 3): 41-106.

NSW Department of Main Roads. 1971. *All About Roads*. Sydney: NSW Department of Main Roads.

NSW Department of Main Roads . 1976. *The Roadmakers: A History of Main Roads in New South Wales*. Sydney: NSW Department of Main Roads.

NSW Heritage Office 2007. State heritage register, Heritage Office, Department of Planning http://www.heritage.nsw.gov.au/ (accessed 19 April 2007)

NSW Land & Property Information. 2001. *NSW Crown Land Administration Maps. Parish Maps: Wagga Wagga Office Set (CD 7 of 11 CDs). County of Hume, Parish of Buckargingah to County of Mitchell, Parish Minosa*. Bathurst, NSW: NSW Land & Property Information.

NSW Legislative Assembly . 1875a. *Volume 4, p. 523. Public Lands Report, Live stock report for 1874*. Sydney: NSW Government.

NSW Legislative Assembly 1875b. *Volume 3, p. 385. Reserves for Travelling Stock (correspondence and circulars).* Sydney: NSW Government.

NSW Legislative Assembly 1876. *Volume 5, p. 767. Public Lands Report, Live stock report for 1875*. Sydney: NSW Government.

NSW Legislative Assembly 1881. *Volume 3, p. 506. Public Lands Report, report from the Chief Inspector of Stock for 1880*. Sydney: NSW Government.

NSW Roadside Environment Committee. 1996. *Managing roadsides*. Sydney: NSW Roadside Environment Committee.

Pauwels, F., and H. Gulinck. 2000. Changing Minor Rural Road Networks in Relation to Landscape Sustainability and Farming Practices in West Europe. *Agriculture Ecosystems & Environment* 77(1-2): 95-99.

Prichard, F. A. 1991. *The History of Lockhart Shire Council: 1906:1990*. Lockhart, NSW.: Lockhart Shire Council.

Read, J. 2003. Parish Map Preservation Project: The Use of Digital Photography, CDs and Computers to Copy, View (and preserve) Old Maps. Accessed 25 November 2003. http://www.lpi.nsw.gov.au/maps/pmap/paper.pdf.

Reynolds, H. 1990. *With the White people*. Ringwood, VIC: Penguin.

Roberts, S. H. 1935. *The Squatting Age in Australia* 1835-1847. Melbourne: Melbourne University Press.

Spooner, P. G. 2005. On squatters, settlers and early surveyors: historical development of road reserves in southern New South Wales. *Australian Geographer* 36(1): 55-73.

Spooner, P. G., and I. D. Lunt. 2004. The influence of land-use history on roadside conservation values in an Australian agricultural landscape. *Australian Journal of Botany* 52 (4): 445-58.

Spooner, P. G., I. D. Lunt, S. V. Briggs, and D. Freudenberger. 2004. Effects of soil disturbance from roadworks on roadside shrubs in a fragmented agricultural landscape. *Biological Conservation* 117(4): 393-406.

Viles, R. L., and D. J. Rosier. 2001. How to Use Roads in the Creation of Greenways: Case Studies in Three New Zealand Landscapes. *Landscape and Urban Planning* 55(1): 15-27.

Williamson, I. P. 1982. Early Regulations for the survey and marking of Crown land in New South Wales. *The Australian Surveyor* 31(4): 246-54.

Winston-Gregson, J. H. 1985. A guide to locating settlements in rural New South Wales. *Australian Historical Archaeology* 3: 3-7.

# Dark Beaches - FDOT's Continued Efforts to Implement Environmentally Sensitive Lighting Systems

**Ann Broadwell** (954-777-4325, ann.broadwell@dot.state.fl.us), District 4 Environmental Administrator, Florida Department of Transportation, 3400 West Commercial Blvd., Fort Lauderdale, FL 33309 USA

**Abstract**

Artificial lighting has two important effects on sea turtles: It reduces the attractiveness of the beach to nesting females, and thus decreases the number of turtles which place nests in a coastal region, and; it interferes with the hatchlings ability to orient normally from the nest to the ocean.

Both of these effects depend upon the overall intensity (energy content) and spectral composition (concentration of heat energy as a function of wavelength) of the light source(s). Habitat alterations associated with FDOT coastal highways contribute to many beach lighting problems. The existing Florida Department of Transportation (FDOT) Roadway Lighting Standards do not take into account the biological conditions of adjacent properties when developing roadway lighting systems.

This problem was identified in the FDOT 2020 Long Range Transportation Plan which was approved by Secretary of Transportation Ben Watts and the Florida Transportation Commission in March 1995. The 2020 Long Range Plan suggested that FDOT incorporate the findings of the ecosystem management task force into Department procedures, including such ideas as identifying critical sea turtle nesting habitat where alternative street lighting could be installed. In 1998, FDOT entered into a research study with Florida Atlantic University (FAU) that would address the impacts of coastal roadway lighting on adjacent sea turtle nesting beaches. Originally, the purpose of this study was to (i) identify coastal roadway lighting problems, (ii) determine how they can be corrected, and (iii) use this information to develop new and improved lighting standards for roadway design engineers, coastal communities and utility companies. It was expanded to include an embedded roadway lighting demonstration project as well as an evaluation of the safety and roadway user response to embedded roadway lighting that was conducted by the Department of Civil and Coastal Engineering at the University of Florida (UF). These findings were presented at the 2001 ICOET conference in Keystone, Colorado. A recommendation of the UF research study was the need for the development of an Engineering Manual for Designing Roadway Lighting Systems in Environmentally Sensitive Areas. The manual would not necessarily offer new lighting criteria, but would show the designer how to use alternative lighting products in the design of coastal roadway lighting systems. It was determined that this would be a valuable resource for Florida and for the nation (Ellis and Washburn, 2003). The manual would allow the implementation of specialized Coastal Roadway Lighting Standards that would meet the needs of the roadway and satisfy the requirements of the Endangered Species Act.

The purpose of this paper is to provide an overview of this latest implementation of FDOT sponsored research to address coastal roadway lighting and its impacts on adjacent sea turtle nesting beaches. This recent project is a work in progress with anticipated completion date of September 2007.

# Developing Fauna-Friendly Transport Structures: Analysis of the Impact of Specific Road Engineering Structures on Wildlife Mortality and Mobility

**Christof Elmiger** (41-52-721-18-44, christof.elmiger@gmx.ch), Environmental Consultant, Kaden und Partner AG, Office for Ecology and Software Engineering, CH 8300 Frauenfeld, Switzerland
**Marguerite Trocmé** (41-31-322-80-03, marguerite.trocme@bafu.admin.ch), Senior Scientist, Swiss Agency for the Environment, CH 3003 Bern, Switzerland

**Abstract:** The barrier effect of roads is now well documented and solutions such as fauna passages are readily implemented (Trocmé et al. 2002). Less well known is the mortality caused by specific engineering structures used along roads, such as drainage systems. This research focuses on censusing wildlife hazards caused by such structures and developing solutions. Structures such as drainage systems, kerbs, gullies, culverts, noise barriers, lighting, retaining walls, were all examined. Small fauna specialists and maintenance teams were interviewed to gather information on known impacts as well as solutions found. Wildlife hazards were identified. Drainage systems with gullies often provoke high mortality for amphibians and other small fauna. Other structures such as retaining walls increase fragmentation by creating complete barriers. Designs more permeable to wildlife need to be enhanced. Certain solutions such as escape ramps from drainage systems have been tested on a local scale.

After identifying the problematic structures an analysis of Swiss road standards was made underlining which ones needed to be completed or modified so as to limit the impact of transport structures on wildlife. Further studies will be necessary so as to develop standardised solutions taking into account wildlife, maintenance and safety issues.

## Engineering Structures as Obstacles to Habitat Connectivity

In the past 50 years urban sprawl and fast extension and densification of transport networks have caused with the intensification of agriculture high fragmentation of open spaces and natural areas. Biodiversity continues to diminish as many natural areas are too isolated and small to sustain viable wildlife populations. In countries with transport infrastructure networks as dense as in Switzerland, the preservation of links between natural habitats and the restoration of ecological corridors has become a priority.

Part of the negative impact of transport networks can be mitigated through specific measures. The Swiss Association of Road and Traffic Experts (VSS) has emitted a series of norms on fauna passages with the goal of restoring as best possible connectivity (VSS 2004). However fauna passages do not solve all problems. A number of annexe structures cause high mortality and also have an impact on populations. The goal of this research was to collect field knowledge on the impact of various road and rail structures on animals and suggest mitigation measures. Depending on their design such structures can have negative effects, acting as traps (gullies) or positive effects, offering refuges for animals (stone walls) or movement corridors for wildlife along transportation axes (natural verges). The research report should serve as a reference for further standard revision and as a guide for engineers so as to avoid the use of structures dangerous to animals and diminish causes of indirect mortality.

## Research Methods

The study focused on gathering as much available information as possible, collecting known data about the negative side effects of infrastructure elements of road and railway systems and investigating potential issues not described so far. The impact of the following structures was examined: avalanche galleries, central reservation, curbs, drainage systems, verges, fences, lighting, noise barriers, overhead contact wires, retaining structures, road pavement, track ballast and rails. To gain an overview a thorough study of literature was conducted. In a second step, around 100 telephone interviews were conducted to gather more information. For this, regional environmental authorities, scientists, conservationists, were contacted, as well as road maintenance personnel who are directly confronted with the results of the conflict between fauna and infrastructure. The large quantity of information that was gathered in this process was stored and processed with the help of a database system. Field investigations were undertaken to learn more about new ideas not documented so far.

## Examples of Problematic Infrastructures

The following paragraphs present a selection of problematic structures with a strong impact on mortality and habitat connectivity of wildlife. The complete list of infrastructures and their main impact on the fauna is given in table 1. These structures are a problem when they cross natural habitat.

Table 1: List of problematic structures and their main impact on wildlife

| Infrastructure | Main impact | Description of impact |
|---|---|---|
| avalanche gallery | barrier | Terrestrial animals are unable to cross the structure. |
| central reservation | mortality | Central reservations with vegetation such as shrubs attract birds and expose them to a high risk of collision with vehicles. |
| curb | barrier | Small animals are unable to cross the structure. |
| drainage system | mortality | Small animals, mostly Amphibians, become trapped in the chutes. |
| culvert | barrier | Poorly designed culverts can't be used by animals to cross the traffic route. |
| fence | barrier/loss of habitat | Barrier if not used with fauna passage. Also can hinder, if placed far from the roadway, access to verges for large animals. |
| lighting | mortality/barrier | Insects are diverted from their flight path and often die in the process. |
| noise barrier | mortality/barrier | Birds risk mortality through collision with transparent barriers. Small animals are unable cross/by-pass the structure. |
| overhead contact wire | mortality | Birds risk mortality through collision or electrocution. |
| retaining structures | barrier | Terrestrial animals are unable to cross the structure. |
| road pavement | barrier | Insects and other small animals do not cross the structure. |
| track ballast and rail | barrier | Small animals are unable to cross the structure, if gaps are closed during maintenance. |
| verges | barrier | Poorly designed verges create additional barriers. Well designed verges possess great potential to improve habitat availability and overall habitat connectivity for the fauna. |

### Curbs as Obstacles for Small Animals

Local roads in Switzerland are often not drained over the shoulder into a ditch, but by means of curbs, sewers, and a subterranean drainage system as it is standard for roads in residential areas. As distances between villages are short, there may also be sidewalks following the road. Curbstones from sidewalks and drainage systems are strong barriers difficult or impossible to overcome for small animals (invertebrates, amphibians, reptiles, small mammals) trying to cross the road and wanting to leave the roadway on either side (Ratzel 1993). Even adult amphibians somehow feel compelled to follow the vertical structure instead of jumping over it (Ratzel 1993). Animals blocked from leaving the roadway are subject to traffic mortality, predators, climatic adversities, or may find an exit only far from the original destination.

Figure 1. This curbstone is known to guide Amphibians directly into the tunnel.

Figure 2. On this sidewalk excessive tidiness in the form of granite blocks prevents that small animals from habitat on the other side of the road can reach the meadow.

**Retaining Walls as Barriers**

Retaining walls, often built as smooth concrete walls, can pose similar problems as curbs but on a bigger scale. In natural surroundings such walls, often 2-3 m high, act as complete barriers for terrestrial wildlife. The barrier effect of the walls depends on height and length. Animals may become trapped on roads and therefore be more exposed to traffic mortality.

Figure 3. Retaining walls often border close to the roadway, blocking animal movements between habitats on either side of the road.

Figure 4. Even low retaining structures can be a strong barrier and prevent free crossing of a structure by small animals. (Photo courtesy to KARCH, Neuchâtel).

**Drainage Systems as Amphibian Traps**

Besides creating curbstone-barriers for small animals, the extensive drainage system along Swiss roads poses a second risk: small animals fall through the gully-covers when following the curb on the search for an exit. Amphibians are most threatened by this issue: searching moist shelter they intentionally let themselves drop into sewer chutes. Some wastewater treatment plants count several thousand amphibians each year, that come flushed through the drainage system (Bally 1998). These numbers are a minimal estimate as only survivors are found leaving the rest in the chute (Ratzel 1993).

Figure 5. This gully traps many amphibians each year, even though there is no curbstone guiding the animals to the entrance. The animals climb into the opening, expecting a humid shelter.

Figure 6. With no direct exit possibility, trapped toads and frogs either die in the chute or will, in the course of the next rain storm, get flushed into the sewer system via the siphon. (Photo courtesy to Amphibtec, Gelfingen)

**Poorly Designed Culvert**

Culverts, leading water underneath the transport infrastructure, are often barriers to both terrestrial and aquatic wildlife due to insufficient design. Fauna friendly culvert design is well illustrated in available publications (e.g. Iuell et al. 2003).

### Railroad-tracks Blocking Migration

Similar to curbstones, railroad-tracks too can physically hinder animals from reaching habitat on the other side of the structure. Time and vibrations from trains usually create gaps between track ballast and rails that suffice for small animals to slip through underneath the rails (Roll 2004). Maintenance crews however regularly reshape the gravel bed meticulously, closing the gaps in the process and therefore eliminating crossing possibilities for small animals. As a consequence, animals may not cross at all or need to search long distances for a gap, risking high traffic mortality and exposing themselves to predators and climatic adversities. As on roads, the problem becomes most evident when amphibians mass-migrate in spring and mortality is high.

Figure 7. Newt and toad killed on migration. The tight alignment between gravel and rail did not permit crossing. (Photo courtesy of Esther Krummenacher, Hausen)

### Mortality and Barrier Effects of Noise Barriers

Transparent noise barriers are well known to cause high casualties among songbirds as birds in flight often do not see the glass and collide with it (Schmid & Sierro 2000). However noise barriers also act as wildlife barriers, fragmenting habitat on verges. In Switzerland, the sunny, sparsely vegetated verges of the national railway network constitute an increasingly important refuge for reptiles amidst a landscape of urban sprawl and intensive managed farm lands (Meyer 2005). Herpetologists are concerned that the construction of noise barriers along the railway tracks may fragment this network by hindering movement both across the verge (barrier effect of the screen) and along the verge (barrier effect of the shade).

Figure 8. Noise barrier along a railroad line.

## Examples of Fauna Friendly Infrastructure Design

The study (Rieder et al. 2007) gives a catalogue of more than 140 proposals of adaptations of engineering structures that reduce negative impacts to animals. Some of these mitigation measures still need testing. In the following paragraphs we summarize a selection of the most promising ideas.

### Slanted Curbs

Drainage over the shoulder of the road is the best way to avoid increasing the barrier effect of roads on small fauna. If roads in natural surroundings require a curb, then the curb should be designed slanted, ideally at an angle of no more than 45 degrees (Weber 1998). Existing vertical curbs can be levelled by pouring concrete into the corner between road surface and curb. If the curb cannot be slanted as a whole, providing slants at regular intervals can be a functional compromise (Ratzel 1993). A less effective, temporary mitigation measure is to let adjacent vegetation overgrow the vertical curb, providing natural shelter and exit structures.

### Securing Drainage Systems for Amphibians

Designing slanted curbs as described above is a good measure to reduce the risk that animals follow the curb and drop into drainage chutes along the way. Modifying the covers of sewers and their positioning along the curbstone are further measures to secure the drainage system from small animals. In order to reduce the risk of accidental trappings, the openings in sewer covers should be as narrow as the necessary water throughput permits. Ratzel (1993) recommends slits no wider than 16 mm. Drainage openings can be offset from the curb so animals following the curb will be guided around it.

Figure 9. An urban example demonstrating that storm water must not necessarily be collected at the edge of the roadway. For roads leading through more natural surroundings, such a design could serve as a measure to reduce animal mortality in drainage chutes.

In the case of amphibians, slanting the curb and offsetting the chute positioning does not fully resolve the problem because of the strong attraction the dampness of gullies exerts on those animals. In some gully systems it is possible to reduce this effect of attraction by improving the drainage of the chute (Ratzel 1993). Covering openings with a fine mesh is very effective but requires much maintenance work as the mesh usually does not last long or gets clogged easily, preventing proper drainage of the street. It is therefore only to be used as a temporary measure. In Switzerland, the best solution where amphibian habitats are concerned is the installation of exit ramps from problematic chutes. Different systems of exit ramps have shown promising results and are currently being tested more thoroughly, for functionality as well as for ease of maintenance (Schelbert pers. comm.).

### Permeable Railroad-tracks

Railroad tracks in sensitive areas, e.g. cutting through amphibian habitats, should be maintained in a way that there are gaps present between track ballast and rails at all times, permitting small animals to cross the tracks. Studies from operating companies in Switzerland have shown, that it does not harm the stability of the rails, if at regular intervals the road bed is graded 5 cm below standard level (E. Krummenacher, pers. comm.). The result of this extra effort in maintenance is a permeable railroad line that permits annual mass migrations in spring (fig. 10) as well as individual migration throughout the year.

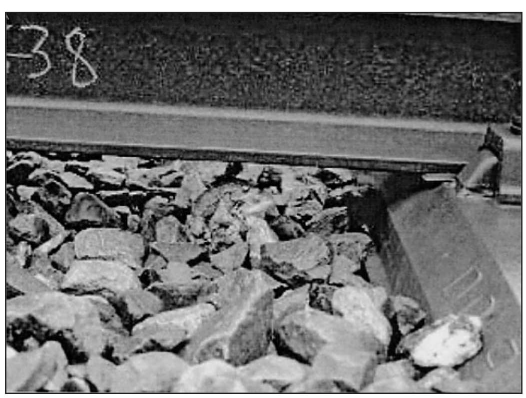



Figure 10. A pair of toads, slipping through the gap between rails and road bed.
(Photo courtesy of Esther Krummenacher, Hausen)

### Fauna-Friendly Retaining Walls

If space permits, a strip of natural surface should be left between the pavement and the wall. Animals unable to climb can use this strip to leave the roadway and follow the vegetation to the nearest habitat. The barrier effect of the wall itself can be further softened by using structured materials such as natural rock that facilitate climbing. Gabions filled with coarse rocks allow reptiles, mice and other small animals to climb upward as well as inward. Walls created with such gabions not only reduce the overall barrier effect of the structure, but also create new habitat for plants and animals (fig. 11). By providing adequate substrate behind the gabions, the wall may even offer valuable, frost-safe shelter for reptiles in winter (KARCH 2005).

Another way to make walls more permeable is to break up the linear structure as shown in figure 13. As a mitigation measure, some walls can be improved by piling up a cone of rocks or by covering parts of the wall with gabions (fig. 12).

Figure 11. This retaining wall built with gabions can be climbed by various animals, reducing the strong barrier effect such structures normally exert. The crevices of the coarse material provide habitat to small animals and plants.

Figure 12. A pile of rocks (left side) or gabions filled with rocks (right side) can improve the permeability of a wall for small animals.

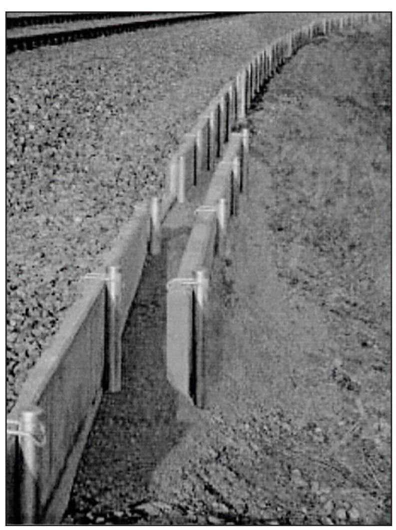


Figure 13. The barrier effect of the wall can be reduced by breaking up the linear structure. What's shown in this photo for a small structure along a railway line, can be achieved for walls with a height of several metres too. The example in the picture is currently being observed as it is not clear if it will successfully permit amphibian migration. (Photo courtesy of Esther Krummenacher, Hausen)

**Designing Animal Friendly Noise Barriers**

If noise barriers must be transparent, then the glass should be intensively patterned in order to disclose the obstacle to the birds eyes (fig. 14). Broad stripes (width of 1 or 2 cm) placed closely (gaps of 5 or 10 cm respectively) have been proven to work very effectively (note: the commonly used self-adhesive silhouettes of birds of prey do not show any effect). It is also very important that all trees and shrubs in the direct vicinity of the transparent barrier are removed to further reduce the attraction to birds (Schmid & Sierro 2000). Newly developed UV-reflecting glass may constitute a good alternative to patterned glass, but in the end, the best solution to avoid infrastructure mortality for songbirds is to renounce transparency entirely (Schmid & Sierro 2000) and work with opaque materials instead, which usually possess better acoustical characteristics and need less maintenance.

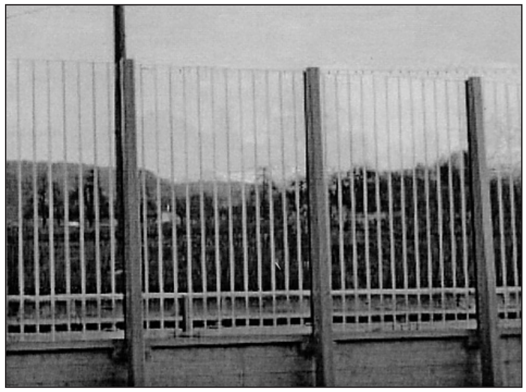


Figure 14. Example of a transparent noise barrier with a striped pattern as recommended by Schmid & Sierro (2000) to disclose the glass to birds eyes. (Photo courtesy of Joggi Rieder, Kaden und Partner AG)

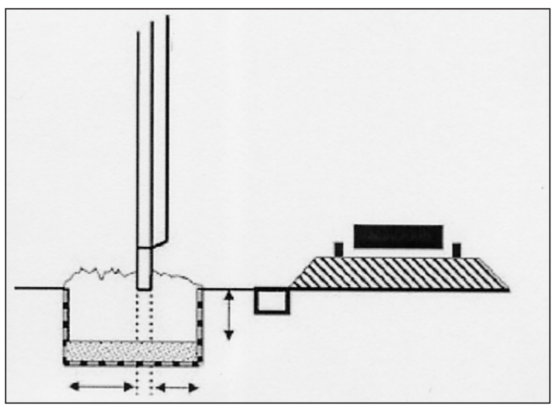


Figure 15. Design study for a reptile-friendly noise barrier. A well drained trench filled with sand and coarse rubble would be permeable for reptiles and other small animals and could serve as hiding-, nesting-, or winter-habitat. (Image courtesy to KARCH, Neuchâtel)

Noise barriers in sensitive areas should feature openings of some sort in order to break up the strong barrier effect of this structure for small animals. The Swiss Association for the Conservation of Reptiles and Amphibians (KARCH) has developed different ideas, how such openings could be implemented (see figure 15; Meyer 2005). The effectiveness has not yet been tested.

**Fauna Friendly Engineering – A New Standard?**

Fauna friendly engineering should no longer be an exception but become a rule. It's important that the awareness of conflicts between traffic infrastructures and the fauna rises, not only among conservationists, but most importantly among engineers. The fauna expert group of the Swiss Association of Road and Traffic Experts (VSS) aims at improving the standards for the construction of road infrastructures in promoting fauna friendly designs. The fauna expert group provides information to other expert groups and critically reviews drafts of new standards and revisions of old standards. The latest product of this collaboration is a new technical standard on the construction of curbs, that now includes considerations on the influence of curb design on habitat connectivity of small animals as well as recommendations on how to mitigate the negative impact (VSS 2006). Other VSS norms that need to be updated in terms of fauna friendly design are technical standards about verges, drainage systems, noise barriers, retaining structures, central reservation. Standards about fences and the renovation of culverts are currently being revised and developed under the guidance of the VSS fauna expert group.

**Biographical Sketch:** Christof Elmiger, born 1977 in Switzerland, has studied biology at the University of Zurich and the Swiss Federal Institute of Technology Zurich attaining a master's degree with a thesis on the ecology of blennies and gobies in Switzerland. Today he is working as an environmental consultant for Kaden und Partner AG, a small company in Frauenfeld.

Born in Paris in 1961, Marguerite Trocmé grew up in Canada before moving to the U.S. and received her bachelor of science degree in biology from Brown University in Providence, Rhode Island in 1983. In 1985, a master's degree in environmental engineering from the Ecole Polytechnique Fédérale (EPFL) of Lausanne, Switzerland followed. She then worked both for the Swiss World Wildlife Fund and the Swiss Ornithological Institute before joining the Swiss Agency for the Environment, Forests, and Landscape in 1989. She is responsible for the impact appraisal of federal infrastructure projects on nature and landscape. She was vice-chairman of the European COST 341 Project. She has led and edited studies and publications in the areas of the impact of high tension lines, roads, and aviation on natural ecosystems. She is president of the VSS fauna expert group.

## References


Iuell, B., G.J. Bekker, R. Cuperus, J. Dufek, G. Fry, C. Hicks, V. Hlavac, V. Keller, C. Rosell, T. Sangwine, N. Torslov, B. le Maire Wandall (Eds.). 2003. Wildlife and Traffic - A European Handbook for Identifying Conflicts and Designing Solutions. KNNV, Utrecht, The Netherlands.

KARCH. 2005. Aménagements à reptiles. Koordinationsstelle für Amphibien- und Reptilienschutz in der Schweiz.

Meyer, A. 2005. Reptilienschutz im Rahmen der Lärmsanierungsprojekte der Eisenbahnen. Koordinationsstelle für Amphibien- und Reptilienschutz in der Schweiz, Schweizerische Bundesbahnen and BLS.

Ratzel, M. 1993. Strassenentwässerung - Fallenwirkung und Entschärfung unter besonderer Berücksichtigung der Amphibien. Bezirksstelle für Naturschutz und Landschaftspflege, Karlsruhe.

Rieder, J., C. Elmiger, S. Schneider, R. Fankhauser. 2007. Vernetzung von Lebensräumen bei der Gestaltung von Verkehrsträgern. Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation UVEK, Bern. 99 pp+CD-ROM.

Roll, E. 2004. Hinweise zur ökologischen Wirkungsprognose in UVP, LBP und FFH-Verträglichkeitsprüfungen bei Aus- und Neubaumaßnahmen von Eisenbahnen des Bundes. Eisenbahn-Bundesamt, 50733 Köln.

Schmid, H., A. Sierro. 2000. Test of measures to prevent bird-strikes on transparent noise-protection walls. Natur und Landschaft 75: 426-430. http://www.windowcollisions.info/e/bibliography.html.

Trocmé, M., S. Cahill, H. J. G. De Vries, H. Farall, L. Folkeson, G. Fry, C. Hicks, J. Peymen (Eds.) 2002. COST 341 - Habitat Fragmentation due to Transportation Infrastructure: The European Review. European Commission Directorate General Transport.

VSS. 2004. Fauna und Verkehr - Schutzmassnahmen. SN 640 694. Schweizerischer Verband der Strassen und Verkehrsfachleute, Zürich. www.vss.ch.

VSS. 2006. Abschlüsse für Verkehrsflächen - Qualität, Form und Ausführung. SN 640 481. Schweizerischer Verband der Strassen und Verkehrsfachleute, Zürich. www.vss.ch.

Weber, D. 1998. Einzelidee 6.07 - Schräge Randsteine. Bundesamt für Umwelt, Bern. Schriftenreihe Umwelt Nr. 280.

# The Establishment Success of Native Versus Non-Native Herbaceous Seed Mixes on a Revegetated Roadside in Central Texas

**M. Jeannine Tinsley**, M.S. (512-292-4200, jtinsley@wildflower.org),
**Mark T. Simmons**, Ph.D. (msimmons@wildflower.org), and
**Steve Windhager**, Ph.D. (stevew@wildflower.org), Lady Bird Johnson Wildflower Center, 4801 La Crosse Avenue, Austin, TX 78739, Fax: 512-292-4627 USA

**Abstract:** Revegetation is an essential component of roadside and building site construction and improvement. In the southern United States non-native grass species are frequently included in revegetation seed mixes used by highway authorities. Non-native species are frequently selected for aggressive growth characteristics, however these same traits also render them potentially invasive, and subsequently hazardous to, adjacent plant communities. Although the use of pure native seed mixes have been rejected in the past due to perceived inferior establishment characteristics, there have been few comparative quantitative field studies that justify this belief. The establishment characteristics of three seed mixes: one containing non-native species and two with native grass and forb species only, were compared in a randomized-block design along a Texas roadside following spring and summer sowing. After 60 days following the spring sowing, the two native-only seed mixes demonstrated 180% and 560% ($F=10.18$; $P<0.0001$) higher seed densities than the recommended native/non-native mix. The summer sowing results were similar with seedling densities 180% and 330% ($F=9.20$; $P<0.01$) greater than the standard non-native seeding. Although an aggressive colonizer from vegetative tissue such as stolons and rhizomes, the non-native Bermudagrass (Cynodon dactylon) has a lower than expected establishment rate thought to be due to high water demand during the first weeks following sowing. Given the invasive characteristics of this common component of many recommended revegetation seed mixes, these results call into question the widespread recommended use of Bermudagrass for such projects. These data indicate that examination of suites of early- and late-succesional native species can provide a highly effective mix for revegetation projects. Furthermore, this reduces the potential for negative ecological consequences and provides added benefits associated with wholly native plant communities.

## Introduction

Revegetation is an essential component of roadside and building site construction and improvement. Successful revegetation requires species that have rapid establishment and growth and minimal input of resources such as water, fertilizer, and pesticides. The final result should be a manageable vegetative cover that fulfils the regional roadside authority's specifications with regard to safety, erosion control, and maintenance. In much of the southern United States non-native grasses such as Bermudagrass (Cynodon dactylon), St. Augustine, (Stenotaphrum secundatum), and Oldworld bluestem (Bothriochloa ischaemum) are frequently included in seed mixes due to their establishment characteristics, low seed cost, and availability (Texas Department of Transport, 1993; Jenkins et al., 2004; Texas Department of Transport, 2004a). Regrettably, these species often spread from their initial locations and become locally or regionally invasive (Jenkins et al., 2004; Diggs et al., 1999), contributing to the 40 million ha. (99 million acres) of already invaded land area in the United States (Babbitt, 1998). This has prompted a call for the decreased use of non-native plants and the subsequent replacement and increased use of native plants in landscaping and revegetation projects. Roadside rights-of-way account for more than 4.9 million hectares (12 million acres) of land in the United States. This land could potentially provide habitat for many native plants and animals (Federal Highway Administration, 1999). Unfortunately, this widespread transportation network often acts as a vector for the spread of ecologically harmful invasive species.

In accordance with this scenario, the Federal Highway Administration issued an Executive Memorandum (November 11, 1995), outlining guidance for landscaping practices on federal lands following the April 1994 Presidential Executive Memorandum on Environmentally Beneficial Landscaping signed into law by President Clinton on April 26, 1994. This included two principles:

1. Use regionally-native plants for landscaping.
2. Design, use or promote construction practices that minimize adverse effects on natural habitat.

Aside from problems associated with non-native plants becoming invasive, the use of native species can also claim other advantages: Regional adaptation can equate to a lower requirement of resources (water and nutrients).They can provide and reinforce habitat for native plants and animals.Many native species provide spectacular seasonal color displays.Native species provide regional character and identity.

Although several studies have examined establishment characteristics of selected native species (see Bugg et al., 1997 and Jenkins et al., 2004 for review), few compare the establishment characteristics of native versus non-native species. The Texas Department of Transportation (TxDOT) sows more than 13,600 kg (30,000 lb) of native wildflower seed annually, covering over 7,000 ha (17,000 acre) across the state as part of its vegetative management program for 484,000 km (300,000 miles) of state roads and highways (Texas Department of Transport 2004b). Most utilized species are native: green sprangletop (*Leptochloa dubia*); sideoats grama (*Bouteloua curtipendula*); sand lovegrass (*Eragrostis trichodes*); Illinois bundleflower (*Desmanthus illinoensis*); lance-leaf coreopsis (*Coreopsis lanceolata*); and over recent years many non-native species have been removed from recommended seed lists. However, several non-natives including the invasive Bermudagrass and bahiagrass (*Paspalum notatum*) persist in the recommended seed lists. Although there are accepted invasive problems associated with using such non-native grasses, there is no evidence to refute the widely held belief that native species are not as effective at rapid revegetation. Because the

Storm Water Pollution Prevention Plan (SW3P) (40 CFR, Part 122 and Federal Register/Vol. 63, No. 128) requires that adequate stabilization measures (e.g. permanent vegetation) be in place within 21 days after construction activity at a site ceases. Most construction contractors err on the side of caution in using mixes that include species with which they have a greater level of familiarity. This reliance by managers on familiar species however, favors heavy use of non-native species. Existing species recommendations typically include non-native species that have been extensively used historically and therefore have known establishment characteristics. Most of the native species that have been available commercially historically are those that are long-lived perennial species that have value as forage grasses. These late-successional species are often slow to establish, particularly under harsh conditions, and are indeed poor choices for rapid revegetation. In recent years, the commercial seed industry has expanded beyond the agricultural forage production, and has begun to make early-successional species available on the market. We believed that a seed mix that combined both early- and late- successional species would both provide rapid revegetation, and permanent vegetative cover for the long-term.

Therefore the goal of this study was to answer the following questions

1. Is there a significant difference in and rate of coverage after 60 days between existing recommended TxDOT seed mix which contains both native and non-native species, and alternative purely native seed mixes?
2. Is there a single native seed mix that could be used both in spring and summer?

## Methods

### Site and Experimental Design

A randomized block design (n=6) was established along a one-mile stretch of a rural highway in southern Travis County, Texas (30º 11'N, 97º 52'W; elevation 247 m; mean annual rainfall 810mm). Climate is subhumid, subtropical with a bimodal rainfall pattern peaking in spring and fall. Soils are Speck stony clay loam (USDA, 1974) with a 10% to 30% southeast-facing slope. Three other blocks were located on an adjacent property approximately 500 m away from the highway, giving a total of 9 replicated blocks. Individual experimental units within each block measured 3 m x 3 m with a 1 m buffer around the perimeter. The buffer was created by herbiciding existing vegetation and scraping away as much vegetative debris and roots as possible. Herbicide was reapplied during the course of the study if the integrity of the experimental unit was threatened by outside invasion.

### Seed Mix Calculations

The establishment successes of the following three seed mixes were compared:

1. *TxDOT mix:* contains recommended native and non-native seed stipulated by Item 64 –Seeding for Erosion Control; TxDOT Specification Manual (1993/Rev. 2001) (table 1). According to TxDOT recommendations, this seed mix can only be sown in the spring due to a belief that it would have poor success in any other season. For summer sowing these specifications recommend the sowing of foxtail millet (*Setaria italica*) as temporary coverage. Temporary coverage is then to be replaced by the following spring season with the perennial TxDOT seed mix.
2. *Commercial mix:* A mix selected by the authors consisting of commercially available native seed (table 2).
3. Non-commercial mix: a mix of native seed selected by the authors containing commercial and non-commercially available seed (table 3).

Table 1: Reference seed PLS and density for TxDOT spring seed mix

| Common | Species | kg PLS $ha^{-1}$ | seeds $gram^{-1}$ | PLS $m^{-2}$ |
|---|---|---|---|---|
| Sideoats grama | *Bouteloua curtipendula* | 2.0 | 318 | 64 |
| Buffalograss | *Buchloe dactyloides* | 6.0 | 60 | 32 |
| Bermudagrass | *Cynodon dactylon* | 1.3 | 4400 | 592 |
| Green sprangletop | *Leptochloa dubia* | 0.7 | 1196 | 75 |
| Indiangrass | *Sorghastrum nutans* | 1.7 | 378 | 64 |
| | | | TOTAL | 827 |

Table 2: Commercially available perennial native seed mix (spring and summer sowing)

| Common | Species | Germination rate (%) | Total seed $m^{-2}$ | Seeds $gram^{-1}$ | Seed grams/site | PLS $m^{-2}$ |
|---|---|---|---|---|---|---|
| Purple threeawn | *Aristida purpurea* | 93.95 | 57 | 300 | 1.7 | 54 |
| Sideoats grama | *Bouteloua curtipendula* | 72.71 | 103 | 318 | 2.9 | 75 |
| Silver bluestem | *Bothriochloa laguroides* | 50 | 474 | 930 | 4.6 | 237 |
| Buffalograss | *Buchloe dactyloides* | 92.67 | 58 | 60 | 8.7 | 54 |
| Canadian wildrye | *Elymus canadensis* | 90.63 | 60 | 205 | 2.6 | 54 |
| Engleman's daisy | *Engelmannia pinnatifida* | 100 | 21 | 105 | 1.8 | 21 |
| Green sprangletop | *Leptochloa dubia* | 92.7 | 116 | 1196 | 0.9 | 108 |
| Mexican hat | *Ratibida columnifera* | 100 | 43 | 950 | 0.4 | 43 |
| Little bluestem | *Schizachyrium scoparium* | 65.62 | 114 | 567 | 1.8 | 75 |
| Indiangrass | *Sorghastrum nutans* | 60.09 | 125 | 378 | 3.0 | 75 |
| | | | | | TOTAL | 796 |

Table 3: Non-commercially available native seed mix (spring and summer sowing)

| Common | Species | Germination rate (%) | Total seed $m^{-2}$ | Seeds $gram^{-1}$ | Grams Seed /site | PLS $m^{-2}$ |
|---|---|---|---|---|---|---|
| Purple threeawn | *Aristida purpurea* | 93.95 | 22 | 300 | 0.7 | 21 |
| Sideoats grama | *Bouteloua curtipendula* | 72.71 | 74 | 318 | 2.1 | 54 |
| Hairy grama | *Bouteloua hirsute* | 14 | 228 | 1666† | 1.2 | 32 |
| Silver bluestem | *Bothriochloa laguroides* | 50 | 64 | 930 | 0.6 | 32 |
| Texas grama | *Bouteloua rigidiseta* | 56 | 384 | 161 | 21 | 215 |
| Buffalograss | *Buchloe dactyloides* | 92.67 | 46 | 60 | 7.0 | 43 |
| Canadian wildrye | *Elymus canadensis* | 90.63 | 23 | 205 | 1.0 | 21 |
| Englemann's daisy | *Engelmannia pinnatifida* | 100 | 21 | 105 | 1.8 | 21 |
| Hairy tridens | *Erioneuron pilosum* | 26 | 165 | 500† | 3.0 | 43 |
| Indian blanket | *Gaillardia pulchella* | 100 | 21 | 277 | 0.7 | 21 |
| Curly mesquite | *Hilaria belangeri* | 5 | 860 | 645† | 12 | 43 |
| Standing cypress | *Ipomopsis rubra* | 100 | 21 | 500 | 0.4 | 21 |
| Fall witchgrass | *Digitaria cognatum* | 50 | 128 | 1400 | 0.8 | 64 |
| Green sprangletop | *Leptochloa dubia* | 92.7 | 58 | 1196 | 0.4 | 54 |
| Horsemint | *Monarda citriodora* | 100 | 21 | 2200 | 0.08 | 21 |
| Texas wintergrass | *Nassella leucotricha* | 18 | 178 | 190* | 8.4 | 32 |
| Hall panicum | *Panicum hallii* | 25 | 44 | 1000 | 0.4 | 11 |
| Mexican hat | *Ratibida columnifera* | 100 | 21 | 950 | 0.2 | 21 |
| Blackeye Susan | *Rudbeckia hirta* | 100 | 21 | 3500 | 0.05 | 21 |
| Little bluestem | *Schizachyrium scoparium* | 65.62 | 49 | 567 | 0.8 | 32 |
| Indiangrass | *Sorghastrum nutans* | 60.09 | 53 | 378 | 1.3 | 32 |
| | | | | | Total | 855 |

*Based on number of seeds per gram after treatment with sulfuric acid.
†Seed heads

For the two native seed mixes, species were selected not only based on their potential for rapid establishment (i.e. early successional), but also for longer-term stability. The germination characteristics of many of the locally harvested species were largely unknown, but considered worthy candidates.

**Seed viability**

To fairly test species performance, seeding densities were also corrected for viability. Tetrazolium chloride was used to check for respiratory activity of seed embryos indicating viability (Association of Official Seed Analysts, 1970). Three replicates of approximately 25 random seeds for each hand-collected species were treated. This number is less than the AOSA recommendation, but the supply of seeds from which these samples were drawn was limited. Species tested were hairy grama (*Bouteloua hirsute*), Texas grama (*Bouteloua. rigidiseta*), hairy tridens (*Erioneuron pilosum*), curly mesquite (*Hilaria belangeri*), fall witchgrass (*Digitaria cognatum*), Texas wintergrass (*Nassella leucotricha*), and Hall panicum (*Panicum hallii*).

Each seed was cut to expose the embryo. The seed was placed cut side down in a thin layer of 0.1% tetrazolium chloride solution in a petri dish. All dishes were covered and placed in the dark for at least 2 hours. The seeds were removed and examined for the presence of a red color indicative of viability. Average viability rate was calculated between the three replicates for each species.

Table 4: Seed viability based on Tetrazolium test, for hand-collected species included in non commercial seed mix

| Common | Species | Viability |
|---|---|---|
| Hairy grama | *Bouteloua hirsute* | 60% |
| Texas grama | *Bouteloua rigidiseta* | 56% |
| Hairy tridens | *Erioneuron pilosum* | 50% |
| Curly mesquite | *Hilaria belangeri* | 40% |
| Fall witchgrass | *Digitaria cognatum* | 50% |
| Texas wintergrass | *Nassella leucotricha* | 18% |
| Hall panicum | *Panicum hallii* | 25%. |

Percent viability does not necessarily reflect germination percentage (Association of Official Seed Analysts, 1970). Testing for actual germination of these species gave excessively low germination rates. Using those rates in Pure Live Seed (PLS: purity x germination) calculations would have created unrealistically high numbers of seeds needed in the non-commercial mix. For the purposes of this study, we adopted the more conservative approach and the viability percentage was used in the PLS calculation.

Additional procedures were implemented to improve germination rate for both Texas wintergrass and curly mesquite. Research indicates that neither of these species germinates successfully by seeding only (Van Auken, 1997; Cory, 1948). For Texas wintergrass, the awn of each seed was broken off and all the seeds were scarified with concentrated sulfuric acid (White and Van Auken, 1996). Curly mesquite spiklets were soaked in 0.7 mM of gibberellic acid (Ralowicz et al., 1992) for five minutes and dried for 24 hours before planting.

To create a comparable mix of different species based on the number of PLS a reference density (PLS $m^{-2}$) was computed by determining the number of seeds per gram of each species based on TxDOT specifications. The range of these stipulated densities varied from 753 to 1076 PLS $m^{-2}$. Therefore, a density of 827 germinating seeds $m^{-2}$ was used to provide a reference PLS density to calculate equivalent densities for the seed mix comparisons. The final species mixes varied only slightly in terms of calculated PLS density compared to the TxDOT mix (+/- 30 seeds $m^{-2}$). The TxDOT mix contained 5 species with 827 PLS $m^2$, the commercially available mix contained 10 species with 796 PLS $m^{-2}$ and the non-commercial blend contained 20 species with 855 PLS $m^{-2}$ (tables 1, 2, & 3). Seed mixes were based on germination rating given on purchased seeds and on results of viability testing (table 4) conducted on the hand-collected species.

*Planting*

Seeds were sown by hand-broadcasting into experimental units. The seed mixes were integrated with damp sand before being broadcast in order to add weight and better adherence to the soil. For the spring sowing, the TxDOT mix and the commercial mix were sown on April 7, 2004; the non-commercial mix was sown April 8, 2004. For the summer sowing, all mixes were sown on August 6 and August 7. Each site was raked, the seeds were spread by hand, and the site was lightly raked again. The back of a cultivator hoe was used to press seeds into the soil.

*Watering*

The spring planting was immediately followed by 2 significant rain events. The sites received 1.62 cm rain on April 10 followed by 2.42 cm on April 11. Total equivalent water received by each plot was 7.09 cm, 5.81 cm, and 31.85 cm, for April, May, and June, respectively. Summer sowing received 0.20 cm of water immediately upon planting. All blocks received 0.41cm water at least once a week, either in the form of rain or from a sprayer. Total water received by each summer plot was 6.07 cm, 5.38 cm, and 13.63 cm for August, September, and October respectively.

*Climate*

The 2003 spring growing season provided typical temperatures and precipitation for the central Texas region. The months of April and May had a range of temperatures from 6.1°C to 32.2°C averaging 21.5°C. Rainfall totals for this area during these two months were 93.98 mm and 45.72 mm respectively.

Summer climate was atypical for the area. June experienced an exceptionally high amount of precipitation of approximately 317.25 mm. Temperatures in June ranged from 33.2°C to 11.8°C with an average of 24.8°C. July and August had relatively mild temperatures for the summer season with a range from 37.3°C to 18.2°C with an average of 27.5°C. July precipitation totaled 26.16 mm. and August totaled 34.8 mm. September temperature averaged 25.7°C, and the amount of precipitation was 29.5 mm. October was another record setting month for precipitation with a total of 153.03 mm. Temperatures were within the range of 32.1°C and 11.4°C with the average temperature of 23.3°C.

*Surveying*

All germinated seed within each experimental unit were counted at 21, 30 and 60-day intervals. Clearly identifiable resprouting tillers of weed species not killed by the herbicide application were ignored. Seedling counts were conducted in two groups: those that could be positively identified as species planted, and unidentified species (possibly volunteers). For 21- and 30-day counts both groups of seedlings were included in the count. However, by 60 days positive identification was possible. Due to increased seedling densities by the 60-day survey date, total counts were estimated from 2 subsamples (2 x 1$m^2$ quadrats) arranged randomly in each experimental unit.

*Data Analysis*

Seedling density data were analyzed using repeated-measures ANOVA with treatment as main factor, and the 60-day count of positively identified species was analyzed with one-way ANOVA. Tukey MSD test was used throughout ($P \leq 0.05$).

Plant species nomenclature follows (Kartesz, 1999).

## Results

### Seedling Establishment - Spring Sowing

Total (identified and unidentified) seedling counts after 14 days revealed no difference between treatments. However, after 30 days, the non-commercial mix had significantly higher total seedling density than the TxDOT, and by 60 days the commercial mix and non-commercial mix densities were respectively 180% and 560% higher than the TxDOT mix ($F=20.18$; $P<0.001$; fig. 1), with a significant seed mix x time interaction ($F=15.38$; $P<0.001$) indicting the increase of the magnitude of the seed mix density effect over the monitoring period. Total identified seedling density revealed a similar pattern with non-commercial mix significantly greater (490%) than TxDOT mix (fig. 2). Sideoats grama, buffalograss/curly mesquite constituted the bulk of the seedlings across all seed mixes. Non-commercial mix also had significant contributions (>5% composition) from hairy tridens (12%), Texas wintergrass (9%), and Indian blanket/Englemann's daisy (7%) (table 5) and this pattern similarly reflected in relative establishment success (table 6).

### Seedling Establishment - Summer Sowing

Both the commercial and non-commercial seed mixes out-performed the TxDOT seed mix at 14 and 21 days, and at the end of 60 days exhibited seedling densities of 180% and 330% greater than the TxDOT seed mix ($F=9.20$; $P<0.01$, fig 1). Examination of 60-day spring-sown species composition expressed as proportion of total identifiable seedlings, showed that all but one species (Indian grass) exhibited some measurable germination. Purple three-awn, sideoats/hairy/Texas grama, buffalograss/curly mesquite, and green sprangletop contributed most to all mixes, with the addition of Texas wintergrass and hairy tridens in the non-commercial mix, and significant contributions from Bermudagrass in the TxDOT mix (table 5). This was reflected in the relative germination success, although the few forbs on average performed better than grasses overall (table 6). For the summer sowing, purple three-awn, sideoats/hairy/Texas grama, buffalograss/curly mesquite, hairy tridens, green sprangletop and hall panicum had the greatest germination success and dominated the composition of the two native seed mixes (table 6). Sideoats/hairy/Texas grama, Indian grass, and green sprangletop showed increased germination success compared to spring sowing. Foxtail millet, the only species in the TXDOT summer mix had relatively low germination success (table 6).

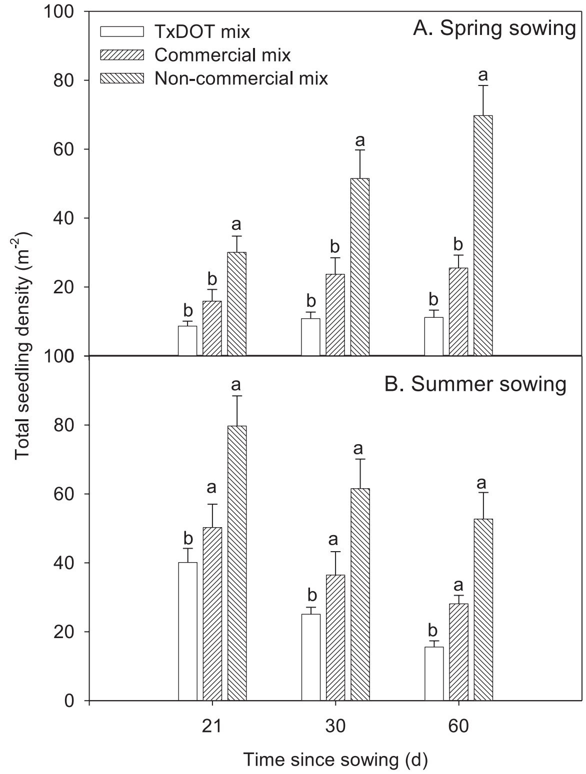



Figure 1: The effect of seed mix on identified and unidentified mean seedling density after 21, 30, and 60 days following sowing in spring and summer. Error bars represent 1 S.E. Bars with different letter are significantly different at P<0.05 level.

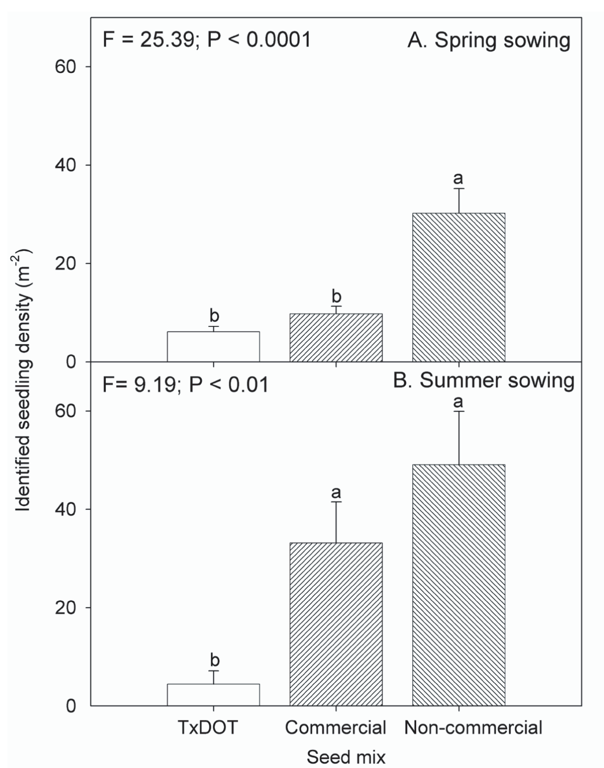



Figure 2: The effect of seed mix on identified mean seedling density at 60 days after sowing in spring and summer. Error bars represent 1 S.E. Bars with different letter are significantly different at P<0.05 level.

Table 5: Proportional (%) species composition of the 60-day plant density for spring and summer sowing. Species are combined where they were indistinguishable at the seedling stage. <1 = 0-1 % total. 0 = sown but not present

| | Spring sowing | | | Summer sowing | | |
|---|---|---|---|---|---|---|
| **SPECIES** | **Commercial** | **Non-commercial** | **TxDOT** | **Commercial** | **Non-commercial** | **TxDOT** |
| *Aristida purpurea* | 12 | 3 | | 40 | 13 | |
| *Bouteloua curtipendula* | 19 | 20 | 14 | 23 | 17 | |
| *Bouteloua hirsute/Bouteloua rigidiseta* | | 4 | | | 6 | |
| *Bothriochloa laguroides* | 6 | <1 | | 1 | 0 | |
| *Buchloe dactyloides/Hilaria belangeri* | 35 | 31 | 47 | 14 | 9 | |
| *Cynodon dactylon* | | | 34 | | | |
| *Elymus canadensis* | 1 | | | 0 | 0 | |
| *Engelmannia pinnatifida/Gaillardia pulchella* | | 7 | | 0 | <1 | |
| *Erioneuron pilosum* | | 12 | | | 19 | |
| *Ipomopsis rubra* | | 4 | | | 1 | |
| *Digitaria cognatum* | | <1 | | | 4 | |
| *Leptochloa dubia* | 15 | 3 | 5 | 20 | 10 | |
| *Monarda citriodora* | | 3 | | | 0 | |
| *Nassella leucotricha* | | 9 | | | 1 | |
| *Panicum hallii* | | 0 | | | 18 | |
| *Ratibida columnifera* | 6 | 1 | | 0 | 0 | |
| *Rudbeckia hirta* | | 1 | | | <1 | |
| *Schizachyrium scoparium* | 6 | 2 | 0 | 0 | 0 | 0 |
| *Setaria italica* | | | | | | 100 |
| *Sorghastrum nutans* | 0 | 0 | 0 | 2 | 1 | |

Table 6: Relative (to initial sowing density) establishment success (%) of species by 60-day plant density spring and summer sowing. Species are combined where indistinguishable at the seedling stage. 0 = 100% mortality, blank cell = species not sown

| | Spring sowing | | | Summer sowing | | |
|---|---|---|---|---|---|---|
| **SPECIES** | **Commercial** | **Non-commercial** | **TxDOT** | **Commercial** | **Non-commercial** | **TxDOT** |
| *Aristida purpurea* | 2.0 | 4.0 | | 24.8 | 30.5 | |
| *Bouteloua curtipendula/Bouteloua hirsute/ Bouteloua rigidiseta* | 2.4 | 2.4 | 1.2 | 10.2 | 3.7 | |
| *Bothriochloa laguroides* | 0.2 | 0.3 | | 0.1 | 0.0 | |
| *Buchloe dactyloides/Hilaria belangeri* | 6.4 | 10.9 | 9.0 | 8.6 | 4.4 | |
| *Cynodon dactylon* | | | 0.4 | | | |
| *Elymus canadensis* | 0.1 | 0.0 | | 0.0 | 0.0 | |
| *Engelmannia pinnatifida/Gaillardia pulchella* | 0.0 | 4.8 | | 0.0 | 0.3 | |
| *Erioneuron pilosum* | | 8.5 | | | 22.0 | |
| *Ipomopsis rubra* | | 5.0 | | | 1.7 | |
| *Digitaria cognatum* | | 0.2 | | | 3.2 | |
| *Leptochloa dubia* | 1.4 | 1.4 | 0.4 | 6.1 | 9.4 | |
| *Monarda citriodora* | | 3.5 | | | 0.0 | |
| *Nassella leucotricha* | | 8.3 | | | 2.0 | |
| *Panicum hallii* | | 0.0 | | | 27.4 | |
| *Ratibida columnifera* | 1.3 | 1.3 | | 0.0 | 0.0 | |
| *Rudbeckia hirta* | | 1.0 | | | 0.7 | |
| *Schizachyrium scoparium* | 0.7 | 1.7 | 0.0 | 0.0 | 0.0 | |
| *Setaria italica* | | | | | | 0.3 |
| *Sorghastrum nutans* | 0.0 | 0.0 | 0.0 | 0.8 | 1.1 | |

## Discussion

This study demonstrates that following spring and summer sowing, several native species are particularly well-suited to bare-ground revegetation and can perform as well if not better than the non-native species examined in this study. The poor performance of Bermudagrass, normally associated with good revegetation characteristics, raises questions about the justification of the widespread application of this species in landscape projects in this region.

Although normal for the region, the study conditions are not representative of other areas where this species is used, and relative performance may differ across regions. Also, the unusually heavy rains two days after planting could have resulted in seed ‘wash-out,’ or alternatively supplemental watering, which was the same for all treatments, may not have occurred at a critical time for Bermudagrass. Many varieties of Bermudagrass are sterile hybrids and therefore not sown from seed. More commonly, this species is propagated vegetatively from rhizomes, stolons or mature stems (Stichler and Bade, 2003). In the southern United States, most seed suppliers recommend that for successful establishment Bermudagrass seedbeds should be kept moist for approximately 2 – 3 weeks. Studies both in US (Landphair et al., 2004) and elsewhere (Andrés and Jorba, 2000; Holmes, 2001) have demonstrated poor establishment of Bermudagrass from seed, and these studies suggest that although mature plants demonstrate a high degree of drought tolerance, and regenerate readily from vegetative tissue, the germination performance of this widely used grass may be overestimated in less mesic environments. The poor germination performance of Bermudagrass may also have been due to the method of planting. In this study, seeds were simply hand-sown, raked, and compacted, due to the small areas to be planted. Actual revegetation projects are much larger and seeds are combined in a hydromulch and sprayed onto the sites. This technique not only supplies immediate moisture but also helps to anchor seeds as well as provide nutrients. However, if this poor performance of a non-native is based on planting technique, this still supports the hypothesis that natives are more effective and are less expensive in the long term. If extra care must be taken in order to ensure a non-native seed’s ability to anchor and germinate, then planting technique may lead to extra expense.

Foxtail millet, used for the TxDOT summer seed mix, also demonstrated relatively poor performance. Species in the tropical genus *Setaria* are warm-season annuals and perennials that demonstrate good tolerance to higher temperatures. However, moist, well-drained soil conditions during the first two weeks of growth, when the species is least competitive, are critical for the successful establish of foxtail millet, (Baltensperger, 1996). Although this species has low water requirements relative to many cereal crops, it is still prone to poor recovery following drought due to a shallow root system (Creamer, 1999). These characteristics suggest that foxtail millet may have higher water requirements in the early stages of growth than many of the native species used in this study.

One further error may be dependent on the viability tests that were intended to ensure that live, viable seed numbers were comparable across treatments. Because of low viability readings, the non-commercial mix contained approximately 3 times the seed density. This difference in bulk of the non-commercial mix may have prevented seed ‘wash-out’ that the TxDOT mix may have experienced.

The results from the 60-day studies raise further questions concerning roadside vegetation species selection. Some species did as well as expected (e.g. sideoats grama, buffalo grass, and green sprangletop) which justifies their presence in the existing recommended TxDOT mix. Other native species that had acceptable establishment rates warrant further investigation, particularly Texas wintergrass, purple three-awn, Indian blanket, and hairy and Texas grama. While some of these species are not currently in commercial production, many of their congeners are, suggesting that they could be effectively produced in the industry.

Although germination was lower than expected on the research plots, there were significant amounts of regrowth, particularly of Bermudagrass, due to vegetative (stolons/rhizomes) from within the plots and from the plot perimeter. As much as possible, regrowth was not considered in the final count. For regrowth of species that were included in the seed mix, notes were made during the 14 and 21-day surveys. If growth of a planted species was seen and it was evident it did not come from the planted seed, then that sprout was not considered. This established an approximate percentage of that species that should be deducted from the later surveys. Bermudagrass was the only regrowth that could have possibly skewed the later results. However, since there was low germination rate of planted Bermuda grass seed, deduction was made only for regrowth coming in from outside the perimeters of the TxDOT research plots.

These data represent results from two seasons only and focus on germination. Data from fall, and winter studies may reveal other germination responses of the same species under different regeneration conditions. In addition, data gathered over several growing seasons may reveal differences in maintenance of diversity, endurance, and resistance to invasion among seed mixes.

## Conclusions

Given the desire to reduce the use of non-natives, this study indicates that some native species may be more than adequately suited for roadside revegetation projects. This finding needs to be tested during other seasons, and in regions. Further study is required to obtain information regarding species-specific germination and commercial production potential for those species that are currently unavailable. Given the invasive characteristics of Bermudagrass, these results call into question the widespread recommended use of this species for revegetation projects. Native species can provide adequate establishment performance without potentially undesirable consequences, with the added benefits associated with wholly native plant communities. These data indicate that examination of suites of early- and late-succesional native species can provide a highly effective mix for revegetation as well as restoration. Too frequently where non-natives are being utilized out of convenience (availability and cost) there are negative ecological consequences. The argument that there are no native alternatives may be an erroneous assumption. However identification of suitable alternative native species will require regional examination.

**Acknowledgments:** The authors would like to thank the Federal Highway Administration for funding this study and TxDOT for permission to conduct this study along state roadside rights of way.

**Biographical Sketches:** Jeannine Tinsley is the research associate for the ecological restoration program at the Lady Bird Johnson Wildflower Center, University of Texas at Austin. Involved in all phases of ecological restoration, her main duties focus on utilizing native plants to solve environmental problems. She is first author for *The establishment success of native versus non-native herbaceous seed mixes on a revegetated roadside in Central Texas* published in Ecological Engineering. Currently, she is researching performance of an array of native plants on greenroofs and performance of native turfgrass mixes. Before coming to the Wildflower Center, Jeannine worked in an environmental consulting firm inspecting oil pumping facilities with one of the concerns being runoff and leaching into groundwater from these sites. She earned her Masters of Science in Environmental Science from North Texas State University of Denton.

Mark Simmons is the ecologist at the Lady Bird Johnson Wildflower Center, at the University of Texas at Austin. His duties are divided between leading the research program, member of the environmental consulting team, and university teaching. His main interests are the application of ecological and ecophysiological mechanisms to specific conservation, restoration and environmental problems in both rural and urban landscapes. Current research projects include: stormwater and thermal response of vegetated roofs in subtropical systems; vegetated erosion mats for ecological restoration in riparian corridors; carbon sequestration modeling for urban landscapes; invasive species control using prescribed fire. He has B.Sc. environmental science from University of Lancaster, United Kingdom, M.Sc. in botany from University of Cape Town, South Africa, and Ph.D. in rangeland ecology from Texas A&M University, USA.

Dr. Steve Windhager is the Director of the Landscape Restoration program at the Lady Bird Johnson Wildflower Center, on the editorial board of *Restoration Ecology*, a past board member of the Society for Ecological Restoration International, and former president and founder of the Texas Society for Ecological Restoration. The Landscape Restoration program at the Wildflower Center conducts basic research in ecological engineering, ecological restoration and land management, offers workshops to professionals and the general public, and provides fee-supported ecological consulting expertise to clients across Texas. Steve has a B.A. in Philosophy from Texas A&M as well as a Masters in Environmental Ethics and a Ph.D. in Environmental Science from the University of North.

## References

Andrés, P., and M. Jorba, 2000. Mitigation strategies in some motorway embankments (Catalonia, Spain). Restoration Ecology 8:268-275.

Association of Official Seed Analysts (AOSA), 1970. Tetrazolium Testing Handbook. Contribution No. 29, Don F. Grabe, Editor. Lincoln, NE.

Babbitt, B. 1998, Statement by Secretary of the Interior on invasive alein species. *in* National Weed Symposium. Bureau of Land Management, Denver, Colorado.

Baltensperger, D. D. 1996. Foxtail and Proso Millet. Pages 182-190 *in* J. Janick, editor. Progress in new crops. ASHS Press, Alexandria, VA.

Bugg, R. L., C. S. Brown, and J. H. Anderson. 1997. Restoring native perennial grasses to rural roadsides in the sacramento valley of california: Establishment and evaluation. Restoration Ecology 5:214-228.

Cory, V. L. 1948. Curly mesquitegrass in Texas and northern Mexico. Wrightia 1:214-217.

Creamer, N. G. 1999. Summer Cover Crops. 2/99 -- HIL-37, North Carolina State University., Raleigh, NC.

Diggs, G. M., B. L. Lipscomb, and R. J. O'Kennon, 1999. Shinners and Mahlers Illustrated Flora of North Central Texas. BRIT, Fort Worth, Texas.

Federal Highway Administration, 1999. Roadside Use of Native Plants. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

Holmes, P. M. 2001. Shrubland restoration following woody alien invasion and mining: Effects of topsoil depth, seed source, and fertilizer addition. Restoration Ecology 9:71-84.

Jenkins, A. M., D. R. Gordon, and M. T. Renda, 2004. Native alternatives for non-native turfgrasses in central florida: Germination and responses to cultural treatments. Restoration Ecology 12:190-199.

Kartesz, J. T., 1999. A Synonymized Checklist and Atlas with Biological Attributes for the Vascular Flora of the United States, Canada, and Greenland. *in* J. T. Kartesz and C. A. Meacham, editors. Synthesis of the North American Flora, Version 1.0. North Carolina Botanical Garden, Chapel Hill, NC. 1626 pp.

Landphair, H. C., J. R. Schutt, J. A. McFalls, P. Northcutt, and J. Mason, 2004. Erosion Control and Engineering Properties of Roadside Vegetation. Project 0-1504, Texas Transportation Institute.

Ralowicz, A., C. Mancino, and D. Kopec, 1992. Technical Note: Chemical enhancement of germination in curly mesquite seed. Journal of Range Management 45(5): 507-508.

Stichler, C., and D. Bade, 2003. Forage bemudagrass: selection, establishment and management. E-179 4-03, Texas A&M University, College Station, Texas.

Texas Department of Transport, 1993. A Practical Guide to the establishment of Vegetative Cover on Highway Rights of Way. Construction and Maintenance Division. Vegetation Management Section, Austin, Texas.

Texas Department of Transport, 2004a. Standard Specification for Construction and Maintenance of Highways, Streets, and Bridges. TxDOT, Austin, Texas.

Texas Department of Transport, 2004b. Pocket Facts. TxDOT Public Information Office, Austin, Texas.

USDA, 1974. Soil Survey of Travis County, Texas. USDA-SCS and Texas Agricultural Experiment Station.

Van Auken, O.W., 1997. Germination requirements of aerial chasmogamous florets and seeds of Nassella leucotricha (Poaceae). Southwestern Naturalist. 42(2): 194-200.

White, J. J. and O.W. Van Auken, 1996. Germination, light requirement, and competitive interactions of *Stipa leucotricha* (Gramineae). Southwestern Naturalist. 41 (1): 27-34.

# A Massive Increase in Roadside Woody Vegetation: Goals, Pros, and Cons

**Richard T. T. Forman** (617-495-1930, rforman@gsd.harvard.edu), PAES Professor of Landscape Ecology, Graduate School of Design, Harvard University, Cambridge, MA 02138 USA
**Robert I. McDonald** (617-495-1930, rmcdonald@gsd.harvard.edu), D.H. Smith Conservation Biology Research Fellow, Graduate School of Design, Harvard University, Cambridge, MA 02138 USA

**Abstract:** An extensive area of frequently mowed open grassy roadsides is designed for highway safety, yet paradoxically, in many locations woody vegetation of various types may make safer highways, and additionally provide diverse valuable benefits for society. Therefore our objective is to identify the goals of greatly increasing woody vegetation, consider the pros and cons, and identify the especially desirable and undesirable locations for it. Today, frequent costly roadside mowing favors many non-native species including invasives. Rare species also live on roadsides, including nearly a quarter of the U.S. federally listed threatened-and-endangered plant species with at least one roadside population. The prime goals of greatly increasing woody roadside vegetation are to: (1) increase wildlife habitat, biodiversity, and landscape connectivity; (2) increase highway safety and driver experience; and (3) decrease pollutant and peak-water-flow inputs to nearby water-bodies. The first goal has few disadvantages and also accomplishes diverse societal benefits. The second goal emerges from a modest decrease in vehicle speed in appropriate areas, plus the use of visually diverse types of roadside woody vegetation. An entrée into the travel-behavior and wildlife literature indicates that drivers drive more slowly on narrow than wide two-lane highways, and suggests that a sharp drop in wildlife/vehicle crashes appears between a posted speed limit of 90 and 70 km/hr (55 and 45 mph). The third goal enhances nearby streams, ponds, and other water bodies, mainly by significantly improving conditions in roadside ditches. Tall shrubs or natural forest/woodland are especially desirable vegetation types for >50% of the 35 situations common along road networks. Mowed grass is especially desirable on 17% of the situations, essentially the most risky driving locations. Meadow/low shrubs and small trees with herbaceous layer are intermediate in overall roadside value. We conclude that a massive increase in woody roadside vegetation offers numerous transportation, environmental, and societal benefits with minor disadvantages. Evaluation by a blue-ribbon panel of diverse experts and widespread pilot projects with research and monitoring are valuable next steps.

## Background

Many nations have a very high density of roads and roadsides, yet even in the medium-road-density USA (0.75 km/km$^2$ or 1.2 mi/mi$^2$), about 1/400th of the entire land area is apparently roadside (Forman et al. 2003). This resource basically provides one major function to society, traffic safety. Intensive costly management commonly maintains roadsides as open grassy areas for driver visibility and errant vehicles. Lines of evidence are presented for an alternative strategy of using woody vegetation extensively, but carefully, in roadsides.

Woody roadside vegetation of various types offers many values for transportation, ecology, and society...ranging from increased wildlife habitat and highway safety to visual quality, aquatic-ecosystem, and carbon-sequestration benefits (Aanen et al. 1991, Forman et al. 2003, van Bohemen 2005). Shrubs and trees in distinctive combinations are no panacea, but when carefully meshed with grassy areas along highways, they offer many more opportunities and benefits than shortcomings.

Interestingly, the primary apparent shortcoming of increasing roadside woody vegetation, i.e., roadkilled animals and wildlife/vehicle crashes, seems likely to change little from the current situation, and could be significantly improved. This issue, involving wildlife populations, landscape connectivity, perceived road width, and traffic speed, will be considered in somewhat greater detail than many other important issues. In addition to evaluating the pros and cons of roadside woody vegetation, emphasis will placed on the optimal type of woody and grassy vegetation on 35 key types of situations along the highway network.

Therefore the objective of this article is to identify the major goals and evaluate the consequences of a massive increase in various types of roadside woody vegetation, while maintaining open grassy roadsides in key areas. To accomplish this, we briefly describe: (a) current species, vegetation, and management of roadsides; (b) goals of greatly increasing roadside woody vegetation; (c) the pros and cons of this development; and (d) its especially desirable and undesirable locations.

## Current Vegetation, Species, and Management of Roadsides

Creating a road corridor significantly alters the environmental site conditions, perhaps most profoundly in the soil. During road construction, roadside soil tends to be homogenized, small depressions filled in, small hills levelled, large rocks removed, and the soil profile mixed horizontally and vertically (Forman et al. 2003, Forman 2004). Immediately adjacent to the road, soil is greatly compacted, reducing water infiltration and root penetration. Consequently plant diversity in roadsides is sharply reduced and one or a few species adapted to these conditions usually predominates. Specific locations however, especially in the outer roadside portion, largely escape the homogenization and compaction processes and may support relatively natural diverse vegetation.

Open grassy roadsides receive direct solar radiation which raises air and soil temperatures and lowers relative humidity. Adjacent roads and vehicles also spread various chemicals, from mineral nutrients and roadsalt to heavy metals and hydrocarbons, across the roadside. For example, road salt often increases chloride, a plant micronutrient, but can also cause sodium toxicity at high levels (Goldman and Malyj 1990). These environmental changes alter the suite of plant species that barely survive or that become competitively dominant on roadsides.

The type of road-corridor management has perhaps the greatest control on vegetation composition (Aanen et al.1991). The road shoulder may be bare earth or covered by low disturbance-tolerant plants, while the nearby roadside area may be mowed frequently, and thus largely covered by grasses and other herbaceous plants. Less frequently cleared areas may have many shrubs, and the lowest-maintenance areas in a forest/woodland climate usually have trees. The forest understory and shrubs may be cleared creating a park-like appearance, or left alone as in a natural forest/woodland. Finally, the manner of vegetation clearing, using mower, wood cutting, herbicide, or even fire, greatly affects the plant species composition (Parr and Way 1988).

Grasses and grass-like plants often predominate close to the road where these environmental alterations are most severe. The remaining vegetation of the road corridor is often more variable, with a mix of native and introduced species. The oldest and tallest vegetation allowed by the management regime dominates. Given the abundance of light along a road corridor, fast-growing shade-intolerant species are usually at a competitive advantage. Nevertheless, significant variation in plant composition along a road corridor occurs due to fine-scale variation in edge orientation, site topography, and management history (McDonald and Urban 2006).

An often-overlooked characteristic of roadsides is as habitat for rare native species. These are usually short-statured plants adapted to relatively open ecosystems like prairies or savannas, and are normally located in the outer roadside portion with less soil alteration. Surprisingly, based on the USDA PLANTS list of federally listed Threatened and Endangered (T&E) Plants for the continental USA (excluding California, which was beyond the scope of our study), 23% of these T&E plants have at least one population on roadsides. Large numbers of such rare roadside plants occur in the Southeast, particularly Florida, mirroring general patterns of plant diversity (figure 1). However the largest proportion of a state's rare species is found on roadsides in a band extending eastward and westward from the Ohio Valley. Previous to European settlement, this region largely had extensive forest and grassland patches, and today's roadsides may mimic grassland conditions for remnant rare species.

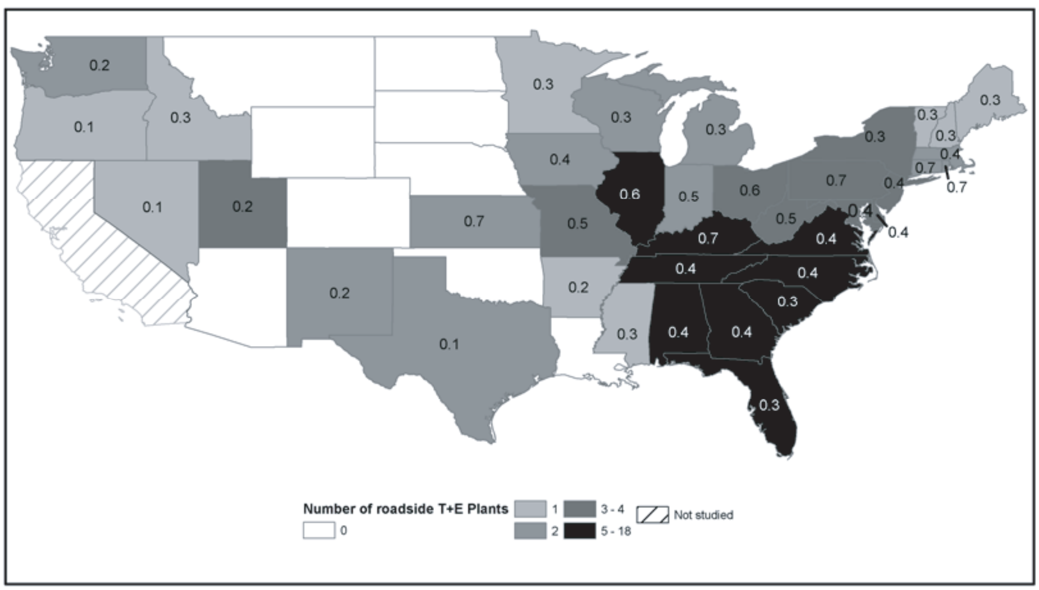



Figure 1. Federally listed Threatened and Endangered plant species in U.S. roadsides. Shading indicates the number of T&E species with at least one known population in a roadside (darker shades indicate more species). The number marked on each state indicates the proportion (ranging from 0 to 70%) of federally listed Threatened and Endangered plant species in a state that occur in a roadside. All species also occur in non-roadside locations.

Rare species and rare natural communities on roadsides are of particular conservation importance in landscapes of intensive human use, such as certain agricultural and built areas (Forman et al. 2003). Indeed, at least nine roadsides in the United Kingdom are designated as protected natural areas, and roadside management in The Netherlands especially protects rare species and natural communities on certain scarce sandy roadsides. Roadside natural areas or road reserves are widespread in Australia's intensive agricultural landscapes (Saunders and Hobbs 1991, Forman et al. 2003).

Roadsides also serve as habitat for invasive species (Harper-Lore and Wilson 2000). Non-native invasive plant species are typically fast-growing shade-intolerant herbaceous species, and thus well adapted for roadsides. Some invasive species such as kudzu (Pueraria lobata) were purposely planted for erosion control, but for most, frequent disturbance simply facilitates their establishment (Randall and Marinelli 1996). Furthermore, road corridors enhance the dispersal of invasive species (Trombulak and Frissel 2000, Forman et al. 2003). Vehicles often transport seeds along the road. Wind and wildlife also move seed along the corridor. In essence, roadsides serve as a connected corridor of suitable habitat for the spread of non-native invasive species.

## Goals of Greatly Increasing Roadside Woody Vegetation

Three major ecological and transportation goals of society are achieved by greatly increasing woody vegetation on roadsides. These are a significant:

1. Increase in wildlife habitat, biodiversity, and landscape connectivity
2. Increase in highway safety and driver experience
3. Decrease in pollutant and peak-water-flow inputs to nearby water-bodies

These goals are discussed along with an evaluation list of pros and cons in the next section.

Several secondary goals are accomplished by a major increase in woody roadside vegetation. These include reduced management/maintenance costs, increased harvestable wood products, recreational benefits, and enhancement of adjoining and surrounding areas (table 1, end), as well as stormwater pollutant control in elongate shrub-lined depressions, nature and culture education, and other benefits. Together these benefits lead to a functionally and visually variegated roadside for society (Forman et al. 2003, Forman 2005).

## Pros and Cons

A diverse list of advantages and disadvantages is presented as a succinct evaluation of the consequences of greatly increasing roadside woody vegetation (table 1). Rather than discussing each pro and con, certain broad themes are emphasized in considering the three major goals just articulated. This list is basically a launch-pad; each reader can add to it.

### Wildlife Habitat, Biodiversity, and Landscape Connectivity

The improvement in wildlife habitat, biodiversity, and landscape connectivity (table 1) results from valuable solutions to several problems such as the following.  With mowed-grass roadsides, many road/vehicle effects including chemicals, noise, and visual disturbance readily spread outward. Grassy roadsides usually have numerous non-native, mainly herbaceous, species including invasives. Shrubland is now scarce in many human-dominated landscapes.  The scarcity of dead wood significantly degrades vertebrate and invertebrate biodiversity as well as forest ecosystem processes.  And wide, open road/roadside strips are significant barriers or filters to crossing by many animal species, which effectively fragments habitats and the landscape. Woody roadside vegetation in forest/woodland climates provides significant benefit for all of these issues.

### Highway Safety and Driver Experience

Driving a multilane highway in Europe with coppiced oaks covering both roadsides recently highlighted the importance of woody roadsides (Forman 2005). Dense stems about 6 cm in diameter and 5 m high extended right to the roadside ditches. A transportation official was asked about the dense woody cover, and she thought that it was to increase traffic safety. Almost immediately, a paradox crystallized. That was the exact opposite of the U.S. strategy of keeping roadsides open for traffic safety.  She explained that research apparently shows that the perceived width of a road ahead is a key determinant of traffic speed. Drivers go more slowly with narrow visibility ahead, and speed up with wide visibility.

Table 1: Pros and cons of covering roadsides with woody vegetation. Adapted from Forman (2005)

| | |
|---|---|
| | **Wildlife Habitat, Biodiversity, and Landscape Connectivity** |
| **Pros:** | Woody vegetation on roadsides adds considerable wildlife habitat and improves habitat in adjoining areas, thus increasing population sizes of numerous species. |
| | Disturbance-favored non-native and invasive species, which are mostly herbaceous, would decrease, though some non-native woody species would probably increase. |
| | Shrubland and associated species, which tend to be scarce in intensive agricultural and built areas, can be sustained. |
| | Dead branches and logs provide habitat and food for numerous species, and organic matter from diverse woody plants enriches the soil. |
| | Narrower road space between roadsides means more connectivity for wildlife movement (decreased road-barrier effect) and less habitat or landscape fragmentation. |
| **Cons:** | With more animals crossing roads and drivers going more slowly, the animal roadkill rate may change little (slight increase or decrease). |
| | **Highway Safety and Driver Experience** |
| **Pros:** | A narrower field of vision ahead means overall lower traffic speed, fewer speeders, fewer vehicle crashes per km, less severe crashes, and therefore a safer road. |
| | A slower-moving driver is less stressed and better able to enjoy the landscape, e.g., in rural, scenic, and tourist areas. |
| | Shrubs absorb/diffuse crash energy much better than does grass or large tree, so well-located abundant shrubs can reduce the human injury/fatality rate. |
| | Diverse types of woody vegetation reduce the monotony of grassy roadsides. |
| | Low-visual-quality places, such as polluted sites and strip development, are screened from drivers. |
| **Cons:** | Woody vegetation can reduce driver visibility around a curve in the road. |
| | Tree shade can slow snowmelt/icemelt resulting in a more hazardous road surface. |
| | An errant vehicle crashing into a large tree typically causes auto damage and human injury/fatality; shrubs may rupture the gasoline tank or hide the vehicle. |
| | More wildlife crossing narrower roads, plus drivers going more slowly, is likely to result in little change (a slight increase or decrease) in wildlife/vehicle crashes. |
| | Slower traffic means more time driving, e.g., commuting, to reach a destination. |
| | Views of diverse landscapes beyond roadsides are reduced. |
| | **Water and Water Pollutants** |
| **Pros:** | Friction along ditches due to woody vegetation decreases peak water flow (i.e., flood hazard) during high-runoff times. |
| | Woody vegetation evapo-transpires more water to the air than does grass, thus reducing water flow in ditches and downstream impacts. |
| | Roadside ditch water is shaded and cooler so nearby streams, ponds, and fish are less degraded by inputs of solar-warmed water. |
| | Sediment flow in ditches is reduced by shrub stems, thus limiting sedimentation and turbidity impacts on fish in streams and ponds. |
| | Woody vegetation limits inputs of mineral nutrients, especially phosphorus, to streams and ponds, resulting in less eutrophication. |
| | Woody vegetation limits the movement of chemical pollutants from roads and vehicles, including hydrocarbons and heavy metals, to streams and ponds. |
| **Cons:** | With less water runoff in shrub-lined shallow ditches, water may saturate a roadbed, causing roadbed failure and/or road surface degradation. |
| | In droughts or dry areas, reduced ditch-water flow could contribute to lowering nearby stream and pond levels. |
| | **Management, Production, and Recreation** |
| **Pros:** | Grass mowing and equipment-related costs should decrease. |
| | Natural vegetation processes replace many maintenance activities and costs. |
| | Wood products include firewood, fence posts, etc. extractable at frequent intervals, pulpwood at intermediate intervals, and lumber at infrequent intervals. |
| | Carbon is sequestered by tree production, helping to balance vehicular CO2 greenhouse gas emissions. |
| | Separate parallel walkways, bikeways, and greenways are partially screened from road and traffic. |
| | Diverse water benefits listed above lead to more fish and more successful fishermen in surrounding water-bodies fed by roadside ditches. |
| **Cons:** | Costs for controlling woody vegetation would increase. |
| | **Adjoining and Surrounding Areas** |
| **Pros:** | Species invasions of surrounding areas may decrease due to the reduced number of non-native herbaceous plants. |
| | Roads and traffic are visually screened from adjoining areas. |
| | Soil berms and noise barriers that decrease noise propagation to adjoining areas are partially hidden. |
| **Cons:** | Local business may decrease where drivers are screened from strip development. |

A literature search was launched and the scattered evidence over decades and continents supported the official's thesis. An entrée into the literature, plus some particularly salient points, is useful here, though this is not a critical review (which should be done). Although research frameworks and methods in the relevant fields vary (Gale et al. 1996, Rothengatter and Huguenin 2004), seven useful points emerge. (1) On average drivers drive more slowly on narrow than wide two-lane highways (Godley et al. 2004, de Waard et al. 2004, Lewis-Evans and Charlton 2006). The difference is independent of driver's sex and driving experience (Recarte and Nunes 1996, Lewis-Evans and Charlton

2006, Conchillo et al. 2006), though younger drivers (in an age range of 18 to 53) rated wide roads as less risky (Lewis-Evans and Charlton 2006). (2) In diverse controlled studies with traffic speeds generally in the 60-120 km/hr (37-75 mph) range, the difference in drivers' speed between wide and narrow two-lane highways is roughly 5-15 km/hr (Recarte and Nunes 1996, Conchillo et al. 2006, Lewis-Evans and Charlton 2006). (3) With a posted speed limit of 80-100 km/hr, drivers on two-lane highways estimate their speed quite closely, whereas on wide multilane highways drivers underestimate their speed by nearly 10 km/hr (Conchillo et al. 2006). This may be related to decreased ability to estimate speed in the presence of parallel same-direction traffic or traffic complexity (Nunes and Recarte 2005, Conchillo et al. 2006). (4) Drivers on narrow highways drive further from the road edge, i.e., in their traffic lane but closer to the center line (van Driel et al. 2004, Lewis-Evans and Charlton 2006). (5) Drivers may not perceive the narrow highways to be narrower, though they do perceive narrow highways to be more risky and more likely to produce accidents (Wilde 1988, Lewis-Evans and Charlton 2006). This driver perception is at odds with the evidence that on wider roads vehicles travel faster and closer to the road edge, both actions placing the driver at increased accident risk. (6) Slower driving on narrow highways seems to be an inherent subjective response, rather than an objective decision based on an increase in edge information, such as noticing objects close by in the peripheral visual field of drivers (Denton 1980, Godley et al. 2004, Nunes and Recarte 2005, Lewis-Evans and Charlton 2006). (7) The research results linking slower safer driving to narrower highways seem generally consistent with traffic safety analyses of accidents (Fildes and Lee 1993, European Transport Safety Council 1995), traffic calming approaches (County Surveyors Society 1994, Burrington and Thiebach 1998), and visual and observational insights of landscape architects and planners in road/roadside projects (Appleyard et al. 1964, U.S. Department of Transportation 1997, Olin 2000, Schneider 2003, Givens 2003). Still, the overall evidence is not exhaustive and research is needed.

The lead author of this article tested his own driving speed in rural locations of Spain and Wyoming where buildings or high vegetation are close to both sides of the road. He found that the limited lateral vision ahead increased his concern for safety and resulted in his significantly reducing speed (by about 10-20 km/hr). If most other drivers also reacted this way, the result would be somewhat lower overall traffic speed (for instance, more drivers driving the legal speed limit) and fewer less-severe crashes per kilometer, effectively creating a safer road.

An extensive study of moose-vehicle collisions on two-lane highways in Sweden links wildlife/vehicle crash rates to posted traffic-speed limits (Seiler 2003). The average number of moose-vehicle collisions per 100 km of unfenced road per year was 1 at 50 km/hr, 2 at 70 km/hr, slightly >10 at 90 km/hr, and slightly <10 at 110 km/hr. The five-fold drop in wildlife/vehicle crashes from a posted speed limit of 90 to 70 km/hr (55 to 45 mph) is striking, and of planning and policy importance. Reducing traffic speed in this apparently critical range should dramatically reduce rates of roadkilled animals and wildlife/vehicle crashes. For instance, a 10-20 km/hr decrease by all vehicles should greatly improve safety, yet perhaps crash rate would decrease much more by designing roads and roadsides to especially slow down the fastest-moving vehicles.

Wildlife underpasses and overpasses are the safest way for wildlife to cross roads, but expense essentially limits them to especially critical locations for major wildlife corridors (Trocme et al. 2003, Luell et al. 2003, Forman et al. 2003, van Bohemen 2005, Clevenger and Waltho 2005). Most animal crossing from roadside to roadside presumably will always occur on the road surface. With woody roadside vegetation in many areas and an associated slight decrease in traffic speed (Table 1), the roadkill rate might slightly increase or slightly decrease. Irrespective, the increase in wildlife population sizes due to more woody roadside habitat should far outweigh any decrease in population sizes by roadkill, thus providing a net ecological gain.

The benefits to highway safety and driver experience primarily emerge from a modest decrease in vehicle speed in appropriate areas, as well as the use of visually diverse types of roadside woody vegetation (Table 1). Roadsides can become much more a key element in designing highways for safe and pleasant driving, rather than designing them for "stressed driving" and speeders. Fast-moving vehicles are not only at risk of hitting vehicles, structures, pedestrians, and wildlife, but also they consume more fossil fuel, emit more greenhouse gas, distribute more chemical pollutants along the road, and cause more traffic noise. Shortcomings of roadside woody vegetation for safety exist (Table 1), but overall, reducing vehicle speed provides major societal benefits.

**Water and Water Pollutants**

Finally, using roadside woody vegetation to decrease water and water-pollutant inputs to nearby water-bodies helps address flood hazard and pollution problems (table 1) (Forman et al. 2003, Forman 2004, 2007). Normally road construction significantly alters hydrology. Both the size and shape of water bodies and the blockage or acceleration of water flows tend to be noticeably changed. Most distinctive is the creation of straight roadside ditches that funnel stormwater (and snowmelt water) to downslope surface water-bodies, such as streams and ponds, creating potential flood hazards. In addition, ditch water in open roadsides carries lots of pollutants…heat from the sun, particles from road/vehicle wear, sediment from roadside erosion, mineral nutrients from roadsides, and toxic chemicals from diverse vehicle and road sources. The nearby receiving streams, ponds, aquatic ecosystems, and fish populations are therefore subject to major doses of these hydrologic and pollutant inputs flowing through open ditches. Maintaining woody vegetation adjacent to roadside ditches decreases all of the inputs, and thus helps protect surrounding water-bodies.

## Especially Desirable and Undesirable Locations

Thirty-five common situations along highways are evaluated for the relative suitability of different types of roadside vegetation (table 2). Five types of vegetation are considered: (1) mowed grass, (2) meadow/low shrubs, (3) tall shrubs, (4) small trees with herb layer, and (5) forest/woodland. The highway situations selected and qualitative estimates of the suitability of vegetation are mainly based on the authors' recent observations in Massachusetts, North Carolina, Catalunya (Spain), and New South Wales (Australia).

### Two-Lane Highways

For each roadside vegetation type, the number of especially desirable highway situations and the associated rationale are encapsulated as follows.

*Mowed grass* appears to be especially desirable in 6 of the 35 situations (17%) (table 2). These locations are the most risky or dangerous for driving, where vehicles are particularly at risk of crashes with vehicles, structures, bikers, or pedestrians. In some cases drivers are also at risk for wildlife/vehicle collisions. Mowed grass requires the highest management effort and cost.

*Meadow/low shrubs* is especially desirable in 11 cases (31%). Many of these highway situations represent a balance between open conditions for driver visibility and somewhat natural vegetation conditions. Some cases apply to non-forest/woodland climates.

*Tall shrubs* represent especially desirable vegetation in 20 of the 35 situations (57%) (table 2). Existing good visibility for a driver and the appropriateness of a lower driving speed characterize most of these cases. Tall shrubs provide good cover for almost all forest wildlife, so these locations are particularly important for wildlife crossing of highways. Dense shrubs also sometimes provide valuable soil and water benefits.

*Small trees with herb layer* is an especially desirable roadside type in 10 cases (28%). These highway situations generally combine relatively good driver visibility with certain forest conditions, such as shade and partial wildlife cover.

*Natural forest/woodland* serves as an especially desirable condition in 19 of the 35 cases (54%). Most of these highway situations have existing good visibility for drivers and are appropriate for lower-speed driving. Here tall trees are suitable next to the road. A shrub layer in the forest provides good wildlife cover, and these situations are especially important for wildlife crossing of the highway. Management effort and cost are low.

The relative frequency of desirable and undesirable vegetation types is somewhat similar among the four broad categories of Table 2…highway, local roadside conditions, local area conditions, and surrounding broad landscape conditions…which represent increasing spatial scale. Thus the benefits of, for example, natural forest/woodland or of mowed grass apply at a relatively consistent level from narrow- to broad-scale situations.

Although the vegetation patterns illustrated in table 2 refer only to one side of the two-lane highway (the driver's side), roadsides on both sides are important for certain variables and situations. For example, maintaining the same vegetation on both sides of a highway, especially tall shrubs or natural forest/woodland, facilitates wildlife crossing of the road surface. Thus roadside design and management must focus on the combination of vegetation types on opposite sides of the road. This will often require evaluating whether the same or different vegetation is optimal on both sides, such as the contrasting desirable conditions for uphill and downhill driving on the same slope (Table 2).

Highway driving involves both specific locations and long highway stretches, and all five vegetation types are found to be desirable (or undesirable) in both situations (table 2). Estimates of the relative lengths of each highway situation, plus the current vegetation characterizing those situations, would permit calculation of the amount of roadside change required to reach the optimum for the road network. Where roadside vegetation is currently mowed grass, all changes in vegetation type presumably would represent a saving in management effort and cost. More important however, are the rich benefits (Table 1) to transportation, ecology, and society.

Table 2: Especially desirable and undesirable roadside vegetation types in different highway locations. Five major types of roadside vegetation are given with their typical heights: (1) mowed grass, 0.3 m; (2) meadow/low shrubs, 1 m; (3) tall shrubs, 2.5 m; (4) small trees with herb layer, 5-15 m; and (5) natural forest/woodland with all layers, 5-30 m. + = especially desirable vegetation type; - = especially undesirable; dot = advantages and disadvantages about equal. Results refer to a natural forest/woodland climate. Maintenance intensity and cost generally decreases from mowed grass to natural forest/woodland. Roadside vegetation refers to the 10+ m zone next to the road surface alongside the driver's lane (natural vegetation is often suitable beyond that zone). Meadow/low shrubs provide cover for mid-sized wildlife. Both high shrubs and natural forest/woodland provide cover for large animals, which also are primarily involved in wildlife/vehicle crashes. Special local or site conditions of course may alter the broad-pattern results

| Mowed Grass | Meadow | Tall Shrub | Small Trees | Forest Wood | |
|---|---|---|---|---|---|
| | | | | | **Highway: Straight, Curves, and Hills** |
| - | . | + | + | + | *Straight flat highway section.* Wildlife movement more likely to be detected by driver. |
| - | . | + | + | + | *Outside/outer curve.* Geometry means that driver faces and has good view of roadside. |
| + | + | - | . | - | *Inside/inner curve.* Poor driver visibility ahead. |
| - | - | + | . | + | *Uphill section.* Shorter vehicle avoidance/stopping distance. |
| - | . | + | + | + | *Hillcrest.* Reduced driver visibility ahead; short vehicle avoidance/stopping distance; hilltop/ridgetop with distinctive vegetation/animals; ridgetop is wildlife-movement corridor. |
| + | + | - | . | - | *Downhill section.* Long vehicle avoidance/stopping distance, especially on wet or icy surface. |
| | | | | | **Local Roadside Conditions** |
| - | - | . | . | + | *Behind guardrail.* No danger of crashing into large tree; poor driver visibility. |
| - | - | + | - | + | *Fillslope on lower side.* Diverse and deep woody roots reduce earth-slides and surface erosion; little effect on driver visibility due to lower surface and (usually) guardrail; wildlife tend to enter road slowly. |
| + | + | - | . | - | *Gradual cutbank on upper side.* Avoid fallen trees/branches on road; wildlife have wide view, may rapidly enter road. |
| - | . | + | + | - | *Steep cutbank on upper side.* Woody plants reduce surface erosion/sedimentation and rockfalls; few animals enter road; avoid fallen trees/branches on road. |
| - | . | + | . | - | *Equator side of east-west road in cold climate.* Trees shade road surface; ice forms readily and snow/ice melts slowly. |
| | | | | | **Local Area Conditions** |
| - | - | + | + | + | *Approach before road-intersection area.* Slows vehicles by creating narrowed visibility ahead for driver. |
| + | + | - | . | - | *Immediate area around road intersection.* Enhanced driver visibility for children, elderly persons, and vehicles crossing; relatively unsuitable location for most wildlife. |
| - | - | + | + | + | *Approach before edge of rural town or village.* Slows vehicles by creating narrowed visibility ahead for driver. |
| + | + | - | + | - | *Edge and inside of rural town or village.* Enhanced driver visibility for children, elderly persons, and vehicles. |

| Mowed Grass | Meadow | Tall Shrub | Small Trees | Forest Wood | **Local Area Conditions (cont.)** |
|---|---|---|---|---|---|
| - | - | + | . | + | *Before and after bridge over water/land.* Helps slow vehicles (along with guard rail and narrowed roadside), including before icy bridge surface; reduces blockage of wildlife movement along stream/river corridor. |
| - | . | + | . | + | *Local wildlife crossing zone.* Short (e.g., 100-1000 m) continuously marked and monitored zone for terrestrial animals of local importance to cross road. |
| - | - | - | . | + | *Arboreal-animal crossing zone.* Short continuously marked zone with guardrail and large trees by road; on both sides, tree branches/artificial structures connect over the road. |
| - | - | - | . | + | *Windbreak.* Taller vegetation reduces streamline wind velocity for a longer distance; medium-porous vegetation reduces turbulence. |
| - | - | - | . | + | *Snowbreak.* Wide dense bands of low-branched trees several meters upwind of road surface accumulate snow to keep surface clear; relatively close upwind high trees reduce blowing-snow on roadways. |
| | | | | | **Surrounding Broad Landscape Conditions** |
| - | . | + | + | + | *Park, scenic, and recreational roads.* Slower driving with major goal of seeing wildlife/viewing natural landscapes; facilitates natural wildlife movement across road. |
| - | - | + | . | + | *Road between nearby natural vegetation areas.* Areas between natural-vegetation patches have abundant wildlife movement and road crossing; woody vegetation reduces the road barrier or disruption effect. |
| - | + | - | . | - | *Road in matrix between sustainable emeralds.* Near an emerald network (large natural areas connected by major wildlife corridors for the future), need to balance tendency of wildlife to cross a less-suitable matrix separating natural patches, and the goal of encouraging wildlife to use well- located and protected wildlife corridors elsewhere. |
| - | - | . | - | + | *Road crossing location of a future major emerald-network wildlife corridor.* Short (e.g., 100-1000 m) continuously marked zone for key wildlife from emeralds to cross road. |
| + | - | - | - | - | *Existing high-roadkill-rate site not at future major emerald-network corridor location.* Reduce roadkills, wildlife/ vehicle crashes, and wildlife crossing here. |
| - | + | - | - | - | *Road in grassland climate zone.* Woody vegetation is normally incompatible except by water sources. |
| - | + | + | - | - | *Road in shrubland climate zone.* Trees usually incompatible. |
| - | + | + | - | - | *Road in desert climate or desertified zone.* Mimic the natural vegetation of the surrounding landscape, which may vary from no vegetation to dispersed shrubs. |
| - | + | - | - | - | *Road in fire-prone area.* Road serves as barrier disrupting natural fire movement, but a greater problem is increased human-caused fire frequency, so highly flammable shrubs and small trees close to roads are typically undesirable. |
| - | + | + | - | - | *Scenic view from road.* Where roadside trees are ecologically desirable, periodic rather than continuous stretches without trees are appropriate for visual benefit. |
| - | - | . | + | + | *View of the road.* In a relatively natural landscape, trees are useful to obscure roads and traffic from view. |

**Multilane Highways**

In contrast to the preceding patterns for two-lane highways, multilane highways typically have a range of different environmental effects, including: high traffic volume (density); periods of intense congestion that spread diverse pollutants, including hydrocarbons, heavy metals, and NOX (plus greenhouse gas); a wide habitat-degradation or wildlife-avoidance zone on both sides of the highway, in part due to numerous fast vehicles creating traffic noise (which may be reflected/absorbed by soil berms, sunken roadways, and/or noise-barrier structures with or without plants); and major wildlife-barrier and habitat-fragmentation effects. Woody vegetation on outer roadsides here provides important benefits, though some advantages are reduced by these environmental patterns.

Nevertheless, vegetation on the central median strip of multilane highways is particularly significant from three perspectives. (1) Headlight glare. On an inside/inner curve, drivers have good visibility of the median and have little oncoming traffic-headlight glare at night.  On an outside/outer curve, drivers have poor visibility of the median and considerable headlight glare, and on straight highway sections headlight glare is significant.  Tall shrubs are especially appropriate to cut headlight glare of oncoming vehicles.  (2) Wildlife.  Tall shrubs enhance wildlife crossing of the wide multilane highway.  But setting shrubs back from the road surface enhances driver visibility, especially in the adjacent fast-traffic lanes (where vehicles have longer avoidance/stopping distances), thus helping to reduce roadkills and wildlife/vehicle crashes.  Trees and branches in median strips of forest/woodland are particularly subject to windfall.  (3) Water/sediment.  Shrubs along a drainage ditch in the median should decrease erosion and sedimentation.  Tall shrubs on the equatorward side of a drainage ditch provide shade that helps maintain cool water temperature, thus reducing degradation of nearby water-bodies and fish populations.  In brief, tall shrubs are the best of the five vegetation types for most median strips of multilane highways.

## Conclusion

The advantages of greatly increasing roadside woody vegetation appear to far outweigh the disadvantages. Tailoring the type of vegetation to the different situations along highways is a key to success. The prime benefits gained are wildlife/landscape connectivity, driver safety and experience, and water and pollutant improvements in nearby water bodies, yet many ancillary benefits are identified. The key challenge is to spatially arrange the vegetation types and societal benefits so that wildlife/vehicle crashes do not increase, but instead decrease. Greatly increasing roadside woody vegetation is quite consistent with the broad objectives for road ecology in serving and benefiting transportation and society (Forman 2007). Important next steps are to establish: (1) widespread monitored pilot projects and empirical research; and (2) a key council of ecology, safety, travel behavior/psychology, roadside management, and other experts to rigorously evaluate the net benefits for society, plus outline a trajectory and timetable for appropriate implementation, of this potentially wonderful transformation of our roadsides.

**Biographical Sketches:** Richard T. T. Forman is the PAES Professor of Landscape Ecology at Harvard University, where he teaches ecological courses in the Graduate School of Design and in Harvard College.  His research and writing include landscape ecology, road ecology, changing land mosaics, land-use planning and nature conservation, urban region ecology, and, more broadly, spatially meshing nature and people on the land.  He received a B.S. from Haverford College, Ph.D. from the University of Pennsylvania, honorary Doctor of Humane Letters from Miami University, and honorary Doctor of Science from Florida International University.  He formerly taught at Rutgers University and the University of Wisconsin.  He served as president or vice-president of three professional societies, and has received awards and honors in France, Colombia, England, Italy, China, Czech Republic, Australia, and the USA.  Professor Forman has authored numerous articles, and his books include Landscape Ecology (1986), the award-winning *Land Mosaics* (1995), *Landscape Ecology Principles in Landscape Architecture* and *Land-use Planning* (1996), *Road Ecology* (2003), *Mosaico territorial para la region metropolitana de Barcelona* (2004), and *Urban Regions: Ecology and Planning Beyond the City* (2007 forthcoming).

Robert I. McDonald is a D.H. Smith Conservation Biology Research Fellow, based in the Graduate School of Design at Harvard University. His research and writing focuses on the implications of urban growth on conservation of biodiversity and ecosystem services. He received a B.S. from the University of North Carolina at Chapel Hill and a Ph.D. in ecology from Duke University. His articles cover a wide variety of topics, and have been published in journals such as *Ecology, Conservation Biology, Biological Conservation, Biological Invasions, Forest Ecology and Management, Landscape Ecology,* and *Landscape and Urban Planning*. An article, entitled "A World of the City, by the City, for the City", has been published in a recent book, *Taking Sides: Clashing views in global issues* (2007).

## References

Aanen, P., W. Alberts, G. J. Bekker, H. D. van Bohemen, P. J. M. Melman, J. van der Sluijs, G. Veenbaas, H. J. Verkaar, and C. F. van de Watering.  1991.  *Nature engineering and civil engineering works*.  Pudoc, Wageningen, Netherlands.

Appleyard, D., K.  Lynch, and J. Myer.  1964.  *The View from the Road.*  MIT Press, Cambridge, Massachusetts.

Burrington, S. H. and V. Thiebach.  1998.  Take Back Your Streets: How to Protect Communities from Asphalt and Traffic.  Conservation Law Foundation, Boston.

Clevenger, A. P. and N. Waltho.  2005.  Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals.  *Biological Conservation* 121: 453-464.

Conchillo, A., M. A. Recarte, L. Nunes, and T. Ruiz.  2006.  Comparing speed estimations from a moving vehicle in different traffic scenarios: absence versus presence of traffic flow.  *The Spanish Journal of Psychology* 9: 32-37.

County Surveyors Society (R-U).  1994.  *Traffic Calming in Practice.*  Landor Publishing Co., London.

de Waard, D., F. J. J. M. Steyvers, and K. A. Brookhuis.  2004.  How much visual road information is needed to drive safely and comfortably?  *Safety Science* 42: 639-655.

Denton, G. G.  1980.  The influence of visual pattern of perceived speed.  *Perception* 9: 393-402.

European Transport Safety Council.  1995.  *Reducing Traffic Injuries Resulting from Excess and Inappropriate Speed.*  Brussels.

Fildes, B. N. and S. J. Lee.  1993.  *The Speed Review: Road Environment, Behavior, Speed Limits, Enforcement and Crashes*.  Report CR 127.  Federal Office of Road Safety, Canberra, Australia.

Forman, R. T. T.  2004.  Road ecology's promise: what's around the bend?  *Environment* 46: 8-21.

Forman, R. T. T.  2005.  Roadside redesigns – woody and variegated – to help sustain nature and people.  *Harvard Design Magazine* (Fall 2005/Winter 2006): 36-41.

Forman, R. T. T.  2007.  Major objectives for road ecology to benefit transportation and society.  In *International Conference on Ecology and Transportation 2007 Proceedings*, Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina.  In press.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road Ecology: Science and Solutions*. Island Press, Washington, D.C.

Gale, A. G., I. D. Brown, C. M. Haslegrave, and S. P. Taylor, eds. 1996. *Vision in Vehicles*, V. Elsevier, Amsterdam.

Givens, J. S. 2003. Rural rustic roads in Virginia – implementation of program guidelines and pilot projects. *Transportation Research Board* 1819: 155-165.

Godley, S. T., T. J. Triggs, and B. N. Fildes. 2004. Perceptual land width, wide perceptual road centre markings and driving speeds. *Ergonomics* 47: 237-257.

Goldman, C. R. and G. J. Malyj. 1990. *The Environmental Impact of Highway Deicing*. University of California, Davis, California.

Harper-Lore, B. L. and M. Wilson, eds. 2000. *Roadside Use of Native Plants*. Island Press, Washington, D.C.

Iuell, B., H. (G. J.) Bekker, R. Cuperus, J. Dufek, G. Fry, C. Hicks, V. Hlavac, V. Keller, C. Rosell, T. Sangwine, N. Torslow, and B. le M. Wandall. 2003. *Habitat Fragmentation due to Transportation Infrastructure: Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions*. COST 341. KNNV Publishers, Brussels.

Lewis-Evans, B. and S. G. Charlton. 2006. Explicit and implicit processes in behavioural adaptation to road width. *Accident Analysis and Prevention* 38: 610-617.

McDonald, R. I. and D. L. Urban. 2006. Edge effects on species composition and exotic species abundance in the North Carolina Piedmont. *Biological Invasions* 8: 1049-1060.

Nunes, L. M. and M. A. Recarte. 2005. Speed, traffic complexity, and visual performance: a study on open road. Pages 339-354 in G. Underwood, ed. *Traffic and transport psychology: Theory and application*. Elsevier, Amsterdam.

Olin, L. 2000. *Across the Open Road*. University of Pennsylvania Press, Philadelphia.

Parr, T. W. and J. M. Way. 1988. Management of roadside vegetation: the long term effects of cutting. *Journal of Applied Ecology* 25: 1073-1087.

Randall, J. M. and J. Marinelli. 1996. *Invasive Plants: Weeds of the Global Garden*. Brooklyn Botanic Garden, New York.

Recarte, M. A. and L. Nunes. 1996. Perception of speed in an automobile: estimation and production. *Journal of Experimental Psychology, Applied* 2: 291-304.

Rothengatter, T. and R. D. Huguenin, eds. 2004. *Traffic and transport psychology: Theory and applications*. Elsevier, Amsterdam.

Saunders, D. A. and R. J. Hobbs, eds. 1991. *Nature Conservation 2: The Role of Corridors*. Surrey Beatty, Chipping Norton, Australia.

Schneider, K. L. 2003. *The Paris-Lexington Road: Community-Based Planning and Context-Sensitive Highway Design*. Island Press, Washington, D.C.

Seiler, A. 2003. *The toll of the automobile: Wildlife and roads in Sweden*. Silvestria 295. Swedish University of Agricultural Sciences, Uppsala, Sweden.

Trocme, M., S. Cahill, H. (J. G.) de Vries, H. Farrall, L. Folkeson, G. Fry, C. Hicks, and J. Peymen, eds. 2003. *Habitat fragmentation due to transportation infrastructure: The European review*. COST Action 341. European Commission, Brussels.

Trombulak, S. C. and C. A. Frissel. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14: 18-30.

U.S. Department of Transportation. 1997. *Flexibility in Highway Design*. Report FHWA-PD-97-062. Federal Highway Administration, Washington, D.C.

Van Bohemen, H. D. 2005. *Ecological Engineering: Bridging Between Ecology and Civil Engineering: A Practical Set of Ecological Engineering Principles for Road Infrastructure and Coastal Management.* Directorate-General of Public Works and Water Management, Delft, Netherlands.

van Driel, C. J. G., R. J. Davidse, and M. F. A. M. van Maarseveen. 2004. The effects of edgeline on speed and lateral position: a meta-analysis. *Accident Analysis and Prevention* 36: 671-682.

Wilde, G. J. S. 1988. Risk homeostasis theory and traffic accidents: propositions, deductions and discussion of dissension in recent reactions. Ergonomics 3: 441-468.

# Prescribed Fire is Cool on Florida Highway

**Jeff Caster** (850-414-5267, jeff.caster@dot.state.fl.us), State Transportation Landscape Architect, Florida Department of Transportation, 605 Suwannee Street, Mail Station 37, Tallahassee, FL 32399 USA. Contributing authors: Willson McBurney and Patricia Farley, PBS&J; Rose Rodriguez, Lane Green, and Kevin McGorty, Tall Timbers Research Station USA

**Abstract:** Though unprecedented in the sunshine state, plans for a prescribed fire on US319/SR61, Kate Ireland Parkway in north Florida sparked enthusiasm and excitement among roadside managers. The recently expanded high speed corridor passes for ten miles through the Red Hills Region (www.ttrs.org/rhcp); a rural landscape that is host to America's largest remnant of the great longleaf pine forest (www.longleafalliance.org). Prescribed fire is a necessary and popular landscape management tool used by generations of adjoining private land managers with responsibility for conserving this scenic, natural, and cultural resource. Using prescribed fire along this highway is safe and appropriate. It is authorized to maintain a commitment to visually and ecologically restore and reconnect the landscape that is bisected by the four lanes of pavement. Further, the high visibility of this location, provides a dramatic means to inform the public about the benefits of prescribed fire, and to demonstrate that motorists can travel safely in the presence of prescribed fire.

Years before the burn, landscape architects, landscape contractors, landscape ecologists, engineers, foresters, firefighters and friends initiated their collaboration with the Florida Department of Transportation and Division of Forestry to prepare a landscape plan and management plan for the corridor. The plan complements the natural beauty and function of the adjoining plantations. Fortunately, Tall Timbers Research Station (www.ttrs.org) is only three miles from the parkway. At Tall Timbers, scientists study the ecology of fire and natural resource management. Without their expertise and leadership, the burn would not have been possible. Finally, after manually and mechanically managing fuels within the wide forested medians, and after planting fire adapted ground cover, understory, and canopy tree species, it was time for the first authorized prescribed burn on a Florida state highway. Weather permitting, the burn was scheduled in concert local news media, and with Florida's annual Prescribed Fire Awareness Week.

On schedule, March 7, 2005, from the peach state line, south for one and a half miles, a perfectly executed prescribed burn ignited a new era in Florida roadside management.

- A traffic control plan similar to what is used during construction, proved safe and effective. Smoke was managed well, except in one instance for a short time near a drain. The Florida Highway Patrol acted quickly to redirect traffic to another lane. There were no accidents or injuries.
- Eighty percent or more of the targeted median area burned, significantly reducing fuel load and potential for wildfire.
- Ninety percent or more of the small hardwood sprouts were eliminated, leaving behind the vigorous longleaf pine saplings and clumps of wiregrass.
- Longleaf saplings were generally scorched back close to the apical meristem, potentially acting as a control on pathogens on the old needles.
- Cogongrass, *Imperata cylindrical*, and other invasive plant species known to be in the vicinity thrive after fire. The burn, however, increased their visibility, and provided easier access for treatment.
- Hundreds of motorists enjoyed a safe driving experience with a close up view of the prescribed burn. Over the following weeks and months thousands enjoyed resprouting foliage and blooming wildflowers.

Prescribed burning along the ten miles will continue in three phases, on a three year or shorter interval. In addition to being safe and cost effective, Florida's roadside managers can now report that prescribed burning helps reduce the risk of wildfire, increases native species diversity, enriches habitat, and releases bountiful wildflowers. Though it may never become routine, where appropriate, and where resources and expertise are available, prescribed burning has proven to be safe and effective for roadside vegetation management.

## Introduction

Though unprecedented in the sunshine state, plans for a prescribed fire on US319/SR61, Kate Ireland Parkway in north Florida sparked enthusiasm and excitement among roadside managers. The recently expanded high speed corridor passes for ten miles through the Red Hills Region (www.ttrs.org/rhcp); a rural landscape that is host to America's largest remnant of the great longleaf pine forest (www.longleafalliance.org). Prescribed fire is a necessary and popular landscape management tool used by generations of adjoining private land managers with responsibility for conserving this scenic, natural, and cultural resource. Using prescribed fire along this highway is safe and appropriate. It is authorized to maintain a commitment to visually and ecologically restore and reconnect the landscape that is bisected by the four lanes of pavement. Further, the high visibility of this location, provides a dramatic means to inform the public about the benefits of prescribed fire, and to demonstrate that motorists can travel safely in the presence of prescribed fire.

*In Florida, fire is as natural as wind and rain.* Only *you* can prevent forest fires! For all our lives we've heard this message. Now, we know it is not true. You can't *prevent* forest fires. We can, however, prevent catastrophic wildfires. The new message from Smokey is "Only you can prevent *wildfires*." Forest fires will occur naturally, as surely as wind and rain. Forest fires need to occur; frequently. The frequency and intensity of fire, and the amount of damage they cause can be managed, but absolute prevention is beyond our ability. Wildfires, the kind we see on the evening news, with 100 foot flames can be prevented. Prescribed fire, by comparison, is very cool.


Before the continent was widely settled, fires crept for day, weeks, or months across the southeastern pine forests, great plains, and western slopes. Native flora and fauna that are part of these fire adapted communities rely on frequent fire to sustain their ecosystems. Unlike today's wildfires, these natural fires occurred frequently, before ground fuels could build up to catastrophic proportions. Insects, plants, and animals flourished. Homes, schools, businesses, and highways were not impacted. Smokey Bear and associates effectively suppressed most fires for the past 100 years, giving time for hazardous fuels to accumulate. The dense and unnatural under-story extirpated many native plants, insects, birds, mammals, and reptiles. At the same time, millions of families moved into suburban homes, now surrounded by volatile fuel.

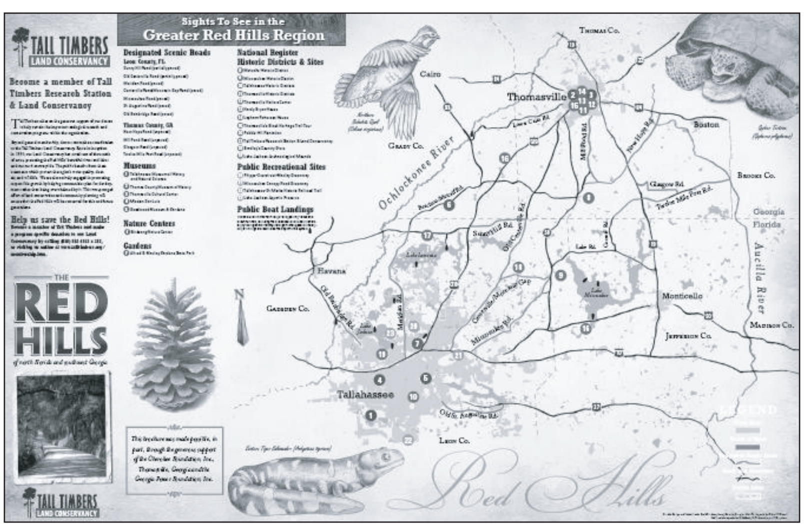
*Prescribed burning is the controlled application of fire to existing naturally occurring fuels under specified environmental conditions, following appropriate precautionary measures, which allows the fire to be confined to a predetermined area and accomplishes the planned land management objectives. Florida Division of Forestry*

Prescribed burning is safely used in Florida to replicate the effects of natural fires. Prior to the wildfires of 1998, there was significant resistance to prescribed fire from fire marshals, air quality regulators, highway safety officials, and unhappy neighbors. Now, though some resistance endures, the demand for prescribed burning exceeds the limits of the assigned personnel and resources. Where ground fuels have been managed, firefighters are able to safely and effectively stop the conflagration. Prescribed burning has proven itself to be the best insurance against wildfire.

Having lost our understanding and appreciation of the natural role of fire, and now having regained it, land managers are scrambling to restore a natural balance, to meet ecological, economic, aesthetic, and safety objectives. In many places, this is nearly impossible, and frequently prohibited. Fire suppression policies over the past 100 years or so, gave planners, architects, and landscape architects freedom to practice without consideration of the natural role of fire. As a result, homes, businesses, communities, highways, farms, and forests have been planned in a fashion that is incompatible with any kind of fire. Throughout Florida, and elsewhere, there are places where fuel has accumulated to catastrophic proportions. Eliminating the fuel is the only way to eliminate the hazards. Fuels can either be mechanically removed or burned with prescribed fire. Mechanical control is often too expensive to be a viable alternative. Prescribe fire is relatively inexpensive, but not always possible if there is too much fuel, or if the location is too close to homes, schools, hospitals, airports, or other sensitive areas. The *urban wildland interface* is a dangerous place to live. Where neither fuel reduction alternative is available, the inevitable risk is building.

**<u>Fire in the Red Hills</u>**

The Red Hills Region of north Florida and southwest Georgia is a distinct American landscape. These private scenic lands, from Tallahassee, Florida to Thomasville, Georgia and from the Aucilla River to the Ochlockonee River, form an ecologically rich area protecting some of the last remnants of the great longleaf pine forests remaining in the nation. This region also serves as some of the highest recharge areas for the Floridan Aquifer, a pristine underground sea critical to the drinking water supply for residents of Florida, Georgia, and Alabama. The Red Hills is a model working landscape in which the stewardship ethic of landowners is paramount to ensuring the future health of the Region's forests and wetlands. Sustainable forestry, agriculture, and recreational hunting are the land use traditions of the Red Hills.




Longleaf Pine-Wiregrass ecosystems once covered approximately 90 million acres in the southeast United States. This unique ecosystem, shaped by thousands of years of natural fires, relies on frequent fires to maintain biological richness and to keep the Pine-Wiregrass ecosystem healthy. Fire events in this type of ecosystem mold tall, majestic pine trees with open tops that seldom touch one another, allowing sunlight to nurture grasses and forbs in the ground cover. The Longleaf Pine is valuable in many ways due to their tolerance of fire and ability to survive well in poor conditions. There are more than 30 plant and animal species associated with Longleaf Pine ecosystems including the Red-cockaded Woodpecker and the Northern Bobwhite Quail.

While a Longleaf Pine forest may appear to be comprised solely of Longleaf Pines and wiregrass, a closer look reveals that the ground cover of wiregrass is actually comprised of a number of forbs, grasses, and low woody species. Many of these resident species are considered endangered or threatened because this type of ecosystem is rare and the species are found only in these fire-maintained habitats. The variety of plant species found in these communities are among the highest reported in North America, with more than 40 countable species in a ten foot area and well over 100 possible species in a quarter of an acre.

## Planning and Planting for Fire

When the Florida Department of Transportation was ready to widen US Highway 319 (Thomasville Road), the two lane rural highway north of Tallahassee that crosses into Grady County, Georgia, additional right of way needed to be acquired. Nearly all that was needed was part of a few large historic plantations. Owners of Foshallee, one of the largest plantations, agreed to donate enough right of way and scenic easements on both sides of the highway to construct four lanes, and preserve the rural character of the corridor. One stipulation of the 1992 right of way agreement was that the Department of Transportation would collaborate with the Division of Forestry to manage the right of way with prescribed burns, just as the donated land had been managed for generations. This would maintain the continuity of the landscape across the full field of view as one travels north and south.

Years before the first prescribed burn along US Highway 319, landscape architects, landscape contractors, landscape ecologists, engineers, foresters, firefighters and friends initiated their collaboration with the Florida Department of Transportation (FDOT) and Division of Forestry to prepare a landscape plan and management plan for the corridor. The plan complements the natural beauty and function of the adjoining plantations. In 2001 Department of Transportation staff and consultants were called to Foshallee Plantation to meet with Miss Kate Ireland, and to learn of her intent to donate funds to be spent on landscaping of the Kate Ireland Parkway (US 319). Kate Ireland's previous donation allowed motorists to experience a true "parkway", open and rolling with a wide, forested median. The corridor was appropriately named in honor of her generosity and life long record of landscape conservation. Miss Kate (as she is known by friends) desired to provide money to install plants that would compliment her vision for the landscape to include "plantation-type" plants and ones that would provide four-season interest. During the development of landscape concept drawings, the FDOT was re-introduced to Mr. Wilbur Jones, a former Florida Road Board Chairman (1955) and friend of Miss Kate's. Mr. Jones, a historic proponent of conservation and beautification, apparently had played a key role in Miss Kate's donation of the right of way for the widening project.

Along with the extensive right of way previously donated by Kate Ireland; in 2003 she donated $300,000 to the FDOT to transform the parkway into a scenic corridor, and compensate for any landscape disturbance caused by construction in the area. Miss Kate is the Chairman of the Tall Timbers Research Station and Land Conservancy Board of Trustees. Tall Timbers, located just three miles from the corridor, is a non-profit, charitable organization committed to fostering good land stewardship through research, conservation and education. There, scientists study the ecology of fire and natural resource management. Without their expertise and leadership, along with the Division of Forestry, the Kate Ireland Parkway prescribed burn would not have been possible. Fulfilling Miss Kate's vision, plans were developed to enhance the landscape and to create a sense of place for those driving through this rural gateway into the state of Florida.

Landscape concepts were developed that identified dominant vegetative communities within the medians, and proposed planting concepts to provide the longleaf pine and wiregrass appearance that is commonly found through the Red Hills region of North Florida and South Georgia. The concepts were turned into construction drawings using the FDOT District-wide Landscape Architecture consultant. The plans had many features to ensure a successful re-vegetation/restoration project. Ultimately five phases were planned and constructed. The design consultant remained involved during the construction phases of the projects; being present at pre-bid and pre-con meetings to discuss the importance of the project with the contractor, and to ensure the contractor had no issues with the information and requirements found in the plans. In the field, the consultant remained focused solely on providing the Department with the necessary expertise to ensure a project was delivered that met the requirements of the plans. In addition, it was critical that the team remained on site for:

1. Inspection of plants prior to and after installation to determine if the plants met a Florida number one quality.
2. Determining if proper preparation of planting sites was occurring
3. Preparation of punch lists of items in the contract found to be deficient during construction and during the one-year establishment phase.

Finally, after manually and mechanically managing fuels within the wide forested medians, and after planting fire adapted ground cover, understory, and canopy tree species, it was time for the first authorized prescribed burn on a Florida state highway. Weather permitting, the burn was scheduled in concert with local news media, and with Florida's annual Prescribed Fire Awareness Week.

On schedule, March 7, 2005, from the peach state line, south for one and a half miles, a perfectly executed prescribed burn ignited a new era in Florida roadside management.


- A traffic control plan similar to what is used during construction, proved safe and effective. Smoke was managed well, except in one instance for a short time near a drain. The Florida Highway Patrol acted quickly to redirect traffic to another lane. There were no accidents or injuries.
- Eighty percent or more of the targeted median area burned, significantly reducing fuel load and potential for wildfire.
- Ninety percent or more of the small hardwood sprouts were eliminated, leaving behind the vigorous longleaf pine saplings and clumps of wiregrass.
- Longleaf saplings were generally scorched back close to the apical meristem, potentially acting as a control on pathogens on the old needles.
- Cogongrass, Imperata cylindrical, and other invasive plant species known to be in the vicinity thrive after fire. The burn, however, increased their visibility, and provided easier access for treatment.
- Hundreds of motorists enjoyed a safe driving experience with a close up view of the prescribed burn. Over the following weeks and months thousands enjoyed resprouting foliage and blooming wildflowers.


With the success of the prescribed burn event in 2005, FDOT confidently executed other burns along the corridor in 2006 and 2007. Led by Division of Forestry professionals and supported by staff and resources from Tall Timbers, prescribed burning along the ten miles will continue in three phases, on a three year or shorter interval. In preparation for the next burn:

- Care will be taken to delineate areas with fire sensitive species.
- Invasive species and other non-native grasses and forbs will be treated with herbicides.
- Fire adapted species will be planted to replace non-native species.
- Badly damaged and undesirable trees and snags will be removed
- Stumps will be ground

In addition to being safe and cost effective, Florida's roadside managers can now report that prescribed burning helps reduce the risk of wildfire, increases native species diversity, enriches habitat, and releases bountiful wildflowers. Though it may never become *routine*, where appropriate, and where resources and expertise are available, prescribed burning has proven to be safe and effective for roadside vegetation management.

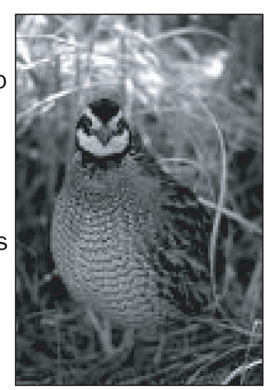
**Interdisciplinary Cooperation**

Landscape architects were a critical component of the project team that also included other transportation professionals, engineers, surveyors, forestry professionals, a native plant specialist and a highway beautification specialist. Throughout design and construction, the team worked together to address challenges and to create solutions to keep the project on schedule. The team's problem-solving abilities and flexibility were critical to navigating the project's budget, time and material constraints.

When developing the project's design, a major concern was the lack of sufficient budgeting for an accurate survey for this length of project. As a result, the team had to locate existing trees, drainage features and structures along the entire corridor through field verification.

Irrigation during construction also proved challenging. A sprinkler system used during Phase One proved an inappropriate method for a natural wooded median. The sprinkler system watered project areas that should have remained dry, which created a maintenance problem with weeds and vines. In Phases Two and Three, the team found a watering truck was the best irrigation method to use during the remainder of the project.

The landscape was enhanced in three distinct areas: Oak Hammock, Longleaf Pine-Wiregrass Habitat, and Wet Area Plantings. The Oak Hammock areas are the dominant feature of the entire corridor. The Longleaf Pine-Wiregrass areas were developed with the intention that FDOT would allow for prescribed burns within the right-of-way. This is believed to be the first time that sections of a US highway have been designed with the intent of utilizing prescribed fire as part of routine maintenance. The Longleaf Pine-Wiregrass areas were designed in the first three of five phases. In spite of all the trials encountered, the team successfully created a sense of place by preserving the Oak Hammock and Longleaf Pine areas, and enhancing the wet areas with suitable plant communities. An ecologically-sound environment was created, recreated, and conserved at this gateway to Florida for visitors and residents to enjoy.



This project's preservation and conservation efforts seek to initiate a growth trend for the expansion and flourishing of the Longleaf Pine-Wiregrass ecosystem. This would help increase the population of numerous flora and fauna species and secure their existence for many years to come.

Preservation along the corridor was a major concern addressed in the concept plan because of the Oak Hammock and Longleaf Pine that exist within the medians and along the right-of-way. Leaving the Oak Hammock and Longleaf Pine as they were, exotic flora species were removed and replaced with native plants. These changes enhanced the corridor and opened up the views of the grand Live Oaks and Longleaf Pines. Preservation was also a concern in areas that are either dominantly or seasonally wet. Here again, native plants were used to replace any exotic species to improve water quality, to reduce erosion, and to beautify the corridor.

## Inspired Conservation

In an invitation to the public to join and support Tall Timbers' efforts, Kate Ireland states, "*The Red Hills Region of Southwest Georgia and North Florida is a truly unique and special place. Designated as one of America's "Last Great Places*", the Red Hills contains some of the finest remaining examples of old-growth longleaf pine forests and woodlands anywhere. This landscape is teeming with wildlife, majestic forests, and magnificent lakes and streams from which we all enjoy clean air and water." There is great importance in the preservation and conservation of the Longleaf Pine-Wiregrass forest to maintain the delicate ecological balance needed to sustain and protect the biodiversity of the various species that reside in it.

Frequent fire creates and sustains Longleaf Pine-Wiregrass habitat. The benefits of prescribed burning are: reduction of hazardous fuels, altering vegetative communities, improving wildlife and livestock habitats, controlling pest problems and tree diseases, restoring the maintained natural communities, reducing chances of destructive wild fires, perpetuating fire-adapted plants, cycling nutrients and opening scenic vistas.

Only with leadership provided by the Division of Forestry, Tall Timbers Research Station and Land Conservancy, and FDOT Midway Operations could the necessary research and planning be completed. Their time and talent helped determine the most effective and feasible alternatives to create a beautifully landscaped corridor that is both aesthetically pleasing for a sense of place, and ecologically friendly for a safe and balanced habitat for flora and fauna to flourish. The result was the creation of Longleaf Pine-Wiregrass areas along the corridor that can offset the impacts of a high speed high volume highway.

## Project Contribution to Road Ecology Body of Knowledge

With the cooperation of State highway and forestry officials and Tall Timbers, prescribed burning was used for the first time ever on a US highway in Florida. As a State precedent, if not a national one, it is one from which both State highway officials and landscape architects alike can learn. For decades, transportation agencies have been well trained and equipped with mowers and herbicides. Now, when conditions are right, and resources are available, prescribed burning is a demonstrated safe alternative.

The Kate Ireland Parkway (U.S. 319) is an important, groundbreaking first step in the right direction of encouraging options and maintenance methods for preservation and conservation. The benefits of prescribed burning on some ecosystems and in the urban wildland interface is too important and valuable to ignore. Hopefully, in the future, prescribed burning will be used more frequently in areas where it is compatible with the surrounding natural landscape to achieve a safer and healthier environment.


**Biographical Sketch:**

Jeff Caster

Born in the Garden State
Celebrating 30 years of good fortune… to live in La Florida, land of flowers

Life long conservationist

Florida Registered Landscape Architect

Florida Department of Transportation, Since 1993
Present position: State Transportation Landscape Architect

Adjunct Assistant Professor of Landscape Architecture
Florida A&M University, School of Architecture
1997-2007

Member and Past President, Florida Chapter, American Society of Landscape Architects
Vice Chair, Florida Wildflower Advisory Council

BS, Community Development, Purdue University
BS, Landscape Design, Florida A&M University
Master of Landscape Architecture, Cornell University

## References

Caster, Jeff
Prevention and Mitigation of Wildfires, It's Hot in Florida.  2000

Rodriguez, Rose
The Kate Ireland Parkway- Conservation in Practice 2006

McBurney, Willson
Farley, Patrica
Project Narrative, Kate Ireland Parkway, 2006

McGorty, Kevin
Green, Lane
Tall Timbers Website. www.ttrs.org

# Washington State Department of Transportation Bridge Maintenance and Inspection Guidance for Protected Terrestrial Species

**Marion Carey** (360-705-7404, careym@WSDOT.wa.gov), Washington State Department of Transportation, P.O. Box 47331, Olympia, WA 98504 USA

**Abstract:** Protected wildlife species that utilize the Washington State Department of Transportation (WSDOT) bridges and structures may be susceptible to impacts from routine maintenance and inspection activities. In response to community-driven concerns related to the conservation of protected terrestrial species and due to the lack of existing guidance for bridge related activities, WSDOT expanded their Highway Maintenance Environmental Compliance Guidance for Protected Terrestrial Species to include guidance for bridges. Two documents were developed, one document specific to bridge inspection activities, and one specific to maintenance activities. The guidance is performance outcome based, and requires that inspection and maintenance activities avoid adverse impacts to nesting protected birds and other wildlife. The guidance has been implemented and is successfully being used by bridge inspection and maintenance staff.

## Introduction

Protected wildlife species that utilize the Washington State Department of Transportation (WSDOT) bridges and structures may be susceptible to impacts from routine maintenance and inspection activities. In response to community-driven concerns related to the conservation of protected terrestrial species and due to the lack of existing guidance for bridge related activities, WSDOT expanded their Highway Maintenance Environmental Compliance Guidance for Protected Terrestrial Species to include guidance for bridges. Two documents were developed, one document specific to bridge inspection activities, and one specific to maintenance activities. The maintenance activity guidance is region specific, as different regions are subjected to different climatic conditions and may encounter different species. The bridge inspection guidance is a statewide document used by all the bridge inspectors. Guidance is necessary because WSDOT owns over 3,000 bridges, at least 15% of which are occupied during some part of the year by wildlife. In addition, most maintenance and inspection activities need to occur in spring and summer – the same timeframe that many wildlife species are using the bridges for nesting. This has resulted in conflicts between protected species and WSDOT activities.

## Development of the Guidance

The guidance documents were developed with the assistance of appropriate personnel from both the maintenance and bridge inspection offices who provided information on the types of activities they normally conduct and the types of species they often encounter. Because of the diversity of activities, diversity of structures and the variety of ways each activity can be conducted; the guidance is performance outcome based. The performance outcomes were developed to insure compliance with state and federal laws addressing protected species. Laws addressed by the guidance include the federal Migratory Bird Treaty Act (MBTA) and Washington State Regulations: Fish and Wildlife Enforcement Code, Chapter 77.15 RCW. The MBTA is administered by the U.S. Fish and Wildlife Service, and makes it illegal to take, possess, import, export, transport, sell, purchase or barter any migratory bird or the parts, nests, or eggs of such a bird without a permit. Nests are covered when they contain eggs or young. There are over 972 species of birds protected under this act, thus all birds which may be found on state bridges, except for rock doves, English house sparrows and European Starlings are protected.

The Washington state Fish and Wildlife Enforcement Code, Chapter 77.15 RCW. prohibits the unlawful taking of endangered and protected fish or wildlife. The regulation stipulates that a person is guilty of unlawful taking if they hunt, fish, possess, or maliciously kill protected /endangered fish or wildlife or if the person possesses of maliciously destroys the eggs or nests of wild birds except when authorized by permit. The regulation results in the protection of all birds except for black-billed magpie, American crow, European starling and the English house sparrow. This regulation is more stringent that the MBTA, as it protects empty nests, not just nests containing eggs or young. Thus between these two regulations, almost all of the birds and nests occurring on state bridges are protected. WSDOT obtains a yearly permit to allow for the removal of empty swallow and other common species nests from bridges.

To help insure compliance with the laws protecting wildlife, the guidance identifies sensitive seasons for commonly encountered wildlife, and identifies of sensitive non-disturbance zones. Sensitive seasons are defined as the time of year that the species are engaged in activities that are very sensitive to disturbance such as nesting. Sensitive zones are defined as the spatial boundary around an active nest site where the majority of hunting, perching and feeding activities occur during nesting season, and in which the species might be more sensitive to disturbance. Best Management Practices (BMPs) were developed based on the performance outcomes, sensitive seasons and sensitive zones. The BMPs were designed to meet the performance outcomes.

Both documents also contain guidance on what to do if the work activities are not covered by or if they cannot be completed by following the guidance. In those instances, regional biologists will be called in to develop a site specific, activity specific BMP plan. The site-specific BMP plan focuses on completing the work without disturbance to protected species during their sensitive times. If work activities are unable to meet the performance standards, and must be completed during a sensitive season and within a sensitive zone, then appropriate permits will need to be obtained to insure compliance with state and federal regulations. The guidance does not apply in emergency situations, because separate procedures were previously developed for emergency maintenance and inspection actions.

**Bridge Inspection Guidance**

The bridge inspection guidance is specific to the nine inspection activities performed by the bridge inspectors. These range from visual inspections using a Under Bridge Inspection Truck (UBIT) and boats, to pre inspection cleaning, ultrasonic and dye penetrant testing, drilling of timber members, and the use of focused lights. Impacts from these activities can range from minor (inspecting bridge piers is unlikely to impact ospreys nesting on the top of the structure, to major (pre-inspection cleaning can result in the accidental removal of a nest). The three performance outcomes the inspectors must avoid are: (1.) Removal of nests containing eggs or young. (2.) Activities which cause the death of adult or young birds –i.e. activities which would cause pre-fledge young to leave nest prematurely or adults to abandon eggs or young. And (3.) Removal (without replacement) of nests, which are used by protected birds year after year. An example of a nest that must not be removed without replacement is an osprey nest.

The document provides species specific information for species which are commonly encountered on WSDOT bridges. This includes peregrine falcons (there are 13 bridges with nesting peregrines), ospreys (there are 8 bridges supporting nesting ospreys), Pelagic cormorants (there is one bridge which supports over 300 nesting pairs of cormorants), owls (the second most common species nesting on bridges after swallows), swallows, and pigeon guillemots (there is one bridge which supports a colony of guillemots).

For each species or species group, specific information on nesting characteristics is given. This includes identifying the nesting season (ie. March 15- October 15), the sensitive period (including the number of days incubation occurs and the number of days between hatching and fledging), nest structure description, a description of where the nest is often located on the structure, nest guarding behavior, and the number of known bridges in the state occupied by the species.

Specific inspection recommendations are made for each specific species or species group. The most restrictive recommendation is the single bridge supporting pelagic cormorants. Due to the large number of cormorants on the structure, inspection is recommended to occur outside the nesting season. Unfortunately, this colony has a extended nesting season with eggs and young occurring on the bridge from March 15 through October 15. Nesting season peaks in July, when there are over 300 active nests with eggs or young.

Ospreys and peregrines have the second most restrictive set of BMP recommendations. These include (listed in order of preference): 1. Inspect the bridge outside nesting season. 2. If inspection during the nesting season is required, inspect outside the incubation and fledging period. (This requires that actual nesting status of the individuals nesting on the bridge be known or determined prior to the inspection). 3. If inspection during the incubation or nestling period is required, inspect the portions of the bridge that are not used for nesting, remaining outside a site specific sensitive nesting zone. (i.e. Inspecting below the bridge on bridges occupied by osprey, or above the bridge on bridges occupied by peregrine falcons.) The sensitive nest zone will be determined by the biologist who will also supervise the inspection to monitor the behavior of the birds. If disturbance appears like to occur, the biologist could require the inspection to stop. 4. On rare occasions inspection near an active nest may be required. In this case a site specific BMP plan will be developed by a biologist to address the inspection activities.

To date most bridge inspections on bridges occupied by peregrines and ospreys have occurred outside the nesting season or incubation and fledging timeframes. We did have one case where peregrine falcons initiated nesting just prior to inspection, and inspection was able to occur in the early part of the nesting season. A project occurring on the bridge outside the nesting season, prevented the moving of the inspection date.

No timing restrictions are recommended for the inspection of bridges containing owls or swallows. Observations of active swallow nests during inspections indicate the inspections are only slightly disruptive to incubating and feeding activities. Inspectors tend to move across the structure in a quickly and smoothly, spending just a few minutes in each area resulting in minor, short term disturbance to these species.

While biologists have not been able to monitor bridge inspections occurring on bridges with nesting owls, feedback from the bridge inspectors indicates that barn owls are fairly tolerant of disturbance, returning to their nests very quickly after the inspectors have moved on. Local Department of Fish and Wildlife biologists have indicated very little concern over inspection activities and barn owl nests, indicating that they are even tolerant of having nests moved. Barn owls are the most common owl found nesting on WSDOT bridges. Most other owls that have been encountered (great horned, screech and saw-whet) were utilizing the bridges for roosting.

One technique to allow an inspection to occur during the nesting season is to develop a site-specific BMP inspection plan. This plan is developed in coordination with the biologist and the bridge inspectors. It considers the time of year the inspection is planned at, the status of the species within the nesting cycle, and the location of the nest or nests. The biologist will conduct a site visit to determine the statues of the nest, and the potential sensitive nest zone. It may be that the inspection can be allowed to occur with out any restrictions, or some restrictions may be required.

The guidance is designed to function as a planning document. The bridge inspectors use it in setting the yearly inspection schedule. Every January, the bridge inspection scheduler contacts Headquarters Biology with the list of bridges that contain known peregrine and osprey nests that may need to be inspected during the nesting season. The list is then sent out to the appropriate regional biologists. The regional biologists monitor the nesting status of the bridges and coordinate the inspection with the bridge inspection office.

The goal of the guidance is to avoid inspecting the bridges occupied by nesting protected species during the nesting season. However, with over 3,000 bridges which require inspection every two years, it is not always possible to avoid inspecting during the nesting season, and thus the recommendations were developed to give a greater priority of avoiding the nesting season to species with the greatest sensitivity.

## The Bridge Maintenance Guidance

Bridge maintenance differs from bridge inspection in the breath of activities that can occur and the length of time the activities can take to complete. Activities that are covered in this guidance range from regular bridge structure cleaning and debris removal to touch up or repair painting, sandblasting , deck maintenance, structure maintenance, expansion joint maintenance, bridge mechanism maintenance, electrical maintenance and hydraulic maintenance. In addition the guidance is specific to each WSDOT region, as different regions may have different species occupying the bridges. For instance only one region has bridges with cormorants and pigeon guillemots, while other regions have busy-tailed wood rats or dippers. A list of bridges that are known to be occupied by nesting wildlife is included along with the sensitive time frames for each species.

The maintenance guidance is also performance outcome based. The outcomes that must be avoided include: 1. Conducting work activities that create sources or noise or visual disturbance close to the nests of protected birds that result in adult nesting birds to flush-pushing eggs or young off the nest, or to abandon or show prolonged inattention to nests with eggs or young. 2. Conducting maintenance work activities that create sources of noise or visual disturbance that result in young flushing prematurely from the nest leading to their demise. 3. Destruction or removal of nests containing eggs or young of protected species. 4. Removal without replacement of nests that are used year after year by a protected species, this includes osprey nests but not swallow nests. 5. Noise or visual disturbance that causes a maternal bat colony to leave a maternal roost site.

The maintenance guidance is similar to the inspection guidance in that it identifies sensitive nesting or breeding seasons for all the species known to occupy bridges in the region and it identifies a restrictive zone for each species. The restrictive zone is the area in which work should not be conducted, as it would be disruptive to the breeding activities. Zone sizes are set by the sensitivity of the species, disturbance potential of the activity, and the amount of time the activity will occur. Long term, noisy activities in sites with very sensitive species result in larger restricted zones than short term, quite activities in sites with less sensitive species.

When bridge maintenance activities cannot meet the performance outcomes, the biologist is contacted and a site-specific BMP plan is developed. These plans focus on the activities, the species, and try to develop methods that would allow the project to move forward while protecting species. In rare instances, when the work must be conducted and BMPs cannot protect the species, a wildlife management plan may be necessary. These plans are developed when nest intervention or removal is required.

Wildlife management plans require the approval of and permits from the wildlife regulatory agencies, the US Fish and Wildlife Service and the State of Washington Department of Fish and Wildlife.

## Implementation

Implementation of the guidance required the creation of several supporting documents including a user guide, guidance to regional biologists on how to create site-specific BMP and wildlife management plans and obtain permits, decision making flow charts and presentation materials. Training was conducted for each user group on the appropriate guidance. Supporting documents showing typical nesting locations, and pictures of the eggs for each commonly encountered avian species was also developed. Since these are living documents, biologists are monitoring typical maintenance and bridge inspection activities to determine if sensitive zones for each species are adequate or if they require modification.

## Conclusion

The guidance has been extremely well received by both maintenance and bridge inspection personnel. Reports from the regional biologists indicate that the guidance is being used and that they have successfully responded to several requests for assistance. Over 3,000 bridges have been inspected using this guidance with the need for just two bridge specific BMP plans. The guidance will continue to be modified as necessary and regular trainings will be provided to insure that all bridge maintenance and inspection staff are familiar with it.

**Biological Sketch:** Marion Carey is the Fish and Wildlife Program Manager in the Environmental Services Office of the Washington State Department of Transportation. She has been with the Department for 12 years. Marion and her staff participate in Endangered Species Act consultations, develop guidance for WSDOT consultants on how to write Biological Assessments, develop state wide policy on wildlife issues, monitor wildlife research projects, monitor deer and elk motor vehicle collisions, engage in habitat connectivity planning, and addressing Migratory Bird Treaty Act issues.

# Transportation and Conservation Planning

*Ecosystem Approaches*

## Application of Ecological Assessments to Regional and Statewide Transportation Planning

**Joseph Burns** (703-358-1712, joseph_burns@fws.gov), National Transportation Liaison, U.S. Fish and Wildlife Service, 4401 N. Fairfax Drive, Arlington, VA 22203, Fax: 703-358-1869 USA

**Abstract**

The application of ecological assessments can facilitate transportation project planning and delivery that can avoid or minimize impacts to the environment and minimize disruptions of critical ecological processes.

This presentation considers the value of ecological assessments designed to integrate regional conservation planning with environmental regulatory compliance that support ecologically appropriate transportation planning and project delivery. Recent transportation legislation (SAFETEA-LU) requires transportation agencies to consider environmental considerations in their regional and state-wide transportation plans. Earlier transportation required Federal agencies to coordinate environmental reviews to address multiple regulatory compliance simultaneously rather sequentially whenever possible. This requirement has been retained in the in SAFETEA-LU.

Ecological assessments have been developed to address a variety of objectives. This presentation will review a subset of assessments and discuss components of those assessments which may offer the greatest value to transportation planners. The presentation will offer a template for developing a rapid assessment that offer a menu of assessment components that state and local transportation planners may consider to facilitate compliance with the new planning regulations that result in streamlined planning and project delivery.

After the passage of SAFETEA-LU, the National Academy of Sciences hosted a workshop to discuss the information needs necessary to support the new provisions such as these new environmental within the recent legislation. The presentation will offer a list of data needs that facilitate the coordination and integration of multiple agency considerations and regulatory requirements.

Follow-up work could include an analysis of the rapid assessment process and how it can be continually improved.

## Developing the "Integrated Transportation and Ecological Enhancements for Montana" (ITEEM) Process: Applying the Eco-Logical Approach

**Amanda Hardy**, Research Ecologist and Project Coordinator, Western Transportation Institute, College of Engineering, Montana State University, Bozeman, MT USA

**Ted Burch** (406-449-5302, theodore.burch@fhwa.dot.gov), Program Development Engineer, and Carl James, Federal Highway Administration, Montana Division Office, 585 Shepard Way, Helena, MT 59601 USA

**Abstract**

Construction and maintenance of transportation systems can result in direct, indirect, cumulative, and secondary effects on ecosystems and can adversely affect the long-term viability of fish and wildlife populations (National Academy of Sciences 2005; Forman et al. 2002). Typically, mitigating adverse impacts associated with highway systems occurs on a project-by-project basis and commonly attempts to restore the same affected resource near the site where the impact occurs, regardless of regional ecological conservation priorities. This piecemeal approach may fulfill regulatory requirements but greater mitigation value may be achieved for a similar investment by evaluating and prioritizing off-site mitigation opportunities important to sustaining ecosystem processes associated with water quality, sustainable resource management practices, wildlife habitat and connectivity, and other environmental assets that contribute to a high quality of life. Further, project-by-project environmental permitting practices frequently involve repetitious procedures that sometimes unpredictably delay project delivery. Agencies want more effective mitigation approaches, while streamlining planning and permitting processes for transportation programs.

A federal multi-agency team recently developed a guide to encourage agencies to consider alternative approaches for more effective ecological mitigation and efficient transportation program delivery. The guide, entitled, "Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects" (Brown 2006; referred to as "Eco-Logical"), provides a framework and examples for agencies to collaboratively and strategically plan infrastructure projects and related mitigation to conserve and connect important habitats while increasing the predictability and transparency of infrastructure planning processes. The ecosystem approach outlined in Eco-Logical encourages expedited regulatory approvals for infrastructure projects – in compliance with applicable laws – while maintaining high standards for safety, environmental health, and effective public involvement.

Following guidance outlined in Eco-Logical, an interagency working group in Montana created the "Integrated Transportation and Ecosystem Enhancements for Montana" (ITEEM) process. As the first known effort to adaptively apply the Eco-Logical guidelines, the cooperating agencies encountered and overcame challenging issues, acquiring perspectives that may be helpful to other collaborative endeavors working to establish an Eco-Logical approach for other regions.

This report summarizes events that led to piloting the suggestions in Eco-Logical. The Eco-Logical document is briefly reviewed, followed by an account of the efforts to develop the ITEEM process using the Eco-Logical guidance, including a description of challenges encountered during the development of the process. The final ITEEM process is also described. The intent of this report is to summarize the outcomes, accomplishments and recommendations of this project for the sponsors and team members. The report also seeks to help other interagency collaborative efforts seeking alternative approaches to increase efficiency of transportation project delivery while mitigating adverse impacts where the conservation efforts are most needed.

To view or download a copy of the full report, please visit: http://www.mdt.mt.gov/research/docs/research_proj/integrated_transportation.pdf

# California's Integrated Approach to Collaborative Conservation in Transportation Planning

**Gregg A. Erickson** (916-654-6296, gregg.Erickson@dot.ca.gov), Chief, Biological Studies and Technical Assistance Office, California Department of Transportation, 1120 N Street, Sacramento, CA 95817 USA

**Abstract:** California's unique biodiversity in the context of strong growth pressures, limited resources and disseminated land use authority creates a unique challenge. That challenge is to integrate conservation planning into complex transportation decisions as necessary to effectively participate in the preservation and recovery of the state's 309 federally listed species, rare habitats, anadromous fisheries, fragmented wildlife and related natural resources while delivering a multi-billion dollar transportation improvement program.

This challenging environment also creates a strong desire and opportunity to learn about the roles of integrated planning, tool development and partnerships in creating a common thread to successfully address regional and national issues. Good decision-making and planning efforts are predicated on the rigor of science, sound engineering and good policy, using innovations such as predictive modeling tools for analyzing such large-scale issues. These show great promise to effectively integrate conservation planning and transportation decisions.

The Department's anadromous fish passage, animal vehicle collision reduction and advanced mitigation planning efforts illustrate challenges, approaches, tradeoffs and lessons learned as programs are developed and implemented. The role of partnerships with stakeholders, universities and resource agency partners provides a foundation for transitioning from accommodation to true stewardship. This collaboration results in better transportation decisions, resource conservation, and common advancement of science as illustrated by related presentations at the 2007 International Conference on Ecology and Transportation (ICOET) and this unifying presentation of integrated approaches.

## The California Challenge: Infrastructure Demand in a Natural Diversity Context

The State of California has a rich and unique geology and geography with varied climates that provides for one of the most biologically diverse areas in the Continental United States. The state's ten distinct bioregions with many microclimates and areas of unique soils has resulted in numerous endemic plants, animals, and invertebrates that occur in relatively small populations that are uniquely adapted to local conditions or dependent upon movement across the landscape.

The same rich and unique geology and geography that contribute to the State's biodiversity also attracts increasing numbers of people from around the country and the world to live and trade. As a major port of entry for international trade and movement of goods the opportunity for many invasive species to be established each year further attenuates natural systems flexibility and distribution as local populations receive pressure from new competitors. The state's population of slightly over 37 million people is projected to increase 23% over the next 20 years, resulting in up to $500 billion of infrastructure needs. This includes increasing the current 10+ billion transportation programs with an additional $19 billion of bond funds and leveraged local financing of up to $100 billion.

The natural rarity and population growth in part explains why over 800 species are considered at risk and over 300 species are state and federally listed as threatened or endangered. The state's endemic rarity, population growth pressure, and need for transportation combine to create unprecedented challenges in conservation and transportation planning at local, regional, and statewide scales. Corresponding conservation efforts have also been growing with recent passage of $15.5 billion in conservation related bonds although not at the same rate as infrastructure. With a broad distribution of rare species and habitats across the state and a transportation system that crosses nearly every habitat type from tidal wetlands to high alpine to redwood to deserts to grasslands, the frequency of interaction between rare species and projects is common and of strategic importance for both transportation and natural resources.

## Seeking Quality of Life

California has twin goals of meeting infrastructure needs and maintaining natural resources for a high quality of life. Sometimes this leads to an apparent conflicting set of expectations for local, state and federal government officials, particularly when one department or agency is only responsible for one portion of the overall quality of life mission. This becomes apparent as California's population (individual citizens and nongovernmental organizations) actively participates in public involvement processes and seeks to reinforce both natural resource and transportation goals. Complicating the dichotomy of expectations is that complex funding and planning processes for each aspect are not intrinsically integrated.

California's strong economy and support for these potentially competing goals provides great opportunity to seek approaches and solutions that meet the public's expectation. The opportunity is particularly fruitful where leaders of agencies, nongovernmental organizations, and communities look beyond the sub-set of goals assigned by their public and seek to use their authority to further the common goals of quality of life. This is the transition from compliance to true stewardship. However, to do so, it is critical that "guiding principles" and "common approaches" be employed to ensure each party is both meeting their mandate and broader expectations of the public.

## The California Approach

### Guiding Principles

Collaborative efforts and priorities can be guided by unified principles that define essential outcomes and methods through which they may be achieved. These serve to properly frame questions and issues in a manner that provides adequate specificity to initiate action while retaining the broader concept for understanding and integration across programs. They also help potential public agencies consider problems in the context of their mandates.

Five fundamental principles drive transportation investments in stewardship and influence policy implementation in California:

1. *Resolve strategic project delivery issues with the rigor of science, sound engineering, effective policies, and strong partnerships.*

Apparent conflicts between transportation and ecology provide unique situations that challenge our understanding of the underlying science and engineering as well as the effectiveness of related policy. Public expectations and institutional responsibilities can drive agencies to resolve substantive issues on accelerated timeframes. However, it can also lead to expensive positional entrenchment and redirection of limited resources that detracts from agency objectives when conducted in a tactical setting with individual projects at stake.

Effective solutions and progress can be accomplished where a strong partnership is formed where people work together to distinguish between validated science and perceptions, challenge engineering limitations; and seek pragmatic policies. This is most effectively accomplished where a specific defined issue that affects a set of planned actions can be addressed in a strategic context where the importance remains high but stakeholder risks can be managed.

Examples of strategic issues under study include: fish passage; invasive species control; aquatic barotraumas; and wildlife movement.

2. *Improve stakeholder options and understanding by advancing science and sharing innovations.*

The greater number of valid solutions available, the more likely an acceptable solution will be available when problems occur to the benefit of all parties. It is essential to broaden the range of options and inform and educate stakeholders about those options so they can understand what is feasible and prudent.

Examples of stakeholder option improvements include: supporting TRB, NCHRP, AASHTO and other research; supporting working groups; synthesis studies; agency partnership; and resource specific studies.

3. *Increase the breadth and depth of ecological expertise and leadership in the planning, permitting, implementation, and maintenance of transportation.*

Effective leadership to resolve issues and make wiser decisions must include input and participation by a broad range of participants. This includes related road ecology education and reinforcement of wise leadership by recognizing positive outcomes and developing an environment where lessons can be learned. Most importantly, this includes outreach to people outside natural resource specialties.

Examples of increases in ecological expertise and leadership include: participate and support of the UC Road Ecology Center; support of the California Biodiversity Council, sponsorship of ICOET; Annual Meeting of California's 150 State road ecologists; and training of local & resource agencies on SAFETEA-LU 6001.

4. *Improve stewardship through better planning, implementation, monitoring and follow-up of restoration, enhancement, avoidance, minimization, and mitigation.*

Stewardship requires ensuring resources entrusted to any public entity are cared for and enhanced while under their action and authority. This requires careful consideration of processes and procedures used to consider resources and ensure compliance with commitments. This element guides roughly $20-30 million of road ecology related studies each year in California.

Examples of stewardship improvements include: programmatic agreements; reimbursed agency liaisons; improved commitment tracking; and environmental management systems.

5. Achieve conservation by integrating resources into all program and project decisions.

Each California state agency considers ways to conserve rare species, habitats and other resources consistent with their authority. While substantial conservation actions are only directly funded for resource agencies, other agencies may also participate provided it is consistent with their mission and funding authorities.

Examples of conservation efforts include: integrated right of way management for rare species; participation is Section 6 programs; and grant program work for fish passage.

**Stepwise Approach**

The identification, resolution and implementation of solutions pursued under any of the five driving principles occur in three general phases: situational analysis; foundational formation; and implementation. This process can be very formal or loosely implemented over a few months to several years without definitive end points. A brief summary of the phases is as follows:

*Situational Analysis*. The most critical stage in ensuring a successful effort and partnerships is situational analysis of the challenge. The problem must be clearly identified, driving forces and the relative risks for conservation and transportation considered. This requires stakeholder input and background research to determine the depth and extent of the issue as well as possible benefits and costs across a range of concerns.

A clear problem statement and analysis of risk then provides justification for participation by partners and stakeholders as well as adoption by sponsoring funding agencies and programs within those agencies. Framed within driving principles the sponsor and partners can match needs to related programs and concerns to develop common goals and objectives that can be used to compare alternatives within available processes and resources.

The risk assessment, background research, and stakeholder interests can then provide a basis from which a program or effort can be planned and strategies jointly developed that consider issues such as staging, scope management and other procedural or process options.

*Foundational Formation*. The most resource intensive phase is developing a sound foundation for agreements or pursuit of new solutions. The step in this phase is the synthesis of available knowledge including science, engineering, policy, processes and organizational constructs.

As the synthesis is completed, stakeholders and partners are engaged to develop a clear picture of what is known, unknown and what uncertainties are most essential to understand or explore. These gaps of knowledge can then be pursued in a rigorous manner with research or policy development with stakeholder oversight and/or participation. This new knowledge then provides a foundation for developing options for adoption by the stakeholders with input from the public as appropriate.

*Implementation.* Complete implementation is often the toughest part. The technical challenges are often largely resolved, quick fixes implemented and funding can be limited unless well-planned. In this phase, agreements are reached, policy is generated, and education and outreach are pursued for all related activities and programs.

**Programs Approach**

Multifaceted issues and conflicts can represent systemic issues will usually have multiple driving principles and result in a set of problem statements and stakeholder objectives. Where justified by the magnitude of the combined risk analysis, a program approach is used. This incorporates a key set of elements including the following:

- Performance Measures: How can success be measured?
- Policies and Directives: What firm limits or requirements are necessary?
- Procedures and Guidance: How can action be effective and efficient?
- Manuals: Which written references are needed or require updates?
- Standards: Minimum thresholds or product requirements.
- Tools: Define job aids or technology needed
- Training: Knowledge skills and abilities needed to be successful
- Reviews and Approvals: What approvals must be done.
- Teams and Critical Partnership: What groups are critical to success?
- Research & Studies: What key new knowledge is needed?
- Budget & Accounting: Funding or Accounting changes +/-.

**<u>Illustrative Programs</u>**

The Department's anadromous fish passage, animal vehicle collision reduction and advanced mitigation planning efforts illustrate challenges, approaches, tradeoffs and lessons learned as programs are developed and implemented. Success requires proactive collaboration between resource agencies, transportation agencies, university researchers and non-governmental organizations.

**Anadromous Fish Passage**

*Challenges*. Declining recreational and commercial salmon fishing, due to shrinking fish populations, has resulted in the substantial loss of a $1.2 billion west coast economy. Outside of Alaska this represents a loss of 62,750 family wage jobs and a substantial contribution to the gas tax. Regulatory Agencies believe that State Highway System road-stream crossings (culverts) are a major impediment to the recovery of salmon and steelhead. Recovery of these populations is central to recovery of coastal communities and the industries that support them.

California regulations require that road crossings do not impede or block passage of "fish" which is defined as fish, mollusks, crustaceans, invertebrates and amphibians. Anadromous fisheries such as salmon are of particular concern because of their need to move between cool inland streams and coastal waters. This movement involves multiple road crossings where blockage at one site can effectively exclude salmon from using all upstream habitats and negates the benefits of any blockage removals in those disconnected reaches of stream. Highway crossings can be particularly problematic because they are often the first crossing low in the watershed and cross tributaries as roads follow major river courses.

Careful consultation has determined that the removal or modification of barriers to allow steelhead and salmon access to historical habitat is the most cost-effective and successful method to achieve recovery of salmon and steelhead. However, the current status of passage and the proportion of road-stream crossings that represent barriers to fish passage is not readily available. The lack of blockage information, multiple landownership and limited survey/analysis funding complicates the development of statewide priorities for stream restoration and determining the relative importance of specific crossings. A lack of agreed-upon priorities also increases the difficulty in determining where very limited remediation grant funding can be applied most effectively and increases the need for detailed regulatory review of projects and onerous permit requirements.

*Approach*. The primary driving principles recognized were the potential to reduce potential strategic project delivery issues and the opportunity to improve stewardship. The secondary driving principles were to improve stakeholder options, understanding, and provide opportunities for improved leadership.

Geographic Information System analysis early in the situational analysis stage indicated a large number of potential crossings based upon the intersection of USGS waterways and roadway alignments. However, this crude estimate did not identify every location and did not provide an indicator of the likelihood that individual sites may have fisheries or blockages. Background searches of culvert and fishery inventories likewise only provided partial data.

A North Coast Pilot Study was conducted by Humboldt State University under a federal research grant and produced an assessment of culvert sites for one Caltrans district. Survey procedures and protocols tailored to the State Highway System needs were developed that formed the basis for statewide assessments. Additional State Planning and Research (SPR) grants were used to scope and prioritize assessment work throughout the remaining coastal watersheds. Assessment work conducted in the southern and central coastal regions, and the San Francisco bay area has allowed refinement of the assessment procedure and an increase in production, but has also shown that we have more culverts to assess than previously recognized and that regional survey procedures are needed, especially for the dryer southern California region. Further study will complete the assessments in the coastal areas, and will begin the preliminary inventory and prioritization for the Great Central Valley and Sierra Nevada regions. Completion of these studies has involved the development of partnerships and working agreements with multiple agencies including the California State University System Department of Water Resources as well as private sector experts to increase the availability of field crews to complete surveys.

Close coordination with other partners was identified as key elements of the foundational phase of the program. Caltrans began reaching out and participating in the California Fish Passage Forum (includes California Department of Fish and Game, National Marine Fisheries Service, US Fish and Wildlife Service, US Forest Service and others) and sharing data via the CalFish Memorandum of Understanding (MOU) partnership (includes California Department of Fish and Game, California department of Water Resources and others) to share insights, priorities and data with other agencies and organizations involved in inventorying, assessing, and remediating fish passage. A critical goal of this effort is to prioritize which sites are in greatest need of rehabilitation or replacement for meeting fish passage requirements. This will help guide the Department in future development of maintenance and capitol construction projects that can then implement corrections. Additional participation on Coho recovery teams provided species-specific coordination and opportunities to share economic information. These partnerships also provide a forum for consideration of stakeholder concerns such as discussion of legislation.

Related stakeholders with interest in fisheries and water issues include the State Legislature, Caltrans Districts, Federal Highway Administration, regulatory agencies including US Fish and Wildlife Service, National Oceanic and Atmospheric Agency (NOAA Fisheries), US Army Corps of Engineers, California Department of Fish and Game, US Forest Service, National Park Service, Bureau of Reclamation, Native American Tribal Governments, California Resources Agency, California State Parks, California Department of Water Resources, California Department of Forestry and Fire Protection, California Energy Commission, California Coastal Commission, California Coastal Conservancy, Pacific States Marine Fisheries Commission, the nationally recognized California Fish Passage Forum, local governments including counties and cities and their special interest organizations such as FishNet 4C (Mendocino, Sonoma, Marin, San Mateo, Santa Cruz and Monterey Counties) and the Five Counties Salmonid Conservation Program, the Tri-County F.I.S.H. Team, local public works agencies, resource conservation districts, farm-oriented groups such as the Northern California Water Association or the Association of California Water Agencies, commercial interests such as the Pacific Coast Federation of Fishermen's Associations (PCFFA), private citizen groups including fishermen, recreationalists, environmentalists, and local watershed councils and groups, specifically California Trout, Inc., Friends of the River, Defenders of Wildlife, Southern California Steelhead Recovery Coalition, various professional groups such as the American Fisheries Society, species or region specific Technical Recovery Teams (TRTs) with interests in the Southern Oregon/Northern California Coast (SONCC), North-Central California Coast (NCCC), California Central Valley, South-

Central California Coast recovery domains, and others such as the Coho Recovery Planning and Implementation Team, the California State University System, the University of California System, various private educational institutions as well as various grade and high school environmental education programs and groups, and employers needing to provide a quality environmental setting to attract top employees.

Implementation of solutions include: policy changes to implement requirements to inventory, assessment and planning for remediation during project delivery; development of an engineering manual; integration of new design standards; progress tracking; outreach to stakeholders; and continue pursue of grant funds to complete surveys.

*Trade-Offs*. The greatest trade-offs occur in the context of procedural limitations. Often funding capital that could be used to restore sites is associated with projects that are located on low priority streams that highlights the opportunistic nature of funding and priorities. This is complicated by the potential for increased permitting time and construction costs that discourages engineers from including crossings in projects if cost and schedules are constrained.

*Lessons*. Partnerships and the inclusion of multidisciplinary teams have been essential to overcome limitations caused by a lack of information and apparently conflicting missions. A second key element is to recognize the level of effort to educate stakeholders and develop the institutional support for success.

**Animal-Vehicle Collision Reduction**

*Challenge*. The California planning environment lacks a base map of wildlife connectivity, methods and tools to evaluate potential wildlife crossings, and adequate collaboration on solutions. This prevents effective advanced planning resulting in increased wildlife mortality and habitat fragmentation. It also increases transportation delivery project costs, delays and frustration, as stakeholders and decision-makers deal with a lack of information on a project-by-project basis. Complicating the challenge is a lack of standard methods of data collection and analysis and questions of sustainability in a context where some stakeholders have concerns about the regulatory implications of designating corridors.

*Approach*. The primary driving principle for animal vehicle collision reduction is stewardship and improving stakeholder options to reduce wildlife mortality, habitat fragmentation and improve safety that are public interests. A secondary driving principle is growing concern by the public and resource agencies that may become strategic issues as it affects project consensus necessary to implement context sensitive solutions. A third critical element is to increase the depth of leadership in the planning and implementation of solutions by stakeholders that influence progress.

The goal of this program is to provide a statewide assessment of habitat and wildlife connectivity that is a critical element for including natural resource considerations in planning per Section 6001 of SAFETEA-LU. Transportation planners, biologists and resource agency staff need a comprehensive, statewide assessment of habitat and wildlife (including plants and animals) connectivity for California. This assessment will identify priority landscape connectivity utilizing the best available science, spatial analyses and modeling techniques to generate statewide connectivity GIS database and maps. Informal steering committees of public agencies and environmental protection groups are beginning to meet to address this need. The effort is being managed by Caltrans and the Department of Fish and Game to ensure that consensus is built on the approach that will be taken to conduct statewide wildlife habitat connectivity analyses. The Defenders of Wildlife is bringing a broader vision of connectivity and technical support by sharing approaches other states or nations have used. The University of California at Davis, Road Ecology Center has been providing insight and guidance on approaches and has brought in many experts from across the world to share possible technical approaches. This analysis will generate maps that would be used in transportation, land use and conservation planning. This GIS based modeling effort will identify animal vehicle collision factors for incorporation in safety improvements.

This effort is taking the following steps: form a steering committee; gap analysis and synthesis of current modeling and documented wildlife movement; base map to identify safety concerns associated with wildlife collision locations and wildlife connectivity; identify next steps and development of work plan for long term eco-region analysis efforts; analyze long term eco-regional needs; and provide training materials.

Transportation planning professionals will be involved to ensure that the products will be utilized in the Regional Transportation Plan and California Transportation Plan updates, local land use planning as well as project level analysis and advanced planning to for wildlife connectivity along highway facilities. This will also provide the data to identify safety concerns pertaining to wildlife-vehicle collisions along state and federal highways.

Stakeholders include Caltrans Division of Transportation Planning, Division of Operations (Safety), Division of Environmental Analysis, Department of Fish and Game, State Parks, USFWS, USFS, FHWA, Councils of Government, cities, counties, The Nature Conservancy, NPS, BLM, Defenders of Wildlife, South Coast Wildlands (a private mitigation banking company), University of California Conservation Biology Institute and other resource and conservation planning organizations.

The first step is to develop a statewide wildlife habitat connectivity map so that transportation, land use and resources agency staff have a common map identifying habitat and wildlife connectivity and the presence and movement of various California species. Prioritization of identified linkage areas will be identified and further analyzed at the ecoregion level. These efforts are anticipated to suit the short-term needs and identify areas where more research or analysis is needed.

After the base statewide connectivity map is completed, a second phase will be launched to develop analyses for each of California's nine eco-regions. This level of eco-regional detail is critical to making the maps and models useful in the regional transportation planning processes of the MPOs and more effective for implementation. The synthesis of statewide connectivity information will be beneficial to validate the eco-regional modeling.

This effort builds upon existing efforts of different stakeholders throughout the state that have identified this need and desire to develop information and methods for analysis and incorporation into respective planning processes. Research on identifying modeling techniques, fragmentation metric development, species behavior research, and road ecology research will compliment this effort.

*Trade-offs*. The most challenging trade-off is the selection of target species during analysis. The target species can substantially affect the outcome of connectivity models and affect the suitability of the output for various stakeholders. Maintaining ecological integrity may call for broader selections while animal vehicle collision safety calls for larger vertebrates while regulations focus solely on rare species.

*Lessons*. Internal and external partnerships are essential to seek objective approaches that can be flexible to accommodate a variety of stakeholder needs. For example, modeling must be neutral and adaptable so different target species and partners can incorporate local variation in order to maintain full participation. It is also essential to develop multiple agency support to allow associated staff time for fully support efforts.

**Advanced Mitigation Planning**

*Challenge*. The State seeks to avoid and minimize impacts to natural resources wherever practicable. However, in some cases it is necessary to also compensate for impacts through preservation, restoration, or creation of resources. Development of compensatory mitigation can be a substantial challenge. It may involve many small or one large transportation project, and must occur within a very short time frame between impact analysis and construction which causes the actual impacts. On an individual project basis, this can be more expensive and less effective due to the short timeframes and efforts that are not contiguous with or planned in concert with larger natural resource planning efforts. Further, failure to meet environmental obligations and project-specific requirements in a timely manner results in project delays, increased costs, and greater regulatory scrutiny.

*Approach*. The driving principles for advanced mitigation are to improve stakeholder options and understanding by advancing science and sharing innovations to allow better conservation of resources at lower costs. However, it will be critical to increase the breadth and depth of ecological expertise and leadership in the planning, permitting, implementation, and maintenance of transportation. The goal of this effort is to provide a statewide and district species assessment of mitigation needs that is a critical element for including natural resource considerations in planning per Section 6001 of SAFETEA-LU. In 2000, a team of Caltrans and Federal Highway Administration staff conducted a review of mitigation practices and processes. The Mitigation Process Improvement Team (MITPIT) in recommended a number of enhancements including taking a more comprehensive or holistic approach to mitigation planning.

The first element of the advanced mitigation effort focused on the deepening understanding of issues by compiling summary of past and on-going mitigation efforts as a baseline to project mitigation needs, costs and issues. With assistance from the University of California at Davis, data from twelve district offices were gathered and compiled with a traditional database. The effort demonstrated that traditional methods of information collection and data entry were labor intensive and difficult to maintain. The value of tracking and sharing of lessons learned, however, was apparent so a web interface was piloted in 2005 that helped define the system requirement for integration into an environmental management system under development for use on all projects beginning in 2008. This new system, being created in partnership with public and private information technology (IT) experts, will allow projection of potential needs and track current needs for programmed projects.

Concurrent with compiling information as part of the situational analysis, a second element that provides more stakeholder options, focuses on changes in the timing of funds available to implement mitigation projects. Policy developed in partnership with experts in budgeting, real estate, accounting, project management and biology now allows state-only funds to be advanced earlier in the project delivery process as a risk decision to allow more time for mitigation project development prior to final transportation project approval. The policy also now allows funds from multiple projects to be combined to unify mitigation projects that could most effectively leverage funds through volume purchases and seize upon opportunities to work with partner agencies and avoid cost escalations. By identifying needs more precisely in advance, this flexible funding provides a greater potential for private-public partnerships to provide mitigation site development services.

The third element of advanced mitigation currently under study is developing methods to project mitigation needs over a 20-year horizon so that those needs can be coordinated with planning for conservation such as state wildlife strategies, species recovery plans, and conservation land purchases. The Department is pursuing twin approaches of empirical and theoretical assessments with the later seeking to provide a contextual understanding of effects based on factors such as location and relative rarity. The theoretical or modeled approach also allows projected or undocumented factors to be addressed such as future land use changes, movement corridors, and undocumented species occurrences. The UC Davis Information Center for the Environment has been instrumental in adapting the latest research in ecological spatial analysis to develop new approaches that may be used.

The combination of a central knowledge base and environmental management system, flexible funding options and methods to project mitigation needs will allow the transportation and resource community to truly engage in environmental planning for the first time as full and educated partners on a broad scale. All of these efforts require close coordination with resource and regulatory agencies as well as with Caltrans' Districts to develop sustainable decisions that warrant investment based upon this planning. Success will be measured by more integrated and effective planning, improve cost effectiveness, and greater environmental protection in the long-term.

*Trade-Offs*. The greatest trade-off or risk with advanced mitigation is dedication of staff time and transportation capital with a degree of concern that decisions can be sustained over time so that individual projects benefit with a lower overall cost. This approach could allow better private-public partnerships to contract for service if appropriate contract methods can be developed, however, it could increase the risk of land speculation where limited resources occur if planning information is not managed well.

*Lessons*. The development of advanced mitigation options requires organizational change, new science & policy and most importantly the formation of long term relationships that can form the trust necessary to implement changes. This change must occur not just in the transportation agency but also at the resource or permitting agencies so that new approach can be accepted.

## Conclusion

California is biologically diverse and under tremendous challenges to maintain its high quality of life as infrastructure and natural resource needs lead to conflicts where the needs of both must be considered. Through careful stepwise consideration using consideration of driving principles, it is possible to develop collaborative approaches that meet stakeholder's needs.

The role of partnerships with stakeholders, universities and resource agency partners provide a foundation for transitioning from accommodation to true stewardship and ideally on to conservation.. This collaboration results in better transportation decisions, resource conservation and common advancement of science as illustrated by related presentations at the 2007 International Conference on Ecology and Transportation (ICOET) and this unifying presentation of integrated approaches. Example presentations at this conference related to California transportation that are consistent with California's approach include:

- Web-based Approach to Compliance Reporting for Caltrans
  - Ivy Edmonds-Hess, PB San Francisco
- Impacts of Different Growth Scenarios in the San Joaquin Valley
  - Karen Beardsley, UC Davis
- Multi-Scale Context-Sensitive Statewide Environmental Mitigation Planning
  - Jim Thorne, UC Davis
- Underpass Effects on Wildlife Activity
  - David Elliott, Cal State Fullerton
- Analytical Framework for Wildlife Crossing Policy in California
  - Jim Quinn, UC Davis
- Integrating Habitat Fragmentation Analysis into Transportation Planning
  - Evan Girvetz, UC Davis

Combined these efforts will provide the proactive information envisioned for coordination under SAFETEA-LU 6001. Each represents development of new methods to analyze effects and understand the natural resource implications of decisions objectively.

**Biographical Sketch:** Mr. Gregg A. Erickson is Chief of the California Department of Transportation Biological Studies and Technical Assistance Office. He is a graduate of San Diego State University with 20 years of private and public service with research interests in microchiroptera in structures and systems ecology. He provides guidance and direction for the Department's team of 150 professional biologists as well as associated local agency and consultant teams. His team establishes the policy, standards and procedures necessary to deliver the State's $10+ billion transportation program in the context of a landscape with high biological diversity and over 300 threatened or endangered species. He guides collaborative policy formation, studies, dispute resolution and research on road ecology issues within California and has served as an analyst on Governor's reviews of natural resource and infrastructure planning and organization. He assisted in the formation of the UC Road Ecology Center and provides input and guidance on issues of regional of national significance through AASHTO initiatives and as a panel member for the National Highway Cooperative Research Program on issues such as Interactions between Roadway and Wildlife, Control of Invasive Species and Evaluation of Use and Effectiveness of Wildlife Crossings. He also provides leadership on the development and implementation of environmental management systems, geographic information systems and other technologies for the Department's environmental planning program.

## References

State of California, California Statistical Abstract, 2006
State of California, California Strategic Growth Plan, 2007

# Habitat Linkage Within a Transportation Network

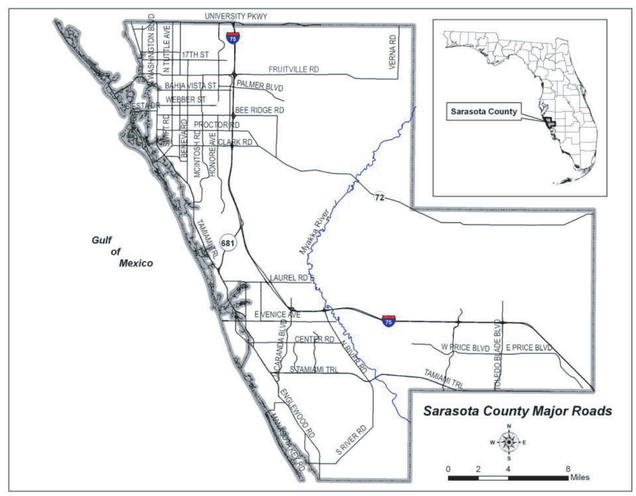
**Sherri Swanson** (941-342-2707, sherri.swanson@hdrinc.com), Environmental Scientist, HDR Engineering, Inc., 2601 Cattleman Road, Suite 102, Sarasota, FL 34232, Fax: 941-342-6589 USA

**Wendy Hershfeld** (941-861-0767, whershfe@scgov.net), Project Scientist, Sarasota County Government, 1001 Sarasota Center Boulevard, Sarasota, FL USA

**Abstract:** Sarasota County is a growing Florida gulf coast community with a strong environmental ethic. As a community, Sarasota has strived to balance growth with habitat protection through a variety of avenues including funding the acquisition of ecologically valuable lands, promoting regional mitigation projects, and encouraging the protection of habitat corridors. Roadways remain one of the greatest threats to the areas protected by these measures, and fragmentation of lands into isolated patches threatens the inherent biodiversity of the landscape. To assess the extent of the problem, Sarasota County Road Program funded several ecological evaluations along local highway corridors. The objective was to identify valuable ecological resources impacted by roadway corridors and develop an integrated approach to reduce the impacts caused by fragmentation. Although these evaluations have been largely observational, when supported by more empirical studies, they have helped provide a framework for developing an objective land acquisition and management process and for formulating local policy. Information obtained through these evaluations has improved project efficiency and in certain instances, allowed for a smoother permitting process. Another significant outcome of the ecological evaluations has been the establishment of a Regional Offsite Mitigation Area program (ROMA) to facilitate the acquisition and restoration of native habitats, many of which "bridge the gap" between established county conservation lands. These land acquisitions and ROMA's, provide compensation for unavoidable environmental impacts associated with infrastructure projects, including wetland mitigation and restoration of Florida scrub-jay and gopher tortoise habitats. Four ROMA sites, ranging from estuarine to scrubby flatwoods restorations, now exist in varying stages of development. Establishment of the ROMA program has not been without permitting hurdles. Differences between state and federal policy, subjectivity in Florida's Unified Mitigation Assessment Methodology (UMAM), and lack of incentives for preserving upland habitat and creating artificial wildlife passages, have been some of the challenges faced by the program.

## Introduction

Sarasota County, Florida is a growing gulf coast community with a strong environmental ethic. Since 1995, the population of Sarasota County has increased over eighteen percent with a current resident population over 367,867 and an additive seasonal resident population estimated at over 80,000 (Sarasota County Planning and Development Services). As the local population continues to expand across the 1,878 km² (464,000 acre) landscape, new urban space and public infrastructure become necessary to sustain the growing demands of the community, reduce traffic congestion and ensure safe and efficient routes for travel. Unfortunately, these expansions place pressure on native habitat and local wildlife populations. This paper describes efforts to maintain and improve habitat linkages across Sarasota County's transportation network. It discusses the results of county funded ecological evaluations along local transportation corridors, describes infrastructure projects designed to promote wildlife movement, and highlights some of the key land protection measures the county has established.




Sarasota County government recognizes the value of protecting and connecting native landscapes and strives to balance growth with regionally significant habitat protection measures. This value is realized through the funding of regional ecological surveys along highway corridors and the establishment of land protection initiatives including: the Environmentally Sensitive Lands Protection Program (ESLPP) and the Regional Off-site Mitigation Area (ROMA) program. Since inception in 1992, ESLPP has ensured the protection of over 66 km² (16,357 acres) of land. The ROMA program has facilitated the acquisition of 1.6 km² (nearly 400 acres). Additional land acquisition groups, funding sources and conservation measures have benefited the community's land acquisition aspirations including: Sarasota County Parks and Recreation, the Southwest Florida Water Management District, Florida Community Trust, and Florida Forever. In total, nearly 23 percent or over 425 km² (105,000 acres) of the land within the county is protected.

Despite acquisition and protection of environmentally significant public lands, fragmentation from infrastructure and development continues to threaten ecologically intact landscapes, inevitably impacting habitat corridors and wildlife populations. Generally, roadways remain one of the greatest threats to the areas protected by these measures, and fragmentation of lands into isolated patches threatens the inherent diversity of the landscape. The need for new roadways and roadway improvements is accelerated in areas exhibiting rapid development and growth, and several local road projects fall adjacent to environmentally significant lands. Consequently, these projects have precipitated the collection of field data with the hope of identifying critical areas to maintain or improve ecosystem connectivity through innovative infrastructure design, strategic land acquisition and large-scale mitigation projects.

To address the ecological pressures associated with expansion of the transportation network, Sarasota County funded two regional ecological evaluations that focused on local highway-wildlife relationships: the SR681/I-75 Regional Ecological Evaluation and the Englewood Interstate Connector Regional Ecological Evaluation. The transportation corridors selected for the study were chosen due to their adjacency to protected land, opportunity for habitat defragmentation, and minimization of ecological degradation.

The objective of the regional ecological evaluations was to identify critical landscape corridors and to develop an integrated approach to reduce impacts caused by habitat fragmentation. The evaluations attempted to identify the effects transportation infrastructure has on local wildlife populations. An equally important aspect was to facilitate improved inter-agency coordination during the design and permitting of local road improvement projects. Although these evaluations have been largely observational, when supported by more empirical studies, they have helped provide a framework for developing an objective land acquisition and management process and for formulating local policy. Information obtained through these evaluations has improved project efficiency and in certain instances, allowed for a smoother permitting process.

The results of the two regional ecological evaluations do not represent the absolute number of individual animals impacted due to factors that may have affected comprehensive data collection including effectiveness of highway cleanup crews, injured wildlife moving outside of the survey limits, scavengers, heavy rains, and motorist collecting specimens (PBS&J, 2006). Despite the scientific limitations of these types of studies, data generated identified trends in wildlife movement and mortality compelling enough to be used to facilitate sustainable transportation design in Sarasota County.

**I-75 and Honore Avenue – Pinebrook Road Extension Regional Ecological Evaluation**

The Honore Avenue – Pinebrook Road Extension is a large road project currently in design in Sarasota County. The project includes widening of the existing roadway and a significant roadway expansion to the north. The proposed alignment parallels the existing Interstate 75 also proposed for roadway expansion. The completed projects will improve a north-south evacuation route and will provide vehicular access to this rapidly developing area. Although the projects should alleviate transportation pressure currently plaguing Interstate 75, construction of the new highways will increase pressure on local wildlife populations. To address the ecological impacts of the road projects, Sarasota County funded a two-year, Interstate 75 and Honore Avenue-Pinebrook Road Extension Regional Ecological Evaluation. In addition, funding associated with the Honore Avenue – Pinebrook Road Extension was used to purchase the adjacent Fox Creek ROMA parcel.

The regional ecological evaluations in this area involved aerial survey of habitat corridors, inventories of future development proposals and nearby roadway projects and wildlife surveys. A local roadway project concurrently evaluated included the Central Sarasota Parkway Interchange, proposed for construction at Interstate 75. To date, results generated by the evaluation has served as a guide during the planning of the road projects and recommendations derived continue to be incorporated into the design and permitting of the projects.

The referenced evaluations were conducted during 2003 (spring, summer and fall), and again during 2004/2005 (spring, summer, fall, and winter). Thirty-seven wildlife species (314 individuals) were identified during the 2003 surveys. Twenty-seven wildlife species (373 individuals) were identified during the 2004-2005 surveys with the highest numbers recorded during the October 2004 and January 2005 survey (PBS&J, 2006). A brief summary of some of the more significant occurrences are highlighted in the following paragraphs.

Data obtained during the two year evaluations suggested that wildlife mortality may be associated with wetland/roadway interfaces. Specifically, roadkill abundances were observed where the roadway bisected a wetland system (PBS&J, 2004). In 2004-2005, approximately 60% of roadkill were recorded within 200 feet of wetlands. Amphibian (primarily ranid frogs) mortality was recorded highest within proximity to wetlands. The number observed appeared to correlate with heavy rainfall events during the summer and early fall of 2003. Water levels in many of the wetlands in the study area were at or near their seasonal high elevations, which may have resulted in the wetland interface moving closer to the highway causing higher incidence of both frog and turtle roadkill (PBS&J, 2004). As anticipated, reptile mortality also occurred within close proximity to wetlands.

The results of the Sarasota County evaluation is consistent with the studies conducted along Payne's Prairie Preserve, in Alachua County Florida, where significant wildlife mortality occurred along a major wetland/highway interface. In addition to the high occurrence of wildlife mortality, animal/vehicular collisions posed human safety concerns. As a result, FDOT implemented mitigative measures by constructing a barrier wall-culvert system along the interface. As seen in the Sarasota County studies, the Payne's Prairie study observed a high number of amphibian (hylid frogs) mortality (Dodd, 2003). The results of a post construction study indicated a 65% reduction in mortality if hylid tree frogs were included, and a 93.5% reduction if hylid tree frogs were excluded (Dodd, 2003). Unfortunately, amphibian mortality is commonly underestimated due to the size of the animal, which allows for the remains to be quickly obliterated by vehicles (Dodd, 2003).

A large number of the roadkill observed along Interstate 75 during January 2005 consisted of birds, primarily the North American robin (*Turdus migratorius*). This occurrence may correspond to a migratory event, as robins are known to flock in large number during the winter months. Brazilian pepper (*Schinus terebinthifolius*), an extremely invasive shrub in Florida, is located in dense stands along the Interstate right of way. Brazilian pepper produces a fruit reported to induce a narcotic effects on birds. Robin mortality was specifically observed in areas where dense stands of Brazilian pepper occurred adjacent to the Interstate. However, it is difficult to assess trends in bird mortality. For example, migratory events are not often captured during surveys and they often consist of a temporary presence in a given area. Additionally, collisions with birds do not necessarily occur on the ground and carcasses are often hurled outside of the survey area.

Patterns related to mammal mortality were not evident in the data collected during these ecological evaluations. Impacted mammals were recorded along most of the length of the corridor with no observed connection to upland or wetland habitat (PBS&J, 2006). An interesting observation involved the feral hog (*Sus scrofa*). Feral hog was virtually non-existent in the Sarasota County roadkill studies, similar to the results of other Florida roadkill surveys. Interestingly, the hog is an extremely common nuisance mammal commonly observed along roadways throughout undeveloped areas within the county. Reduced mortality in this animal is attributed to the wariness of the species (Natural Area News, 2006).

A number of natural creeks and channalized canals crossed by Interstate 75 are proposed to be spanned as part of the Honore Avenue – Pinebrook Road Extension. The ecological evaluation report identified three significant waterways within the study zone as top priorities for the preservation of wildlife movement: Salt Creek, Cow Pen Slough and Fox Creek. The report recommends improvements to these span bridges during the widening of I-75 and creation of more expansive span bridges as part of the Honore Avenue – Pinebrook Road Extension. The report also suggests that existing fencing beneath the Interstate bridges be reconfigured or removed to provide wider, undivided dry passage, that existing culverts associated with smaller water features be enlarged, and that supplemental plantings and/or directional fencing be incorporated to promote wildlife movement. Similar to Payne's Prairie, the report recommended the installation of lipped walls at major wetland interfaces. Unfortunately, local funding limitations may prevent incorporation of this final recommendation.

One of the key design features of the road extension includes construction of a wide span bridge across Fox Creek, a freshwater waterway contiguous to the Fox Creek ROMA and the Sarasota Bay Estuary. The ecological evaluation report identified Fox Creek as a viable wildlife corridor linking estuarine areas along the coast and large tracts of publicly owned land east Interstate 75. The proposed Fox Creek span bridge will parallel the Interstate 75 span bridge, which currently provides limited passage for wildlife movement, as documented by wildlife cameras, roadkill data, and track analyses. Results of the ecological evaluations indicated that fewer animal remains were found along the Interstate within 600 feet north and south of this important creek corridor (PBS&J, 2006). The proposed bridge will, at a minimum, mimic the existing horizontal and vertical clearance of the adjacent Interstate 75 Bridge. When completed, this bridge will represent the largest, most ecologically conservative bridge constructed by Sarasota County.

Both the Honore Avenue – Pinebrook Road Extension and the adjacent section of Interstate 75 extend through a largely undeveloped portion of the county. This area has been identified as a significant habitat corridor. An attempt to maintain this landscape corridor is occurring through innovative mitigation measures tied to the protection of county lands, such as the purchase of the Fox Creek ROMA, as well as the creation and improvement of artificial habitat corridors associated with the design of the roadway projects. Coordination between permitting entities is ongoing and discussions regarding protected wildlife and regulated habitat are at the forefront of these discussions. Although these road improvement projects are largely driven by population growth and development pressure, Sarasota County continues to take important steps toward maintaining the ecological landscape through this portion of the county.

### Engelwood Interstate Connector – Regional Ecological Evaluation

The Englewood Interstate Connector (EIC) is a local county road project in the final stage of design and permitting. The project involves widening of the existing rural two lane road to a four lane divided highway. Significant development is driving this project as large tracts of land in the vicinity of this road are being developed for commercial and residential purposes. In addition, EIC is a major connector providing access from developed coastal communities to Interstate 75. With the continued increase in population and the obligation of the county to provide a safe evacuation route, improvements to this transportation corridor is a county priority. Unfortunately, wildlife mortality is a growing concern in this area and permeability across this roadway is expected to diminish further as the population (and traffic) in this area continues to increase. To address this matter, Sarasota County funded the one year Englewood Interstate Connector Regional Ecological Evaluation to identify the extent of vehicular impact on local wildlife populations and to develop recommendations for reducing wildlife mortality. In addition, funding associated with the EIC project was used to purchase the adjacent Myakka River ROMA parcel.

The regional ecological evaluation for this area began during June 2004, and a final report concluding the study (Kurz *et al.*, 2005a) was completed in July 2005. Data were collected on public lands, along drainage easements, and adjacent to other undeveloped lands. The ecological evaluation along the EIC corridor focused on wildlife utilization of culverts regardless of size or hydrologic function. Significant habitat severed by the road, but not connected by culvert, was also evaluated. Ecologically significant private lands were also evaluated with respect to quality, connectivity potential, and acquisition opportunity. Protected lands, and other ecologically significant landscape features (the Myakka River and unnamed creeks) severed or otherwise, were evaluated for defragmentation opportunities. Specific infrastructure project needs including mitigation, stormwater, and floodplain compensation were considered opportunities for land acquisition. Field investigations were primarily intended to note the occurrence of native habitat and wildlife, recognize zones of high wildlife mortality, and identify wildlife patterns. The ecological evaluations were also intended to assess the benefits and drawbacks of incorporating artificial wildlife corridors into EIC project.

Motion sensor cameras were used to document wildlife movement within and around culverts. It was determined that the majority of culverts were inadequate for optimal wildlife utilization (PBS&J, 2005) due to size, high water levels, and overgrown vegetation at the culvert openings. Although wildlife was documented using several of the culverts, passage was seasonally restricted by inundation. The 2005 report recommended enlarging culverts (both wet and dry) to improve wildlife movement. Several mammal species, including bobcat, armadillo, opossum, and raccoon were observed using the existing culverts during the dryer months and large species of reptiles, including the American alligator, were observed during the wetter months.

Wildlife permeability across EIC is essential, as large tracts of protected land lie along the east side of the road and creek corridors and conservation easements lie along the west side. In an effort to reduce wildlife mortality associated with the EIC expansion, two wildlife underpasses were designed and several culverts proposed for enlargement. The passages were designed to provide safer passage for wetland dependent wildlife (*i.e.* otter, amphibians, reptiles). The location of the two underpasses was based largely on wildlife mortality concentrations, protected habitat linkages and future land use patterns identified in the EIC Ecological Evaluation Report. Both underpasses are designed adjacent to the Jelks Preserve and connect to protected conservation easements on the opposite side of the road. One passage is associated with a natural (channalized) waterway; the other is designed through upland habitat.

The northernmost wildlife crossing proposed at the Sweetwater Gully, Blackburn/Curry Canal will consist of an elliptical culvert 1.5 meter span by one meter rise (5' x 3.2') established above the seasonal high water elevation. Due to the length of the culvert and the economic restrictions of installing a larger culvert, a grate will be installed within the median to allow additional light penetration into the culvert. An artificial ramp is not proposed, as the culvert location was selected to allow a natural earthen approach. Directional landscaping along the approach will consist of sod and native shrubs.

The southern wildlife crossing is proposed as a connection between upland habitat on the Jelks Preserve and a chain of wetlands contained in a private conservation easement. The 2005 report identified a large concentration of reptile and amphibian mortality in this area. There is currently no culvert connection through this area. The proposed culvert will consist of an elliptical culvert 1.5 meter span by one meter rise (5' x 3.2') established at the seasonal high water elevation. The culvert will be buried a few inches to allow establishment of an earthen substrate in an effort to encourage greater utilization by reptiles and amphibians. In addition, a grate will be installed within the median to allow natural light penetration and facilitate thermal moderation within the culvert.

The permitting process for the EIC project has not largely improved by the early ecological evaluations and coordination efforts initiated by the county. One issue encountered during the permitting of EIC, as well as during the permitting of other county projects has been the lack of a mechanism to derive mitigation credit or value for the incorporation of wildlife underpasses into the project design.

Sarasota County government continues to promote sustainable roadway design. Today, planners and designers are beginning to view the ecological landscape as a tool to design a sustainable project rather than an impediment to roadway design. As future roadway alignments are considered, the environmental landscape remains as the forefront of the discussions. County officials, land planners, roadway engineers, local businesses, citizen groups and environmental organizations strive to work together toward maintaining a healthy landscape that supports the diverse interests of the community: smart growth, sufficient infrastructure and a healthy interconnected environment.

## Sarasota County Land Protection Programs

To facilitate the development of an interconnected landscape, Sarasota County developed two local land protection programs: ESLPP and the ROMA program. Each program is unique and applies distinct selection criteria for nominating lands for acquisition. The ESLPP program remains Sarasota County's most celebrated land protection program and is powerful tool and funding mechanism used to acquire land with high ecological value. The ROMA program serves an equally valuable yet smaller role in the land protection arena targeting lands with ecological potential that have been previously affected by anthropogenic activities.

Parcels are nominated for the ESLPP based on habitat quality, connectivity, habitat and species rarity, water resource protection, and manageability. The ESLPP program has had great success in acquiring environmentally sensitive lands through obtaining supplemental grant funding and developing partnerships with state agencies, non-profit organizations, and other county divisions and departments. Even with these successes, numerous challenges face the ESLPP program, including competition with developers, escalating real estate prices, land management costs and security expenses. As of February 2007, the program had enabled the acquisition of 66 $km^2$ (16,309 acres).

The ESLPP program (and to a lesser degree the ROMA program) has contributed to the acquisition of public land along the Myakka River corridor, a distinct landscape feature within Sarasota County. The Myakka River meanders through

Sarasota County creating a natural sinuous network of essential habitat linkages. The ESLPP program has been at the forefront of land protection along this essential habitat corridor. To date over 333 $km^2$ (82,423 acres) of ESLPP (and ROMA) protected parcels buffer this waterway including:

- Ainger Creek (202 acres)
- Albritton Regional Stormwater Facility (1,000 acres)
- Carlton Reserve (24,565 acres)
- Deer Prairie Creek (7,335 acres)
- Englewood Water District (30 acres)
- Forest Addition (103 acres)
- Fox Creek ROMA (165 acres)
- Jelks Preserve (582 acres)
- Knight's Trial Park (378 acres)
- Myakka Pines (198 acres)
- Myakka Prairie (8,296 acres)
- Myakka River State Park (18,729 acres)
- Myakka River ROMA (72 acres)
- Myakkahatchee Creek Park (160 acres)
- North River Road (303 acres)
- Old Myakka (295 acres)
- Pinelands Reserve (6,151 acres)
- Rocky Ford (949 acres)
- Sand Islands (179 acres)
- Schewe Ranch (3,989 acres)
- Snook Haven (3 acres)
- South River Road (77 acres)

The ROMA program was created in 2003 (unofficially, in 1998 with the acquisition of the county's first multi-project mitigation parcel). The program has facilitated the acquisition of native habitats, many of which "bridge the gap" between established county ESLPP lands. The program was designed to promote ecologically significant mitigation as compensation for unavoidable environmental impacts associated with Sarasota County infrastructure projects, including wetland mitigation, habitat preservation and the restoration of Florida scrub-jay and gopher tortoise habitat. This regional perspective provides an avenue to fund land acquisition in concert with significant habitat creation, enhancement, restoration, and preservation projects.

The criteria for nominating a ROMA differs from the criteria used to nominate land for the ESLPP. When evaluating parcels for acquisition under the ROMA program, staff scientists relied on GIS analysis to identify lands with potential to provide connectivity to other publicly owned parcels, ability to combine multiple mitigation efforts (e.g. stormwater, wetlands, and wildlife), location within a specific watershed basin, potential for habitat enhancement and restoration, benefit to listed wildlife, and location within the landscape as relates to hydrologic flow ways and future land use.

The intent of the ROMA program is to provide mitigation with high ecological function and value. Sarasota County believes that regional mitigation represents an environmentally responsible approach to provide quality mitigation for County projects. The program is set up to derive reimbursement funds by selling mitigation and floodplain credit for county and FDOT infrastructure projects, as well as other local government mitigation projects. Additional savings may be derived through the consolidation of design, permitting, construction, and maintenance efforts. Finally, purchasing and building mitigation facilities today, as compensation for impacts anticipated in the future, should expedite the permitting process for future infrastructure projects.

The objective of the ROMA program is not to replace traditional on-site mitigation. When viable on-site mitigation opportunities exist, Sarasota County incorporates these on-site options into the project design or may choose a combination of on-site and off-site mitigation opportunities. In general, the majority of the county's linear transportation projects occur in urban settings where on-site mitigation opportunities are limited by right-of-way constraints. The roadside wetlands encountered are often compromised due to proximity to urban development, nuisance vegetation and ecological isolation. The ROMA program provides an opportunity to design quality urban mitigation in a larger setting with focus on enhancing habitat connectivity.

Four ROMA sites, ranging from mangrove forest to scrubby flatwoods, exist in varying stages of development. These sites include: Lemon Bay Preserve, Curry Creek, Fox Creek and the Myakka River ROMA. Each ROMA contains native upland and wetland habitats of regional value. Some of the native habitat types include riverine floodplain; wet, mesic and dry prairie; scrubby, mesic, and hydric flatwood; seepage-slope floodplain; xeric mesic and hydric hammock; brackish creeks and coastal wetlands. The American bald eagle (*Haliaeetus leucocephaulus*), wood stork (*Mycteria americana*), gopher tortoise (*Gopherus polyphemus*), Florida scrub jay (*Aphelocoma coerulescens*), Eastern indigo snake (*Drymarchon corais*), Sherman's fox squirrel (*Sciurus niger shermani*), and gopher frog (*Rana capito*) are a smattering of species that utilize Sarasota's ROMA sites.

**Lemon Bay Preserve**

Sarasota County purchased the core section of the Lemon Bay Preserve (LBP) in 1998 as part of a mitigation effort resulting from a Sarasota County impact to the Florida scrub jay. This 67 hectare (165-acre) coastal scrub and estuarine parcel is bordered to the west by the intercoastal waterway, to the north and east by dense residential development and to the south by a series of private preserves, private development and ESLPP parcels. The nearly contiguous pieces of public and private habitat that now interconnect along this coastline (purchased individually over many years) comprise 91 hectares (226 acres) of protected land. The size of the property, quality and diversity of habitat, and proximity to known scrub-jay populations were significant factors affecting the county's purchase of the parcel. Since purchase, the site has afforded protection to the state and federally threatened Florida scrub jay, the state protected gopher tortoise, the state and federally protected American bald eagle and the state endangered Tampa vervain (Verbena tampensis) plant. Additionally, the site has provided mitigation credit for several Sarasota County road projects.

The LBP project is an example of Sarasota County's effort to purchase large tracts of ecologically viable land for a multitude of mitigation, restoration, and green space needs. LBP naturally represents a mosaic of scrubby flatwoods and mangrove forest. At the time of purchase, the property was extremely overgrown due to fire suppression and historic drainage alterations. Approximately 36 hectares (90 acres) of restorable scrub-jay habitat existed on the site. Additionally, restoration of an interconnected mosquito ditch network served as an opportunity for a state and locally funded stormwater restoration effort within the tidally influenced Lemon Bay. To date, the site has undergone periodic prescribed fire, roller-chopping, soil disking, exotic removal, native planting and canopy thinning, and a large portion of the mosquito ditches have been restored to estuarine habitat.

The primary reason for purchase of LBP was to provide after-the-fact mitigation for a scrub jay impact that occurred in 1993. Mitigation credit derived from the purchase and subsequent restoration of the parcel has benefited two local road projects: Pine Street and the Pine Street Extension and is anticipated to benefit the Honore Avenue-Pinebrook Road Extension. Through permitting negotiations with the U.S. Fish and Wildlife Service, Sarasota County agreed to restore the parcel to encourage utilization by at least three scrub jay families in return for three mitigation credits. The first credit was available immediately upon purchase and two additional credits were issued following a five year monitoring program that confirmed utilization of the parcel by three jay families. To date, two families have successfully nested on the parcel and transient jays thought to be associated with a third family regularly occupy the northern region of site. Two of the three credits have been deducted for the Pine Street projects. It is anticipated that the final credit will be used as compensation for impacts associated with the Honore Avenue-Pinebrook Road Extension project.

Annual Florida scrub jay monitoring continues to confirm the presence of nesting scrub jay families on the LBP, and, as part of the ongoing mitigation requirements, Sarasota County is committed to manage the parcel in perpetuity. As intended, the LBP has served a multitude of purposes associated with county mitigation needs. It has facilitated the permitting of two local road projects and is proposed to facilitate a third. The stormwater improvements achieved on the site have benefited residential flooding, water quality and ecological restoration efforts.

**Curry Creek Regional Offsite Mitigation Area**

The 19.2-acre Curry Creek ROMA, located adjacent to Curry Creek in Venice, Florida, was Sarasota County's first regional mitigation facility. The County acquired the parcel in 1997 for floodplain compensation and stormwater treatment associated with an adjacent local road project. Prior to purchase, this coastal site faced strong development pressure due the presence of prime upland habitat, and the proximity to a navigable waterway connecting to two deep water canals. In addition, the Curry Creek site lies within an urban setting within the City of Venice. Sarasota County elected to use the Curry Creek parcel as a ROMA due to landscape location, regional connectivity, habitat rarity and overall ecological value. In addition, the parcel is contiguous to two ESLPP sites and provides an essential link between the two otherwise unconnected parcels. The developed ROMA has satisfied a variety of county infrastructure needs.

Aerial photography (1948) was used in developing the restoration and enhancement plan for this highly altered landscape, with the final layout designed to mimic site conditions similar to those existing prior to anthropogenic disturbance. The project involved conversion of two excavated finger canals into a meandering tidal creek and conversion of historically filled uplands to emergent salt marsh and mangrove forest. In addition to hydrologic restoration, the Curry Creek effort resulted in preservation and enhancement of native uplands. Additionally, two stormwater ponds and a prior mangrove mitigation area are located on the parcel. The final design provides a mosaic of habitat types, including mangrove forest, estuarine marsh, tidal creek, hydric flatwoods, oak hammock, and scrubby flatwoods. The parcel also supports several listed species including a transient American bald eagle, rosette spoonbills (*Ajaia ajaja*), wood storks, West Indian manatee, little blue heron (*Egretta caerulea*), and the tricolored heron (*Egretta tricolor*).

Permitting of the ROMA began in early 2003, and lasted nearly two years. Excavation of the site began in May 2005. Planting began in January 2006 and was completed by May 2006. To date, the parcel has compensated for wetland impacts associated with two permitted road projects: Proctor Road and Bahia Vista Street. Sarasota County is currently negotiating the sale of credits to the FDOT as part of the Senate Bill Program designed to facilitate meaningful mitigation projects for FDOT wetland impacts. Additional mitigation credits are also available for future Sarasota County infrastructure impacts.

Permitting of the Curry Creek ROMA was somewhat convoluted. Due to timing, the permitting process required evaluation of the site using both the state Unified Mitigation Assessment Methodology (UMAM) and the federal Wetland Rapid Assessment Procedure (WRAP). Additionally, the U.S. Army Corps of Engineers (USACE) was not able to directly recognize upland preservation areas as part of the mitigation proposal. As an alternative, the USACE did recognize greater value to the wetlands due to the proximity of the wetlands to the preserved uplands. In the end, the USACE issued less mitigation credit for the project. The inconsistencies between the state and federal evaluations have resulted in the maintenance of two distinct credit ledgers for each project.

Annual habitat monitoring continues at the site to assess vegetative success, soil establishment, water level fluctuations, natural recruitment, wildlife utilization, and benthic colonization. As part of the permit requirements, Sarasota County is committed to manage the parcel in perpetuity. As intended, the Curry Creek site has served a multitude of infrastructure mitigation purposes. As part of the ROMA, it has facilitated the permitting of two local road projects. It has additionally, provided an opportunity for stormwater and floodplain compensation needs. Negotiations are underway to coordinate the sale of credit to the FDOT for a local road project. The improvements associated with the site have benefited local wildlife, water quality and ecological restoration efforts in Sarasota County.

### Fox Creek Regional Offsite Mitigation Area

The Fox Creek ROMA consists of 140 acres and is located in a suburbanized region of west-central Sarasota County, between Fox Creek and Cow Pen Slough (west of I-75). The county purchased the property in 2003 using funding associated with the adjacent Honore Avenue - Pinebrook Road Extension project. Prior to county purchase, the site was slated to become a high-scale residential development. The completed ROMA is proposed to satisfy a variety of mitigation needs for unavoidable wetland impacts associated with Sarasota County infrastructure projects. Negotiations are also underway to determine mitigation opportunities for wildlife habitat restoration. Finally, the site will provide floodplain compensation value for the adjacent Honore Avenue - Pinebrook Road Extension project.

Currently, the Fox Creek ROMA consists of varying quality upland and wetland habitats that have been impacted by cattle grazing and dredging/filling activities. Once construction of the mitigation site is complete, the parcel will comprise a network of freshwater marshes, forested wetlands, pine flatwoods, wet prairies, estuarine marshes, and scrubby flatwoods. The site features several unique aspects, including extensive long leaf pine (*Pinus palustris*) uplands utilized by the state-protected Sherman's Fox Squirrel, two currently abandoned American bald eagle nests, relic Florida scrub jay habitat and uplands occupied by the state protected gopher tortoise. Existing aquatic landscape features directly contiguous to the parcel include Fox Creek, Shakett/Salt Creek, and Cow Pen Slough. One of the reasons for acquiring this parcel was to protect a vital linkage between estuarine areas along the coast and protected lands to the east. The maintenance and enhancement of these aquatic features as habitat corridors has been identified as an important ecological benefit of the site.

To date, Sarasota County has benefited from the release of the first phase of mitigation credit. These credits have been used to permit the Webber Street and Pine Street local road projects. The Honore Avenue - Pinebrook Road Extension project is proposed to derive similar value from mitigation efforts at the site. An additional component of the Fox Creek ROMA is the joint agreement that Sarasota County has made with the FDOT. Through the FDOT State Senate Bill, the FDOT will purchase mitigation credit for the adjacent Interstate 75 project. This agreement is beneficial to the Department, the county and the environment.

Permitting of the Fox Creek ROMA has not been without setbacks. Similar to the Curry Creek ROMA, permitting associated with the Fox Creek site has suffered from differences between the state and federal permitting process, specifically with regard to upland preservation. Although the UMAM process allows for upland preservation, federal regulation has not allowed upland preservation for wetland mitigation. As an alternative, the USACE recognizes greater value to the wetlands in proximity to preserved uplands and considers the value the uplands provide to wetland dependant wildlife. Inconsistency between the state and federal interpretation of the UMAM rule has resulted in the need to maintain distinct mitigation accounting ledgers for each entity.

Aside from the permitting hurdles encountered while assessing the value provided by uplands, discussions regarding the mitigation value of wildlife habitat enhancements have also been ongoing. Specifically, discussions are underway to determine whether the Fox Creek ROMA can be designated as a recipient site for the state protected gopher tortoise. This opportunity would provide a managed landscape for relocation of the tortoise while facilitating a smoother permitting process for local road projects proposed to impact this protected species. The Fox Creek ROMA also contains relic scrub habitat nestled between nearly 16.1 hectares (40 acres) of preserved long leaf pine flatwoods and is immediately adjacent to the Fox Creek corridor. With appropriate restoration and management, the site has the potential to attract offspring from nearby scrub jay families. Sarasota County has initiate discussions with the U.S. Fish and Wildlife

Service to restore this area for mitigation purposes. At this time, it is not known if mitigation value for scrub habitat restoration will be granted at the Fox Creek site.

Annual habitat monitoring is scheduled to begin on the site this year to assess vegetative success, soil establishment, water level fluctuations, natural recruitment, and wildlife utilization. As part of the permit requirements, Sarasota County is committed to manage the parcel in perpetuity. It is the intent that the Fox Creek site served a multitude of mitigation purposes including wetland and floodplain mitigation, wildlife relocation and possibly Florida scrub jay habitat mitigation. The future improvements at this site are designed to benefit local wildlife, water quality and ecological restoration efforts in Sarasota County.

**Myakka River Regional Offsite Mitigation Area**

The 29 hectare (72-acre) Myakka River ROMA parcel was acquired in 2006 by Sarasota County for the purpose of satisfying a variety of ecologically benign project needs including a stormwater facility, EIC mitigation, and the 15.3 hectare (38-acre) mitigation ROMA. This parcel was identified by the Environmentally Sensitive Lands Committee as an ESLPP priority site for purchase, although the site was ultimately purchased by Sarasota County's Road Program Division. The EIC project funded the purchase the Myakka River ROMA, as the project will derive a number of project benefits from the purchase. Prior to purchase, this waterfront parcel faced strong development pressure due the presence of prime upland habitat adjacent to the Myakka River, and the proximity to this navigable waterway. The benefits associated with the purchase of this parcel are expected to extend beyond merely compensating for mitigation needs, as this site adds yet another piece to the protected habitat corridor along the Myakka River.

The Myakka River ROMA is currently in the early stages of design and permitting. The current land use within the limits of the ROMA consists of mechanically disturbed uplands, regenerate hardwood hammocks, isolated wetlands, wet prairie, and a natural creek corridor. The design for the Myakka ROMA expands upon the natural hydrologic features of the parcel, including an incorporation of an interconnected tributary of the Myakka River. Additionally, the design incorporates existing oak hammocks and pine flatwoods and the expansion of wet prairie habitat.

Due to project timing, mitigation required for the EIC project will occur independently on the ROMA site and will include the vegetative enhancement of a 3.3 hectare (8.2 acre) forested creek corridor and seepage slope floodplain and the preservation and enhancement of a 1.4 hectare (3.5 acre) upland habitat adjacent to Myakka River. Required EIC mitigation will also result in the preservation of a significant spine of mesic hammock, a protected upland habitat in Sarasota County. Additional benefits afford the EIC project includes the creation a 2.3 hectare (seven acre) stormwater pond adjacent the roadway. Though permitted as two distinct projects, the EIC and ROMA mitigation projects are designed to be interconnected and mutually beneficial to the area.

Sarasota County's ROMA program targets the purchase of large tracts of ecologically viable land for a multitude of mitigation, restoration, and preservation purposes. All four ROMA parcels were specifically selected due to their landscape position along essential habitat linkages and each is adjacent to a significant waterway feature. The LBP exists along the inter-coastal waterway protecting native coastal scrub from development and linking other protected coastal habitats. The Curry Creek ROMA contributes to an essential link along Curry Creek connecting other protected ESSLP parcels. The Fox Creek ROMA is an important landscape feature situated between three important waterways. Purchase of this parcel maintains a habitat gateway between coastal communities and inland habitats. And finally, the Myakka River ROMA borders the Myakka River. It is adjacent to the Jelks Preserve and the Deer Prairie Creek Preserve and it contributes yet another piece to the protected habitat along the Myakka River corridor. All four parcels contribute to an interconnected network of protected native landscapes across Sarasota County.

**Summary**

Florida's human population is projected to double between 2005 and 2060 from approximately 18 to 36 million (Zwick, 2006). This growth will place extraordinary new pressures on Florida's native habitats, local wildlife populations and human quality of life. This impending pressure has spurred enthusiasm in Sarasota County aimed at protecting the unique natural communities and rare wildlife that still flourish throughout the county. Sarasota County government understands the value of protecting a healthy landscape and is taking significant strides to maintain the uniqueness of the county by supporting regional ecological evaluations aimed at identifying critical habitat corridors and funding land protection initiatives such as the ESLPP and the ROMA program. Additionally, County staff and local environmental teams continue to work to identify critical areas to maintain or improve ecosystem connectivity through innovative infrastructure design. This combined strategic planning continues to afford protection to environmentally sensitive parcels and serve to alleviate fragmentation pressures on many of the county's protected habitats.

The ESLPP program is the most powerful land acquisition tool used to protect land in Sarasota County. The program has been fundamental in acquiring ecologically sensitive parcels across the county landscape. The less recognized, but equally valuable, ROMA program is in the early stages of development. For this reason, many permitting hurdles still need to be addressed and the cost/benefit associated with the ROMA program still needs to be determined. Additionally, the overall ecological value of the program has not been acknowledged by all permitting entities. Sarasota County Road Program has invested significant time and resources in support of the ROMA program in an effort to promote ecologically significant mitigation as compensation for unavoidable environmental impacts associated with

Sarasota County's infrastructure projects. It is the economic intent that this approach facilitates smoother permitting for local infrastructure projects. The ecologically driven goal of this approach is to preserve biological diversity within core areas of the landscape and to maintain a habitat mosaic across the county. Ultimately, the regional mitigation perspective provides an avenue to fund land acquisition in concert with significant habitat creation, enhancement, restoration, and preservation efforts.

Sarasota County government continues to promote sustainable efforts to acquire environmentally sensitive lands, design sustainable infrastructure, and permit environmentally conscious development. New roadway projects are not only aimed at alleviating congestion created by the growing population pressures, but are concurrently viewed in relation to the natural landscape. As future roadway alignments are considered, planners and designers are using the environmental landscape as a tool to design sustainable roadway projects in an effort to preserve a healthy interconnected landscape for future generations.

**Biographical Sketches:** Sherri R. Swanson is an Environmental Scientist with HDR Engineering, Inc. in Sarasota, Florida. Her professional responsibilities involve project management related to transportation projects, habitat restoration, and resource management. Prior to joining HDR in 2006, Ms. Swanson was a Project Scientist with Sarasota County where her professional responsibilities involved project management and oversight of the County's Regional Mitigation Program, coordination of the county's regional ecological evaluations, and permitting of local roadway projects. Her career experience in environmental science includes tenures with private business, local government, and non profit organizations. Ms. Swanson has spent the majority of her career consulting on both private and government sector projects. She has also been involved with environmental outreach and natural resource management. She holds a Bachelor of Science in Environmental, Soil and Water Science from the University of Arkansas.

Wendy E. Hershfeld is a Senior Scientist at Scheda Ecological Associates, Inc. in Sarasota, Florida. Her current responsibilities include management of projects related to restoration, transportation, and permitting. She recently worked as a Project Scientist for Sarasota County Road Program Design where her professional responsibilities involved project management and oversight of the County's Regional Offsite Mitigation Program. Previously, she worked for PBS&J's West Florida Sciences program based in Sarasota where she served as a project manager to several public agency clients for projects related to transportation improvements, restoration, water quality evaluations, and natural resource management. She holds a Bachelor of Science in Marine Biology from the University of New England. Other professional experience involves State ERP and NPDES regulation and permitting and marine and freshwater ecological assessments.

**Acknowledgements:** This paper is the result of collaborations between various Sarasota County departments and HDR Engineering, Inc. Special thanks goes to Wendy Hershfeld for her work as both a PBS&J and Sarasota County employee. Additional thanks go to Sarasota County staff Brad Robertson, for his GIS expertise and Nancy Edmondson and Brian Pavlina for providing monitoring data for Lemon Bay Preserve. Additionally, the acceptance and support of Sarasota County Mobility has been essential to this project's success.

## References

Dodd Jr., CK, Barichivich, William J., Smith, Lora L., 2003. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation 118 (2004) 619-631.

Kurz, R.J., Conn, M., and Hershfeld, W. 2005a. *Englewood Interstate Connector (EIC) Corridor:Wildlife Mitigation Preliminary Design Investigation*. PBS&J, Sarasota, FL.

Kurz, R.J., Conn, M., Hershfeld, W., and Dracup, J. 2005b. I-75/SR 681 *Cost Analysis and Follow-up Monitoring*. PBS&J, Sarasota, FL.

Kurz, R.J., Alshouse, Alan, Hershfeld, W., 2004. Regional Ecosystem Evaluation for the I-75 Corridor Between SR681 and Laurel Road, Sarasota County, Floriday. PBS&J, Sarasota, FL.

Rossmanith, Robin J, Smith, Henry T., 2006. Wildlife Road-kills in a Southeast Florida Park. Natural Area News.

Zwick, P.D. Ph.D and Carr M. H. (2006) Florida 2060 - A Population Distribution Scenario for the State of Florida. Geoplan Center at the University of Florida.

# Effects of the Configuration of Road Networks on Landscape Connectivity

**Jochen A.G. Jaeger** (+41-44-632-0826, jochen.jaeger@env.ethz.ch), Research Associate, Swiss Federal Institute of Technology ETH Zurich, Department of Environmental Sciences, Ecosystem Management, Universitaetstrasse 22, CHN F 73.2, CH-8092 Zurich, Switzerland

Abstract: Wildlife biologists, traffic planners, and decision makers are increasingly concerned about the effects of landscape fragmentation caused by transportation infrastructure. Data on the degree of landscape fragmentation are urgently needed for monitoring environmental change, identification of trends, and as a basis for investigating the effects of fragmentation on larger scales. The method of effective mesh size is currently used in several countries for national environmental reporting, e.g., as one of 24 core indicators in Germany. The objectives of this paper are to develop a new method for the quantification of landscape connectivity that incorporates variable barrier strengths into the effective mesh size, and to apply it to the question of how the configuration of transportation networks affects landscape connectivity, using empirical data on ungulates and amphibians. The paper also addresses the question of how crossing structures can enhance landscape connectivity most efficiently depending on their placement and spatial arrangement.

The outcomes include the following principles: (1) The more crossing structures were implemented, the higher the resulting landscape connectivity. (2) The higher traffic volume, the larger the difference between the configuration with and without crossing structures, and the more pronounced the differences among the various configurations with crossing structures. (3) The more patches can be accessed from any patch by few road crossings (i.e., high number of nearest neighbours and next nearest neighbours), the higher the degree of landscape connectivity. (4) The closer to each other the roads are (i.e., the more bundled the roads are), the higher the degree landscape connectivity. (5) However, putting all traffic on one road can be better or worse for landscape connectivity, depending on how quickly crossing success decreases with increasing traffic volume. (6) The number and quality of crossing structures are highly relevant. Wildlife passages that are not satisfactorily functional provide little benefit to landscape connectivity. (7) Large patches should be connected first. Only once the large patches are well enough connected does the additional connection with smaller patches provide higher additional connectivity than an improvement of the connectivity between the large patches.

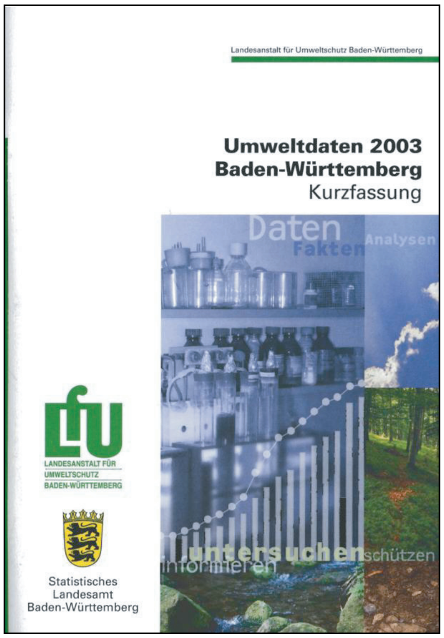
The results demonstrate that the topology-sensitive effective mesh size is a suitable tool to study the effects of road network configuration and wildlife passage location on landscape connectivity. Because traffic volume may vary over time, landscape connectivity can vary over a day, week, or year. This new method will probably be applied widely in the future as the current lack of quantitative empirical data on the barrier strength as a function of road type, traffic volume, and animal species is currently addressed more and more systematically by wildlife biologists.

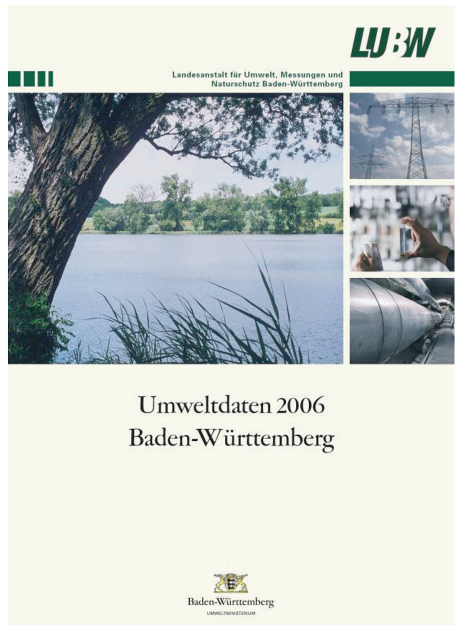
## Introduction

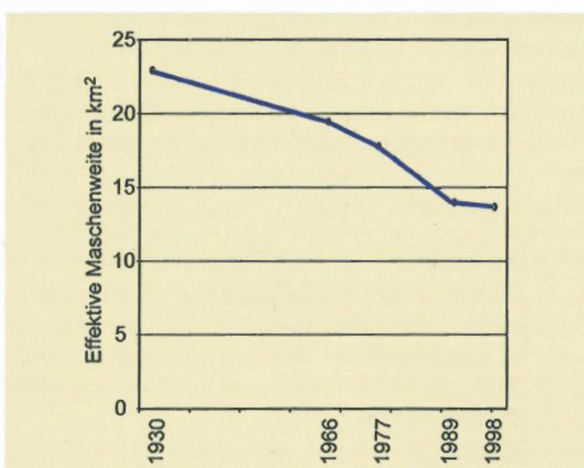
Landscape fragmentation caused by transportation infrastructure is a serious threat to the sustainability of human land uses because it has a number of detrimental effects on the environment including spread of noise and pollution from traffic, effects on local climate, reducing the size and persistence of wildlife populations (e.g., by the dissection of populations and the isolation of habitats), and impairing the scenery and recreational quality of the landscape (Underhill and Angold 2000, Jaeger 2002, Forman et al. 2003). Data on the increasing degree of landscape fragmentation are urgently needed for monitoring environmental change, identification of trends, and as a basis for investigating the effects of fragmentation on a regional and national scale (Jaeger 2002, Heinz Center 2002, Kupfer 2006, Jaeger et al. 2007).

The scientific literature offers a number of metrics to measure the degree of landscape fragmentation (e.g., Hargis et al. 1998, Gustafson 1998, Jaeger 2000, Riitters et al. 2000, Rutledge and Miller 2006). However, few of them have been developed in a form that can be easily applied to transportation infrastructure. For example, it is notoriously difficult to use raster-based metrics since the resolution of raster images of the landscape is often too course to depict smaller roads correctly. Even with larger roads, there can be problems when the size of the raster cells is in the order of the width of the roads. Consequently, the lines of raster cells representing roads may be discontinuous, i.e., may have holes, which can lead to flawed results when the patches on either side of the roads appear to be connected through these “holes”. For this reason, vector data should be used preferably, and therefore, metrics should be chosen that are applicable to vector data.

In most cases, former methods to quantify the degree of landscape fragmentation have based the decision of whether or not to include roads as barriers on the road’s category (e.g., include district roads but exclude municipal roads) or on a minimum amount of traffic (e.g., include only roads with >1000 vehicles/day, BfN 1999, Gawlak 2001). Therefore, these methods do not take into account the varying degree of a road’s barrier strength that depends on traffic volume, on several characteristics of the road itself (e.g., width, type of surface), and on the surrounding landscape (e.g., slope). For example, the effective mesh size (see below) is based on the ability of two animals – placed in different areas somewhere in a region – to find each other within the landscape (e.g., for reproduction), and in its most basic version, it only includes those connections between points that do not cross a barrier, i.e., it is based on the probability that two randomly chosen places in a region will be found in the same patch (Jaeger 2000, Moser et al. 2007). Following the successful implementation of this indicator in Baden-Württemberg in 2003 (fig. 1), this method is currently used as one of 24 core indicators for environmental reporting in Germany (Schupp 2005), and in the indicator system for Monitoring Sustainable Development (MONET) in Switzerland (fig. 2; Jaeger et al. 2006b, Bertiller et al. in press, Jaeger et al. in press), and it is also used by the European Environmental Agency and by Environment Canada. An ongoing project of the Road Ecology Center at UC Davis determined the current degree of landscape fragmentation in California at multiple scales (Girvetz et al. 2008 in this volume). The inclusion of quantitative data on the degree of landscape fragmentation in environmental reporting is a major progress during the last five years, and in many countries, has not yet been completed.



Landschaftszerschneidung



**Abb. 79:** Umweltindikator: Landschaftszerschneidung: Effektive Maschenweite (Quelle: TA, Uni Stuttgart, LfU, 2003)

Die effektive Maschenweite ist die Größe (in km$^2$) der verbleibenden Lebensräume, die einer Tierart in einer zerschnittenen Landschaft noch zur Verfügung stehen.
Die Definition der effektiven Maschenweite ($m_{eff}$) stützt sich auf die Wahrscheinlichkeit dafür, dass zwei beliebig ausgewählte Punkte, die in einem Gebiet liegen, nach der Zerschneidung des Gebietes noch gemeinsam in derselben Fläche liegen. Diese Wahrscheinlichkeit ist als Begegnungsmöglichkeit von zwei Tieren derselben Art interpretierbar, was eine wesentliche Bedingung für das Überleben der Art ist. Die Begegnungswahrscheinlichkeit wird

62 LfU ©

**LANDSCHAFTSZERSCHNEIDUNG**

*Definition:* Mittlerer Zerschneidungsgrad des Landes, ausgedrückt durch die effektive Maschenweite ($m_{eff}$) in Quadratkilometer ($km^2$) und Anteil der unzerschnittenen verkehrsarmen Räume über 100 $km^2$ in Prozent der Landesfläche (mit Gemeindestraßen) [ESSWEIN ET AL. 2002]. Die effektive Maschenweite bezeichnet die Wahrscheinlichkeit, mit der zwei Punkte (z. B. Tiere) nicht durch Hindernisse (z. B. Siedlungen, Straßen) getrennt sind. Je mehr Hindernisse vorhanden sind, umso kleiner wird die Wahrscheinlichkeit, umso kleiner wird die effektive Maschenweite.

*Bedeutung:* Die Zunahme der Siedlungs- und Verkehrsfläche sowie der stetig wachsende Verkehr führen zu Verlust, Verkleinerung und zunehmender Zerschneidung der Lebensräume von Pflanzen und Tieren. Insbesondere Tierarten mit hohem Raumbedarf und großem Aktionsradius sind auf große unzerschnittene Lebensräume angewiesen. So sind große unzerschnittene Räume und vielfältige Lebensraumtypen wesentliche Voraussetzungen für den Erhalt der biologischen Vielfalt. Räume mit geringer Zersiedelung, Zerschneidung und Verlärmung stellen eine endliche Ressource dar, ihr Verlust ist meist irreversibel.

*Ziel:* Erhalt der in Baden-Württemberg vorkommenden Lebensraumtypen in ausreichender Größe und Qualität [UVM 2000].

*Status:* Die effektive Maschenweite hat mit 13 $km^2$ einen Tiefststand erreicht. Der aktuelle Anteil der unzerschnittenen verkehrsarmen Räume liegt derzeit bei 2,1 % an der Landesfläche. In Baden-Württemberg sind nach neusten Daten 6 unzerschnittene Räume über 100 $km^2$ vorhanden.

*Trend:* Die effektive Maschenweite nahm aufgrund der weiteren Ausdehnung von Siedlungs- und Verkehrsflächen von Jahr zu Jahr ab. Hinsichtlich ihres Zerschneidungsgrades gibt es zwischen den verschiedenen Teilregionen jedoch große Unterschiede. So sind beispielsweise Tallagen und Ebenen wesentlich stärker zerschnitten als die für die Besiedlung in historischer Zeit ungünstigen Hochflächen.

*Datenquelle:* JAEGER ET AL. 2006

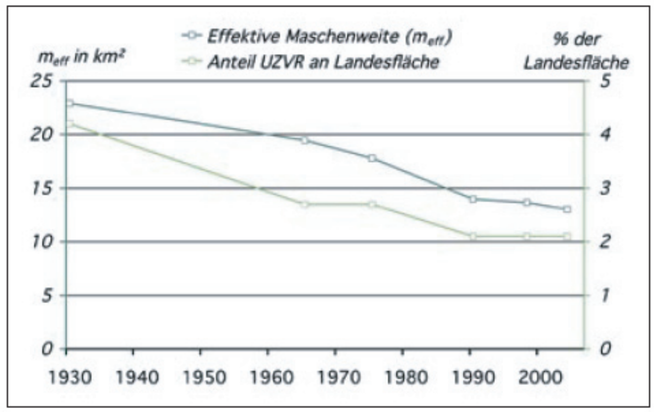



*Abb. 1-8: Landschaftszerschneidung.*

12 | **Umweltdaten 2006 ©LUBW**

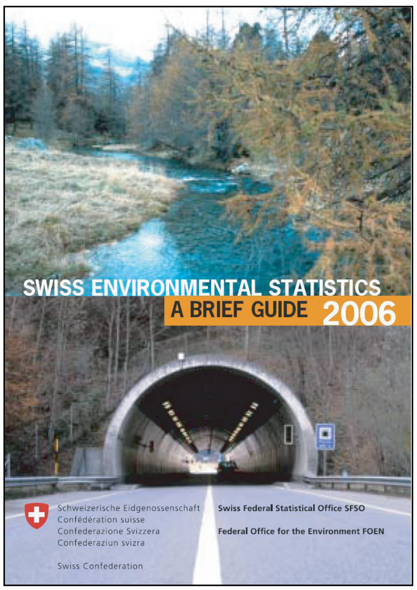
Figure 1. Time series on the degree of landscape fragmentation in the Environmental Report of Baden-Württemberg, Germany, using the effective mesh size (Landesanstalt für Umweltschutz Baden-Württemberg & Statistisches Landesamt Baden-Württemberg 2003; data from Esswein et al. 2002, Jaeger et al. 2006a, Jaeger et al. 2007). A: Title page of the report of 2003. B: Text and diagram for the indicator “Landschaftszerschneidung” [landscape dissection] when it was reported for the first time in 2003 (from p. 62 of the report). C. Title page of the report of 2006. D. Text and diagram for the updated indicator “Landschaftszerschneidung” in the 2006 report (p. 12). (Reprinted with permission from the State Institute for Environment, Measurements and Nature Conservation Baden-Württemberg.)

Landscape fragmentation can be understood as a reduction in landscape connectivity. Landscape connectivity is defined as “the degree to which the landscape facilitates or impedes movement among resource patches” (Taylor et al. 1993, Tischendorf and Fahrig 2000; for a discussion of different interpretations of the term see Fischer and Lindenmayer 2007). Landscape connectivity is species-specific and landscape-specific, i.e., it is a characteristic of a landscape and depends on the movement behaviour of the species. When landscapes become more and more fragmented then the movement of animals among their resource patches is increasingly impeded. Consequently, the degree of landscape fragmentation increases.

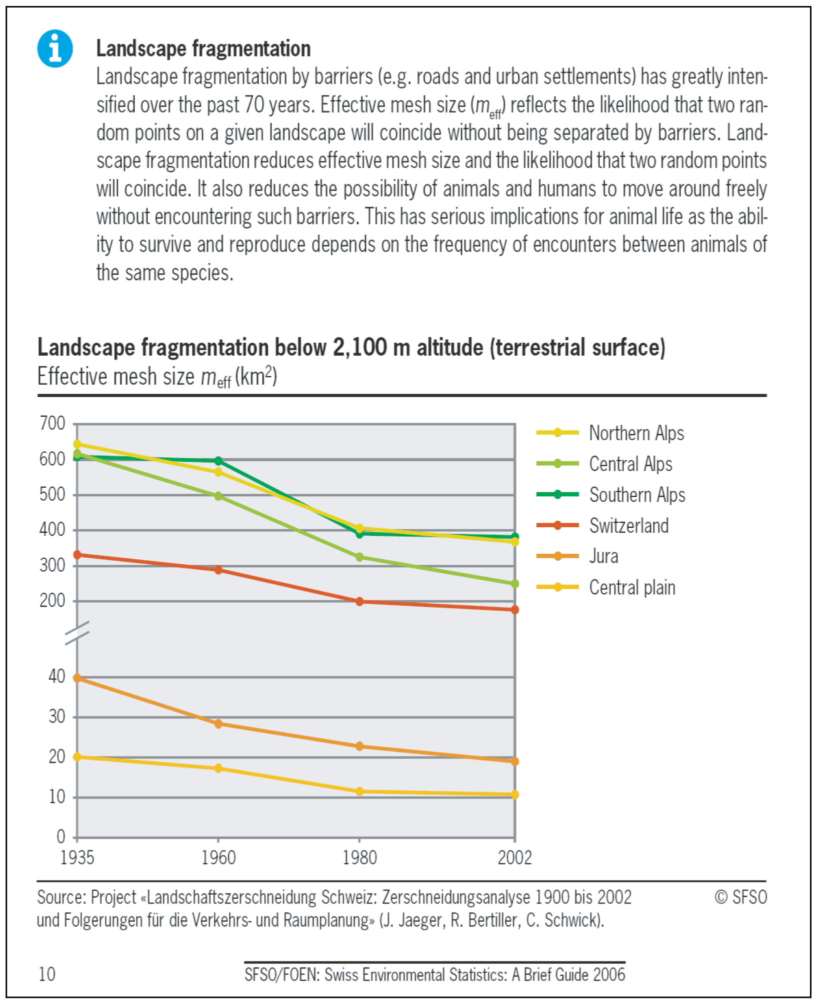
The degree to which transportation infrastructure reduces landscape connectivity depends not only on the location of each road and railroad in the landscape, but also on their spatial arrangement in relation to each other, on their traffic volumes, and on their design (e.g., width, shape of the embankment, presence of jersey barriers). This paper addresses the question of how landscape connectivity is affected by the configuration of road networks and traffic volume on the roads. This requires the following questions to be answered:

1. How can the differing barrier strengths of roads be included in monitoring and reporting on the degree of landscape fragmentation?
2. In relation to what processes should the differing barrier strengths be defined?
   a. In relation to animal species? Which ones?
      i. as a function of traffic volume?
      ii. as a function of other road/traffic variables?
   b. In relation to other effects of fragmentation? Which ones?

The reference to the movement of some species, or to some other landscape process, makes the resulting values of the degree of fragmentation species-specific, or process-specific, respectively. I developed a new method for the quantification of landscape connectivity that incorporates variable barrier strengths into the effective mesh size. The connections across linear barriers are included by introducing additional terms in the formula of the effective mesh size (see below). This new method can also be applied to investigate how the placement of crossing structures affects the degree to which crossing structures enhance landscape connectivity. This paper presents some illustrative examples of how to apply the new method using empirical data on ungulates and amphibians. In these examples, the barrier strength depends on traffic volume (increasing barrier strength with increasing traffic volume).




A.



**Landscape fragmentation**

Landscape fragmentation by barriers (e.g. roads and urban settlements) has greatly intensified over the past 70 years. Effective mesh size ($m_{eff}$) reflects the likelihood that two random points on a given landscape will coincide without being separated by barriers. Landscape fragmentation reduces effective mesh size and the likelihood that two random points will coincide. It also reduces the possibility of animals and humans to move around freely without encountering such barriers. This has serious implications for animal life as the ability to survive and reproduce depends on the frequency of encounters between animals of the same species.

**Landscape fragmentation below 2,100 m altitude (terrestrial surface)**

Effective mesh size $m_{eff}$ (km$^2$)



Source: Project «Landschaftszerschneidung Schweiz: Zerschneidungsanalyse 1900 bis 2002 und Folgerungen für die Verkehrs- und Raumplanung» (J. Jaeger, R. Bertiller, C. Schwick). © SFSO

10 SFSO/FOEN: Swiss Environmental Statistics: A Brief Guide 2006

B.

Figure 2. Time series on the degree of landscape fragmentation caused by transportation infrastructure and urban development in the Swiss Environmental Statistics, using the effective mesh size (SFSO/FOEN 2006; data from Jaeger et al. 2006b, Bertiller et al. in press, Jaeger et al. in press). A: Title page of the report. B: Text and diagram for the indicator "landscape fragmentation" when it was reported for the first time in Switzerland in 2006 (p. 10 of the report). (Reprinted with permission from the Swiss Federal Statistical Office and the Swiss Federal Office for the Environment.)

## Methods

### Effective Mesh Size and Effective Mesh Density

To capture the effect that road construction and road improvement reduce the connectivity of the landscape, the effective mesh size $m_{eff}$ is an expression of the probability that any two points chosen randomly in a region will be connected, i.e., not separated by barriers such as roads, railroads, or urban areas (Jaeger 2000, 2002). It can also be interpreted as the ability of two animals of the same species – placed randomly in a region – to find each other. Therefore, the effective mesh size corresponds nicely with the suggestion by Taylor et al. (1993) that "landscape connectivity can be measured for a given organism using the probability of movement between all points or resource patches in a landscape." The more barriers in the landscape, the lower the probability that the two points will be connected, and the lower the effective mesh size. If a landscape is fragmented evenly into patches all of size $m_{eff}$, then the probability of being connected is the same as for the fragmentation pattern under investigation.

This method aggregates the information on landscape fragmentation into a single value that can be easily obtained and interpreted. The method has several advantages over other methods used in surveys. It encompasses all the patches remaining in the "network" of transportation infrastructure and urban zones, according to patch size. The effective mesh size is suitable for comparing the fragmentation of regions with differing total area and with differing portions occupied by housing, industry, and transportation structures. This measure can be applied to both vector data and raster data.

The formula of the effective mesh size is:

$$m_{\text{eff}} = \frac{1}{A_{\text{t}}} \sum_{i=1}^{n} A_i^2 \ ,$$

where n = the number of remaining patches (excluding urban development), $A_i$ = size of patch *i*, and $A_t$ = the total area of the region under research which has been fragmented. The definition of the effective mesh size is transparent and makes intuitive sense, since the probability of two points being connected can be directly expressed in a mathematical formula: The probability that a randomly chosen point is in patch 1 is $\frac{A_1}{A_{\text{t}}}$. So is the probability that the second point is in A1. The probability that both points are in patch 1 thus is $\left(\frac{A_1}{A_{\text{t}}}\right)^2$. The probabilities for all the patches 1 to *n* are added up:

$$\left(\frac{A_1}{A_{\text{t}}}\right)^2 + \left(\frac{A_2}{A_{\text{t}}}\right)^2 + \left(\frac{A_3}{A_{\text{t}}}\right)^2 + \ldots + \left(\frac{A_n}{A_{\text{t}}}\right)^2 = \sum_{i=1}^{n} \left(\frac{A_i}{A_{\text{t}}}\right)^2$$

To make this result comparable to the results from other regions with different total areas, the probability of two points being connected is re-calculated in terms of the size of a patch: the effective mesh size. This is arrived at through multiplication with At which leads to the above formula for $m_{eff}$, since

$$A_{\text{t}} \cdot \sum_i \left(\frac{A_i}{A_{\text{t}}}\right)^2 = \frac{1}{A_{\text{t}}} \cdot \sum_i A_i^2$$

The effective mesh size has several highly advantageous mathematical properties, e.g., $m_{eff}$ is relatively unaffected by the inclusion or exclusion of small or very small patches (Jaeger 2000, 2002). The maximum value of the effective mesh size is reached with a completely unfragmented area: $m_{eff}$ then equals the size of the whole area. If an area is divided up into patches of equal size, then $m_{eff}$ equals the size of these patches. However, $m_{eff}$ is not usually equal to the average size of the patches. The minimum value of $m_{eff}$ is 0 $km^2$; such is the case where a region is completely covered by transportation and urban structures. To avoid bias of the resulting values due to the reporting unit's boundaries, the cross-boundary connections procedure should always be applied in the calculation of meff (Moser et al. 2007).

Alternatively, the effective mesh density $s_{eff} = 1/m_{eff}$ can be used which expresses the number of meshes per unit area, e.g., per 1000 $km^2$. It has the advantage that an increasing degree of fragmentation will be represented by an increasing curve.

## The New Method: Topology-sensitive Effective Mesh Size and Mesh Density

The method can be refined in such a way that it includes the varying barrier strengths of roads and railways. This is achieved at by including additional terms in the formula of the effective mesh size. They have the form

$$2 \cdot A_i \cdot A_j \cdot (1 - B) \ ,$$

where $A_i$ and $A_j$ are adjacent patches and *B* is the strength of the barrier between them, 0 < B < 1 (Jaeger 2002, chapter 6.5; Fig. 3A). When the strength of the barrier is 100% (B = 1), then this term is 0 and $m_{eff}$ is as before. When the barrier is 0 (*B* = 0), then $A_i$ and $A_j$ are not separated from each other but just form one patch size of ($A_i + A_j$), correctly taken into account in $m_{eff}$ because

$$A_i^2 + A_j^2 + 2A_iA_j = (A_i + A_j)^2.$$

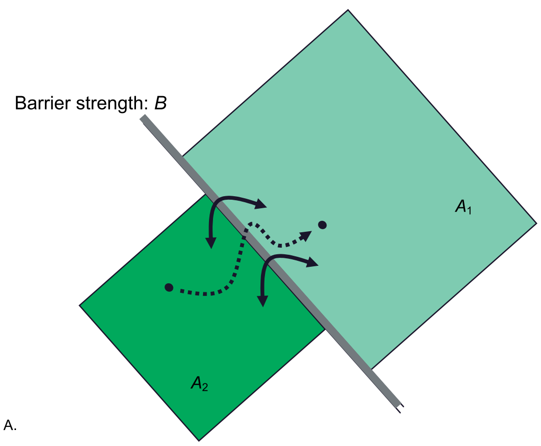
In addition, the animals may be able to cross a suite of barriers in sequence, and the barriers can have differing barrier strengths $B_i$ (*i* = 1, ..., *n*; *n* = total number of barriers crossed). In this case, the additional terms have the form

$2 \cdot A_i \cdot A_j \cdot (1 - B_1) \cdot (1 - B_2) \cdot \ldots \cdot (1 - B_n)$. This situation is illustrated in fig. 4.

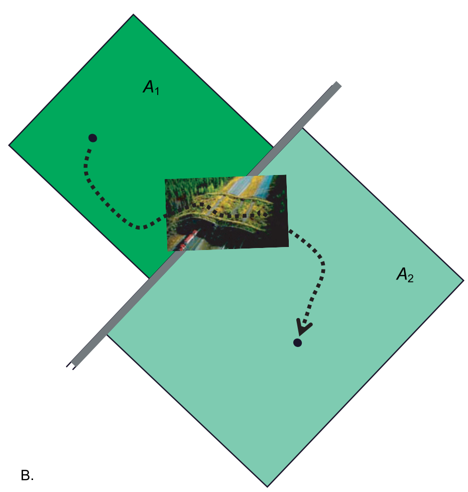
The addition of crossing structures can be taken into account by terms the form of

$$2 \cdot A_i \cdot A_j \cdot D \cdot N \ ,$$

where *D* is the perforation of the road as determined by the number of crossing structures and *N* is the acceptance (likelihood of use) of the crossing structure by the species of interest (fig. 3B).




A.




B.

Figure 3. Illustration of the barrier strength *B* of a road and potential crossings of the road by animals that accept crossing structures. A. The animals can cross from $A_1$ to $A_2$ with a likelihood of (1-*B*). B. The animals can cross the road using a crossing structure with a likelihood of D·N where *D* is the perforation of the road barrier by crossing structures and *N* is the willingness of the species to use crossing structures.

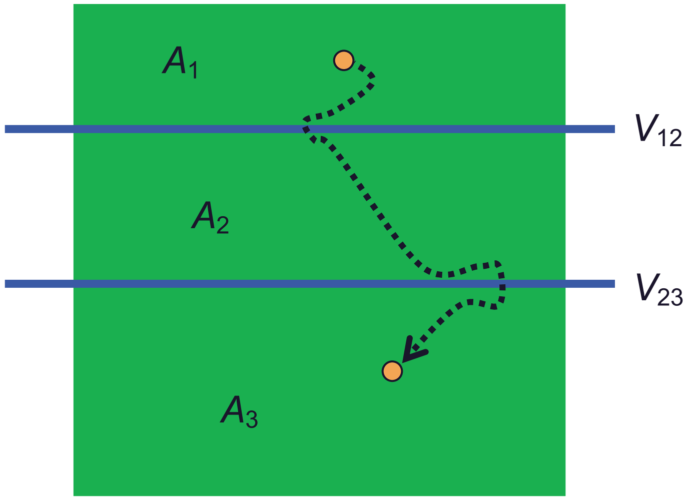



Figure 4. Example of a landscape where the animals have to cross two roads to move from patch 1 to patch 3. $A_1 = 10\ km^2$, $A_2 = 20\ km^2$, $A_3 = 30\ km^2$, $A_t = 60\ km^2$.

In the refined version of the effective mesh size, the relative position of the patches matters (see example below, fig. 7). In mathematical language, the study of the relative positioning of objects is called "topology". Therefore, the refined version of $m_{eff}$ is called "topology-sensitive effective mesh size".

The formula of the topology-sensitive effective mesh size can be written in matrix form:

$$m_{\text{eff}} = \frac{1}{A_{\text{total}}} \vec{A}^T \cdot \vec{L} \cdot \vec{A} \ .$$

For example, for the configuration of three patches as shown in Fig. 7B, the matrix $\vec{L}$ and the vector $\vec{A}$ would look like this (while assuming for the sake of simplicity that the likelihood of successful crossing is the same from either side of the road and is a function of traffic volume $V_{ij}$, i.e., $Q_{ij} = Q_{ji} = f(V_{ij})$):

$$\vec{L} = \begin{pmatrix} 1 & f(V_{12}) & f(V_{13}) \\ f(V_{12}) & 1 & f(V_{23}) \\ f(V_{13}) & f(V_{23}) & 1 \end{pmatrix}, \ \vec{A} = \begin{pmatrix} A_1 \\ A_2 \\ A_3 \end{pmatrix},$$

whereas in the configuration shown in Fig. 7A,  looks like this:

$$\vec{L} = \begin{pmatrix} 1 & f(V_{12}) & f(V_{12}) \cdot f(V_{23}) \\ f(V_{12}) & 1 & f(V_{23}) \\ f(V_{23}) \cdot f(V_{12}) & f(V_{23}) & 1 \end{pmatrix}.$$

**Examples of Application of the New Method**

I applied the topology-sensitive effective mesh size to several road network configurations using data on the likelihood of successful crossings as functions of traffic volume for amphibians (Hels and Buchwald 2001) and moose (Seiler and Helldin 2005) (fig. 5). Landscape connectivity can be reduced for differing reasons.  For amphibians, the reason for the decreasing success ratio is traffic mortality. For moose, the reason for the decrease in success ratio is a combination of traffic mortality and traffic avoidance. At traffic volumes > 20,000 veh. per day, moose almost entirely avoid the road and consequently, very few individuals are killed, whereas amphibians try to cross the road at any traffic volume and consequently, a high percentage of them are killed.

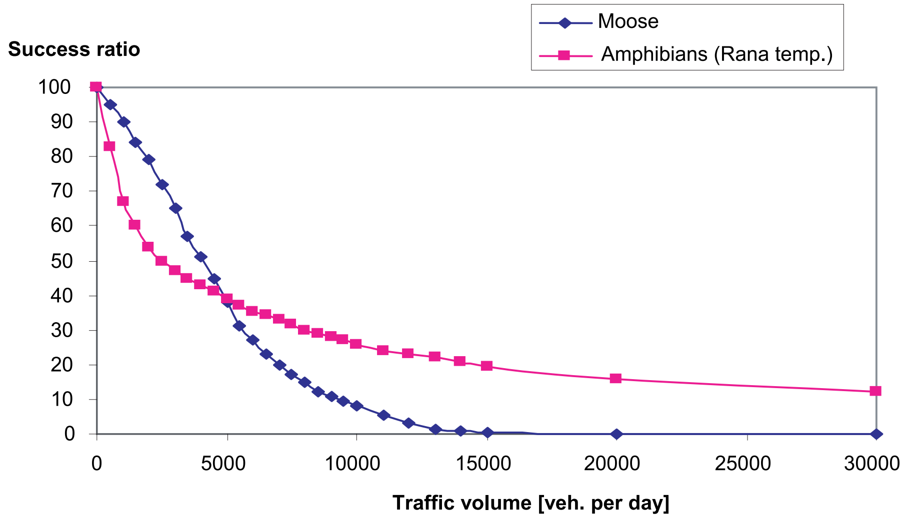



Figure 5. Likelihood of successful road crossings (*Q*) as a function of traffic volume; based on data from Seiler and Helldin (2005) for moose and from Hels and Buchwald (2001) for the Grass Frog Rana *temporaria*.

Using these data, the topology-sensitive effective mesh size for the road configuration shown in fig. 4 becomes a function of the two traffic volumes $V_{12}$ and $V_{23}$. The resulting values of $m_{eff}$ are between 60 $km^2$ when there is no traffic on the roads, and 23.33 $km^2$ when both roads are complete barriers (fig. 6).

How does the configuration of transportation networks affect landscape connectivity, and what configurations are less detrimental to landscape connectivity than others based on the calculated species-specific degrees of connectivity?

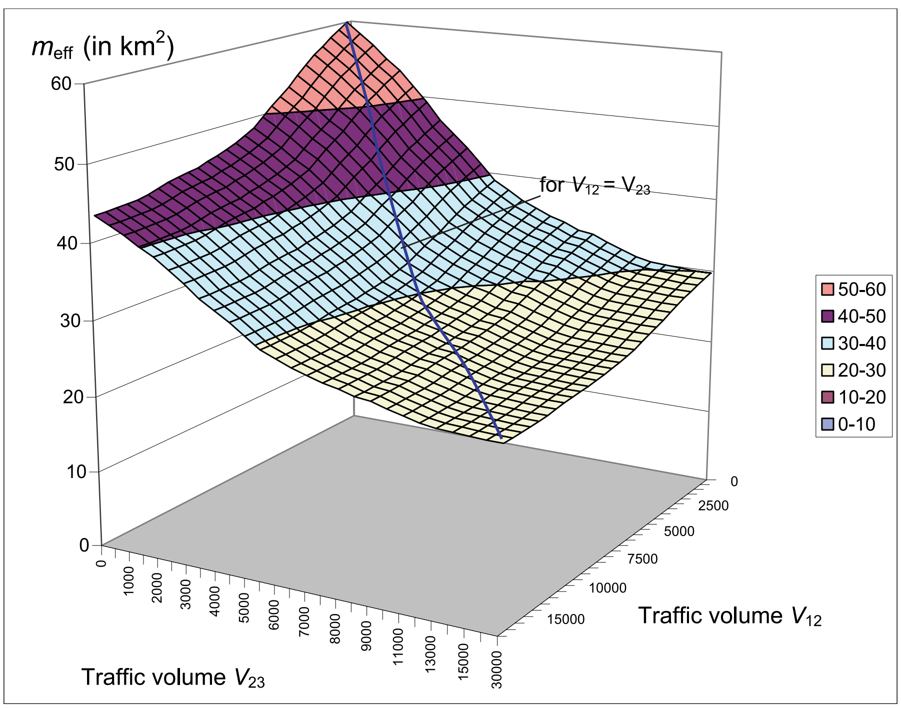



Figure 6. Values of the topology-sensitive version of the effective mesh size as a function of the traffic volumes on the road between patch 1 and 2 ($V_{12}$) and the road between patch 2 and 3 ($V_{23}$) in Fig. 4 based on the barrier strength of roads for moose (from Fig. 5). The line indicates the values of $m_{eff}$ in the case that $V_{12} = V_{23}$. (Traffic volumes in veh. per day.)

I used seven road configurations to evaluate the effect of road network configuration on landscape connectivity (fig. 7), and seven configurations of crossing structures to study the effect of crossing structure location on landscape connectivity (fig. 8). In particular, I was interested in the effects of road bundling and of putting all traffic on one road rather than on several roads (as discussed in Jaeger et al. 2006c). I also asked if a configuration where a patch has only two neighbouring patches has a lower connectivity than one where most patches have three or more neighbouring patches, i.e., a crossed vs. parallel pattern (fig. 7, as in Jaeger et al. 2006c).

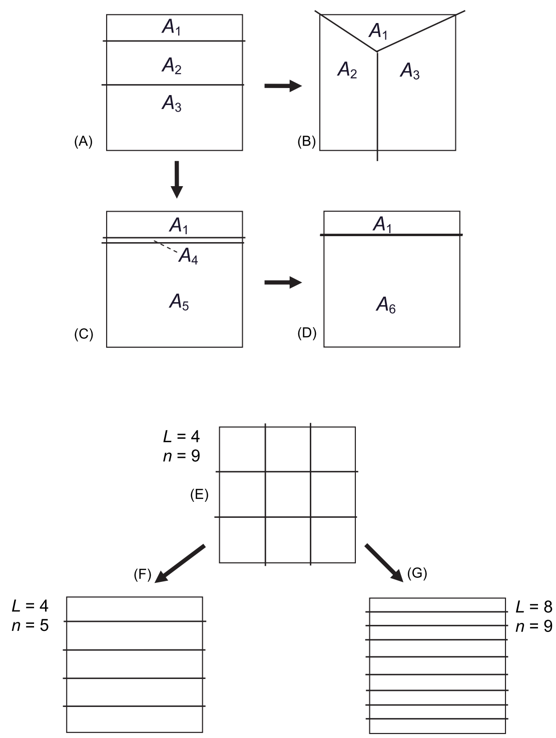



Figure 7. Comparison of road network configurations (parallel configuration vs. Y-configuration, bundling, and combined traffic on one road; gridded pattern vs. parallel configuration). The roads are indicated by black lines. (A-B) Comparing configurations where $A_1$ and $A_3$ are separated by two roads with a configuration where all patches are direct neighbors of each other. (E-F) Comparing configurations with the same number of roads (*L* = 4), and smaller number of patches; (E-G) comparing configurations with the same number of patches (n = 9), and increased number of roads (extended after Jaeger et al. 2006c).

The effect of crossing structures on $m_{eff}$ depends on how strongly adding crossing structures increases the value of *D* in the formula. Future research is needed to determine these values from empirical data. For the calculations, I used the following assumptions: *N* = 0.95 (i.e., acceptance of crossing structures by the animals is 95%), $D_1$ = 0.4 (perforation of a road by the first crossing structure), $D_2$ = 0.6 (perforation of a road by two crossing structures), $D_3$ = 0.75 (perforation of a road by three crossing structures). The more crossing structures are put along the road, the higher the value of *D*, approaching 1 for high numbers of crossing structures: When the entire road is covered by overpasses, the situation would be equivalent to the road being located in a tunnel, and *D* would be 1.

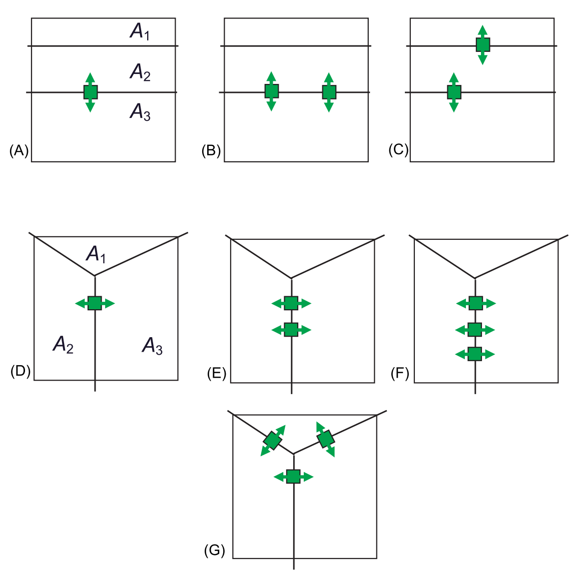



Figure 8. Comparison of the positioning of crossing structures (see text). The arrows indicate the locations of the crossing structures.

## Results

### Road Network Configuration

The resulting values of the degree of landscape connectivity (topology-sensitive effective mesh size; fig. 9) show a clear ranking among the first three road configurations from fig. 7A-C. The difference between the configurations A ("parallel evenly") and B ("Y-configuration") demonstrates that the Y-configuration is advantageous (because the animals need to cross only one road to move from patch $A_1$ to patch $A_3$). However, the difference between these two and the configurations "bundled" and "all traffic on one road" is much larger for traffic volumes > 5000 veh. per day indicating that preservation of large patches is more important at higher traffic volumes when the roads become less permeable. These results are qualitatively similar for moose and grass frogs (fig. 9).

However, the result for configuration D ("all traffic on one road") is less clear: For low traffic volumes, landscape connectivity for D is lower than for configuration C ("bundled") for moose. This indicates that moose more often successfully cross two roads than one road with combined traffic. At traffic volumes > 7000 veh. per day, the order of these two configurations changes. For grass frogs, however, configuration D always has a higher degree of landscape connectivity than C.

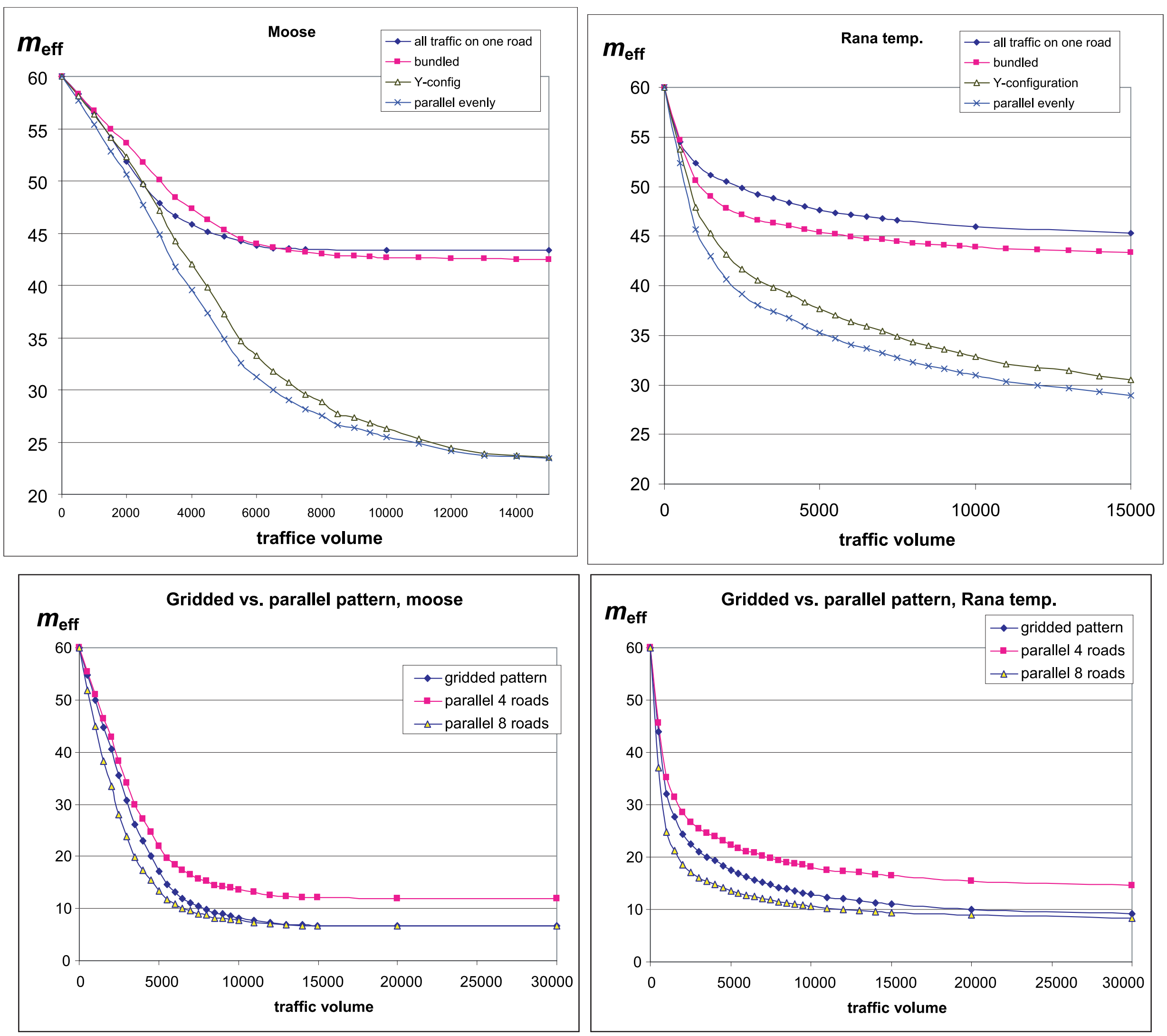



Figure 9. Results of the topology-sensitive effective mesh size for the road configurations shown in Fig. 7 (traffic volume is assumed to be the same on all roads; in the configuration "all traffic on one road", traffic volume is the sum of the traffic of the two roads from the configurations A and C, i.e,. on the x-axis half the traffic volume of the large road is given; in veh. per day). Left column: results for moose, right column: results for grass frog (*Rana temporaria*).

The three other configurations from fig. 7 show a clear ranking: The configuration "parallel 4 roads" has the highest degree of landscape connectivity, and the configuration "gridded pattern" which has also four roads has the second highest landscape connectivity. For low traffic volumes, configurations F ("parallel 4 roads") and E ("gridded pattern 4 roads") have very similar degrees of landscape connectivity indicating that here it is the number of roads that determines the degree of landscape connectivity rather than the number of patches that are created. However, for higher traffic volumes, the effective mesh size depends only on the number of patches, regardless of what their configuration is. Therefore, the difference between "gridded pattern 4 roads" and "parallel 8 roads" vanishes for high traffic volumes (both creating 9 patches). Again, these results are qualitatively similar for moose and grass frogs (fig. 9).

### Location of Crossing Structures

The resulting values of $m_{eff}$ (fig. 10) show a clear ranking among the configurations of the crossing structures from Fig. 8A-C. The crossing structures significantly increased landscape connectivity. The more crossing structures were implemented, the higher the resulting landscape connectivity. The higher traffic volume, the larger the difference between the configuration with and without crossing structures, and the more pronounced the differences among the various configurations with crossing structures. The connection of the two largest patches by two crossing structures (B) was more effective than the placement of one crossing structure on each of the two roads (C).

The placements of crossing structures for the Y-configuration of the roads (fig. 8D-G) also showed a clear ranking order and increasing differences with increasing traffic volume. The number of crossing structures was more important than their location. Surprisingly, the placement of all three wildlife passages on the road between $A_2$ and $A_3$ (fig. 8F) was more effective than placing each one on a different road (G).

However, the ranking of the placements of crossing structures depended on the value of *N*. For lower values of *N*, the results (not shown in the figures here) demonstrated that it is better to improve a crossing structure that is not satisfactorily functional rather than to build a new one which is not fully functional either. Only when the two largest patches ($A_2$ and $A_3$) are well enough connected does the addition of more patches provide higher additional connectivity than an improvement of the connectivity between the two largest patches.

## Discussion and Conclusions

The results on the effects of road configuration on landscape connectivity can be generalized in the following form:

- The more patches can be accessed from any patch by few road crossings (i.e., high number of nearest neighbours and next nearest neighbours), the higher the degree of landscape connectivity.
- The closer to each other the roads are (i.e., the more bundled the roads are), the higher the degree of landscape connectivity.
- However, putting all traffic on one road can be better or worse for landscape connectivity, depending on how quickly crossing success decreases with increasing traffic volume. For grass frogs, this curve (fig. 5) decreases slowly (after a first steep decline), whereas for moose, the corresponding curve (fig. 5) decreases steeply between 0 and 7000 veh. per day.

There is a trade-off between the number of patches a landscape is broken up into, and the accessibility of neighbouring patches. Therefore, the ranking of the configurations can even change when traffic volume changes (see example in Jaeger 2002, chapter 6, and Jaeger 2001).

Regarding the location of crossing structures, the following observations were made:

- The number and quality of crossing structures is highly relevant. Wildlife passages that are not satisfactorily functional provide little benefit to landscape connectivity.
- Large patches should be connected first. When there is room for improvement for the connection between large patches then this is more effective than adding small patches at the periphery. Only once the large patches are well enough connected does the additional connection with smaller patches provide higher additional connectivity than the improvement of the connectivity between the large patches.

The accuracy of these results regarding moose and grass frogs depends on the accuracy of the data provided given by Seiler and Helldin (2005) and Hels and Buchwald (2000). The accuracy of the results on the location of crossing structures depends on the validity of the assumptions on how *D* increases with increasing numbers and quality of crossing structures along a road (see above).

The results demonstrate that the topology-sensitive effective mesh size is a suitable tool to study the effects of road network configuration and wildlife passage location on landscape connectivity. The barrier strength of roads depends on traffic volume which may vary over time. Therefore, landscape connectivity can vary over a day, week, and year. In addition, animal behaviour may also vary over time (e.g., during the rut) which will also affect species-specific landscape connectivity. The topology-sensitive effective mesh size is a convenient tool to investigate such changes.

Using a simulation model of population dynamics, Jaeger et al. (2006c) found that the configuration of road networks influences the degree to which roads affect the persistence of wildlife populations. However, a full species-specific simulation model of population dynamics is often not feasible because of lack of data on the demographic parameters of the population of interest. The degree to which roads reduce landscape connectivity may be much easier to determine using the new method suggested in this paper. This measure can then be used as an indicator of threat

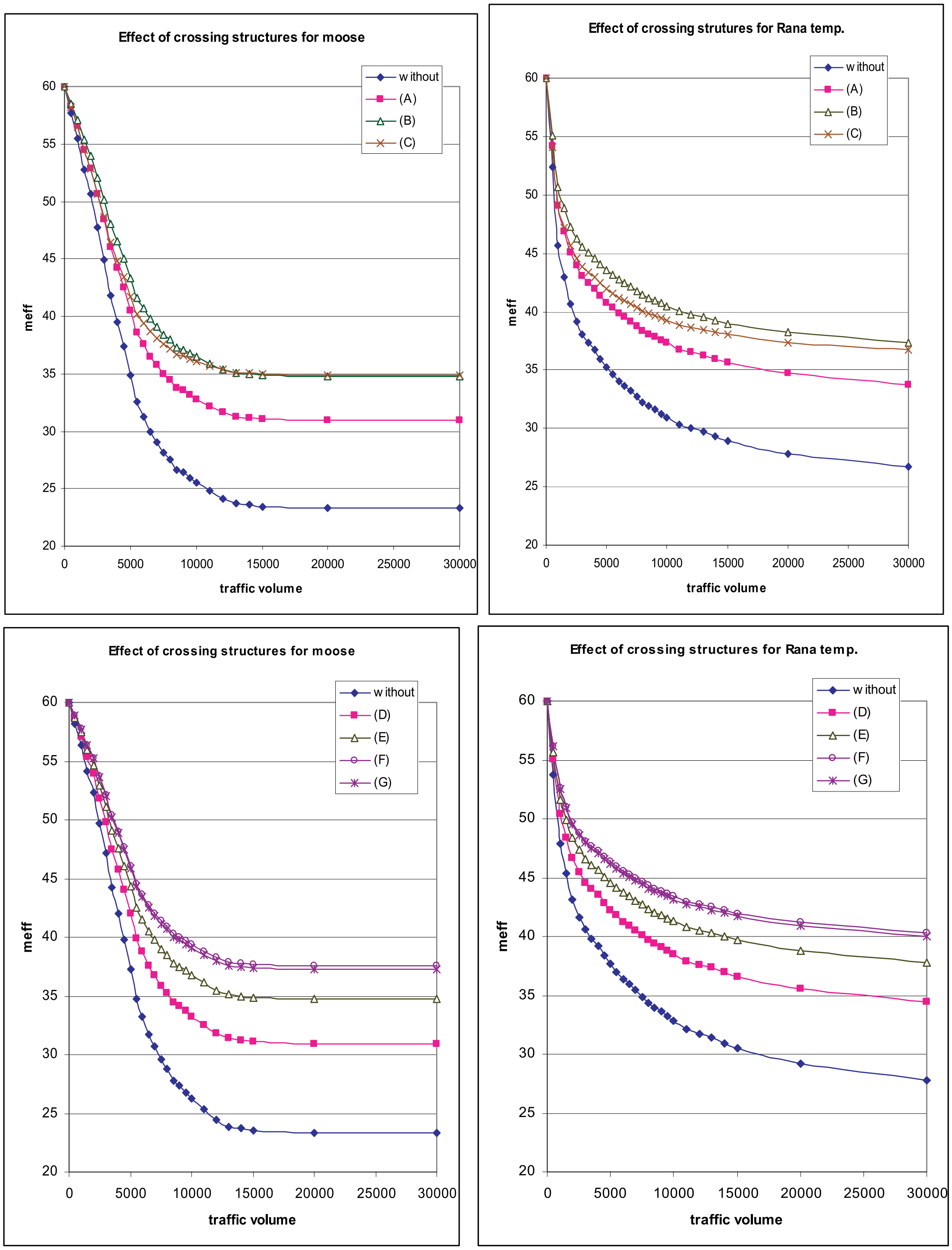



Figure 10. Results of the effective mesh size for the placement of crossing structures as shown in Figure 5.

to the viability of populations due to landscape fragmentation, and as a proxy for assessing and comparing different locations of crossing structures. The more species-specific data are available, the more liable and useful the measure. The results from this paper correspond generally well with the results on the probability of population persistence from the population model. For example, the outcomes of the model demonstrated that the bundling of roads was almost always beneficial (and never detrimental). However, the effect of putting all traffic on one road also was often beneficial (and never detrimental) which was not in agreement with the degree of landscape connectivity for moose for low traffic volumes (see above). This raises interesting questions for future research.

One of the most important applications of the new topology-sensitive method is in environmental reporting. The German Federal Agency for Nature Conservation currently uses a cut-off criterion of 1000 veh. per day for the inclusion or exclusion of roads in the calculation of the degree of landscape fragmentation in Germany (fig. 11). This has the major disadvantage that many roads are not "visible" any more when they branch and the two branches both have less than 1000 veh. per day. I suggest solving this problem by using barrier strength as a function of traffic volume as shown in Fig. 11.

As landscape connectivity is species-specific (because every species has differing crossing success ratios as a function of traffic volume), the resulting time series on the degree of landscape fragmentation will differ. Inclusion of time series for all species in environmental reporting (Fig. 1 and 2) is not practical. Therefore, a small number of representative species should be chosen. However, for investigating the effects of reduced landscape connectivity on animal populations, the new species-specific method is an appropriate tool and should allow for more detailed investigations and hopefully, more accurate results than former methods. To apply this new method to real landscapes, develop it to its full potential, and explore further options, I am currently combining it with graph-theoretical methods (e.g., Urban and Keitt 2001), least-cost analysis (e.g., Adriaensen et al. 2003), and circuit theory (McRae 2006).

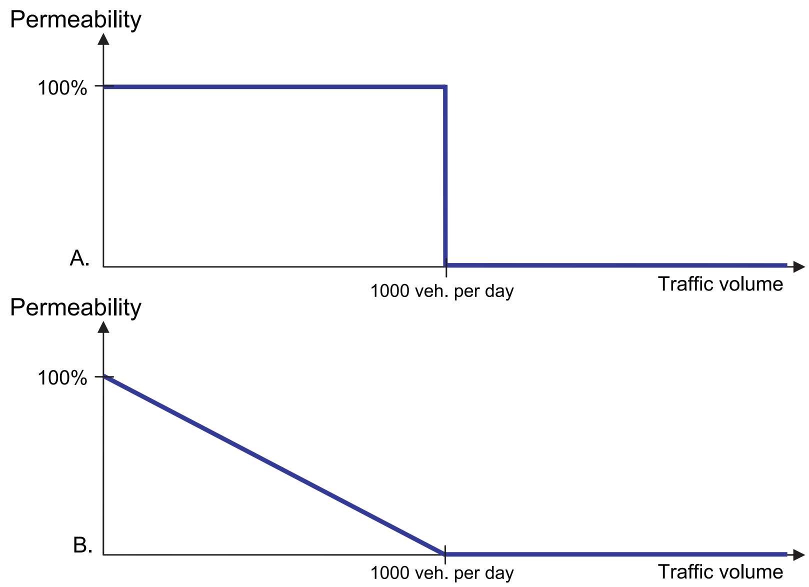



Figure 11. Suggestion of how the cut-off criterion of the German Federal Agency for Nature Conservation for the inclusion or exclusion of roads in the determination of landscape fragmentation in Germany (BfN 1999, Gawlak 2001) (shown in A) should be replaced by a more consistent criterion (B) that can be implemented in the topology-sensitive effective mesh size. Instead of just a linear decreasing line, the curve could also have a different shape.

This new method is likely to be applied widely in the future as the current lack of quantitative empirical data on the values of $B_i$ as species-specific functions of road type and traffic volume is currently addressed more and more systematically by wildlife biologists.

**Biographical Sketch:** Jochen A. G. Jaeger is a research associate in the Department of Environmental Sciences at the Swiss Federal Institute of Technology Zurich (ETH Zurich), Switzerland with Prof. Dr. Jaboury Ghazoul (Group for Ecosystem Management). He studied physics at the Christian-Albrecht University in Kiel, Germany and at the ETH Zurich, and received his Ph.D. from the Department of Environmental Sciences at the ETH Zurich. He held a position at the Center of Technology Assessment in Baden-Württemberg in Stuttgart, Germany, and lectured at the University of Stuttgart, Germany. In 2001, he won a two-year research grant from the German Academy of Natural Scientists Leopoldina and went to Carleton University in Ottawa, Ontario, Canada as a postdoctoral fellow and work with Prof. Dr. Lenore Fahrig in her Landscape Ecology Laboratory (Department of Biology). In 2003, he returned to the ETH in Zurich, funded by a two-year research fellowship from the German Research Foundation (DFG) to work with Prof. Dr. K.C. Ewald. During the time April-June 2007 he was a visiting scholar at the Road Ecology Center at the University of California at Davis, U.S.A. His publications include one book titled *Landschaftszerschneidung* (2002). His research interests are in landscape ecology, quantification and assessment of landscape change, assessment of the suitability of landscape metrics, environmental indicators, road ecology, modelling, environmental impact assessment, urban sprawl, and novel concepts of problem-oriented transdisciplinary research.

## References

Adriaensen, F., J. P. Chardon, G. De Blust, E. Swinnen, S. Villalba, H. Gulinck and E. Matthysen. 2003. The application of 'least-cost' modelling as a functional landscape model. *Landscape and Urban Planning* 64, 233-247.

Bertiller, R., C. Schwick and J. Jaeger. (2007). *Landschaftszerschneidung Schweiz: Zerschneidungsanalyse 1885-2002 und Folgerungen für die Verkehrs- und Raumplanung*. ASTRA-Bericht. Swiss Federal Roads Authority (Bundesamt für Strassen), editor, Berne, Switzerland, in press. 229 pp.

BfN (Bundesamt für Naturschutz), editor. 1999. *Daten zur Natur* 1999. Landwirtschaftsverlag, Bonn, Germany.

Esswein, H., J. Jaeger, H.-G. Schwarz-von Raumer, and M. Müller. 2002. *Landschaftszerschneidung in Baden-Württemberg. Zerschneidungsanalyse zur aktuellen Situation und zur Entwicklung der letzten 70 Jahre mit der effektiven Maschenweite.* Arbeitsbericht der Akademie für Technikfolgenabschätzung Nr. 214 (Selbstverlag), Stuttgart. ISBN 3-934692-69-5 / ISSN 0945-9553. 124 pp.

Fischer, J., and D.B. Lindenmayer. 2007. Landscape modification and habitat fragmentation: a synthesis. *Global Ecology and Biogeography* 16: 265-280.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. Road Ecology. *Science and Solutions*. Island Press, Washington, DC.

Gawlak, C. 2001. Unzerschnittene verkehrsarme Räume in Deutschland 1999. *Natur und Landschaft* 76:481-484.

Girvetz, E.H., J.A.G. Jaeger, J.H. Thorne, and A.M. Berry. 2008. Integrating habitat fragmentation analysis into transportation planning using the effective mesh size landscape metric. In: Irwin, C.L., Garrett, P., McDermott, K.P. (eds.): *Proceedings of the 2007 International Conference on Ecology and Transportation (ICOET)*. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC, in this volume.

Gustafson, E. 1998. Quantifying landscape spatial pattern: What is the state of the art? *Ecosystems* 1, 143-156.

Hargis, C.D., J.A. Bissonette, and J.L. David. 1998. The behavior of landscape metrics commonly used in the study of habitat fragmentation. *Landscape Ecology* 13: 167-186.

Heinz Center (The John Heinz III Center for Science, Economics and the Environment). 2002. *The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States*. Cambridge University Press, New York (available online at http://www.heinzctr.org/ecosystems/report.html).

Hels, T., and E. Buchwald. 2001. The effect of road kills on amphibian populations. *Biological Conservation* 99: 331-340.

Jaeger, J.A.G. 2000. Landscape division, splitting index, and effective mesh size: New measures of landscape fragmentation. *Landscape Ecology* 15(2): 115–130.

Jaeger, J. 2001. Ansätze zur Quantifizierung der Landschaftszerschneidung und die Einbeziehung räumlich-funktionaler Zusammenhänge. – In: Jopp, F., and G. Weigmann (Eds.): *Rolle und Bedeutung von Modellen für den ökologischen Erkenntnisprozeß*. Peter Lang, Frankfurt/Main, pp. 115-126.

Jaeger, J. 2002. *Landschaftszerschneidung*. Eugen Ulmer, Stuttgart (Germany). 447 pp.

Jaeger, J., H. Esswein, and H.-G. Schwarz-von Raumer. 2006a. Landschaftszerschneidung in Baden-Württemberg: Fortschreibung zeigt weitere starke Zunahme der Zerschneidung an. - In: *Zerschnitten, zerstückelt – oder vernetzt? Landschaftszerschneidung contra Lebensraumverbund*. Bad Boller Skripte 3/2006, ISSN 1860-0859 (Tagungsband zum Forum Naturschutz vom 22.10.2005 im Haus der Wirtschaft in Stuttgart), pp. 17-48.

Jaeger, J., R. Bertiller, and C. Schwick. 2006b. Umweltindikator Landschaftszerschneidung in der Schweiz: Zeitreihen zum Monitoring der Nachhaltigen Entwicklung (MONET). *Naturschutz und Landschaftsplanung* 38(10-11), 347-350.

Jaeger, J.A.G., L. Fahrig, and K.C. Ewald. 2006c. Does the configuration of road networks influence the degree to which roads affect wildlife populations? – In: IRWIN, C.L., GARRETT, P., MCDERMOTT, K.P. (eds.): *Proceedings of the 2005 International Conference on Ecology and Transportation (ICOET)*. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC, pages 151-163.

Jaeger, J. A. G., H. G. Schwarz-von Raumer, H. Esswein, M. Müller, and M. Schmidt-Lüttmann. 2007. Time series of landscape fragmentation caused by transportation infrastructure and urban development: a case study from Baden-Württemberg (Germany). *Ecology and Society*, in press.

Jaeger, J. A. G., R. Bertiller, C. Schwick, K. Müller, C. Steinmeier, K. C. Ewald, and J. Ghazoul. (in press). Implementing landscape fragmentation as an indicator in the Swiss Monitoring System of Sustainable Development (MONET). *Journal of Environmental Management*.

Kupfer, J.A. 2006. National assessments of forest fragmentation in the US. *Global Environmental Change* 16: 73-82.

Landesanstalt für Umweltschutz Baden-Württemberg & Statistisches Landesamt Baden-Württemberg. 2003. *Umweltdaten 2003 Baden-Württemberg*. Kurzfassung und Langfassung. Karlsruhe and Stuttgart. ISSN 1612-801X. Greiserdruck, Rastatt, Germany.

McRae, B. 2006. Isolation by resistance. *Evolution* 60(8): 1551-1561.

Moser, B., J.A.G. Jaeger, U. Tappeiner, E. Tasser, and B. Eiselt. 2007. Modification of the effective mesh size for measuring landscape fragmentation to solve the boundary problem. *Landscape Ecology* 22, 447-459. doi: 10.1007/s10980-006-9023-0.

Riitters, K., J. Wickham, R. O'Neill, B. Jones, and E. Smith. 2000. Global-scale patterns of forest fragmentation. *Conservation Ecology* 4(2): 3. [online] URL: http://www.consecol.org/vol4/iss2/art3/

Rutledge, D.T., and C.J. Miller. 2006. The use of landscape indices in studies of the effects of habitat loss and fragmentation. *Naturschutz und Landschaftsplanung* 38(10-11): 300-307.

Schupp, D. 2005. Umweltindikator Landschaftszerschneidung – Ein zentrales Element zur Verknüpfung von Wissenschaft und Politik. GAIA 14 (2): 101-106.

Seiler, A., and J.-O. Helldin. 2005. Mortality in wildlife due to transportation. - In: Davenport J. & Davenport J. L. (eds.). *The ecology of transportation: Managing mobility for the environment*. Springer, Dorecht, The Netherlands, pp. 165-190.

Swiss Federal Statistical Office (SFSO) and Swiss Federal Office for the Environment (FOEN). 2006. *Swiss Environmental Statistics* – A Brief Guide 2006. Berne, Switzerland.

Taylor, P.D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68: 571-573.

Tischendorf, L., and L. Fahrig. 2000. On the usage and measurement of landscape connectivity. *Oikos* 90: 7-19.

Underhill, J. E., and P. G. Angold. 2000. Effects of roads on wildlife in an intensively modified landscape. *Environmental Reviews* 8: 21-39.

Urban, D., and T. Keitt. 2001. Landscape connectivity: a graph-theoretic perspective. *Ecology* 82(5): 1205-1218.

# Integrating Habitat Fragmentation Analysis into Transportation Planning Using the Effective Mesh Size Landscape Metric

**Evan H. Girvetz** (530-752-0225, ehgirvetz@ucdavis.edu) and Alison M. Berry, Road Ecology Center, University of California at Davis, 107 Huerta Place, Davis, CA 95616 USA
**James H. Thorne**, Information Center for the Environment, University of California at Davis, One Shields Avenue, Davis, CA 95616 USA
**Jochen A.G. Jaeger**, Swiss Federal Institute of Technology ETH Zurich, Department of Environmental Sciences, Institute for Terrestrial Ecosystems, Group of Ecosystem Management, Universitätstr. 22, CHN F 73.2, CH-8092 Zurich, Switzerland

**Abstract:** Habitat fragmentation due to transport infrastructure and other human development poses a threat to many wildlife species. This threat may differ depending on the species and types of fragmenting elements. There is a need to quantify the level of habitat fragmentation and the impact of habitat fragmentation on different wildlife species for use in transportation planning. Such measures would be useful in assessing the cumulative impacts of multiple road projects on wildlife connectivity and habitat suitability, for long-range wildlife impact mitigation planning for transportation projects, and as an indicator for the environmental monitoring of habitat fragmentation due to roads.

Effective mesh size ($m_{eff}$) is a biologically relevant landscape metric that quantifies the degree of landscape fragmentation. The definition of the effective mesh size is based on the probability that two randomly chosen points in a region will be located in the same non-fragmented area of land. We calculated effective mesh size to assess the level of landscape fragmentation in the State of California, USA, based on four fragmentation geometries defined by a combination of highways, minor roads, urbanized areas, agricultural areas, and natural fragmenting features (e.g., rivers, lakes, and alpine areas). The effective mesh size for these four fragmenting geometries were calculated for the entire State of California using eight sets of planning units: 1) transportation planning districts, 2) municipal county boundaries, and 3) six levels of watersheds. To demonstrate the methodology, we examined how effective mesh size may impact two species important to transportation planning in California: mule deer (*Odocoileus hemionus*) and mountain lion (*Puma concolor*). The calculated effective mesh sizes were compared with the home range sizes and daily movement distances of the selected focal species to determine the potential impacts of habitat fragmentation and to identify areas where transportation projects will potentially impact these focal species.

Based on the results of this analysis, we suggest that integrating an effective mesh size-based tool into transportation planning frameworks would be valuable to improve identification of potential landscape level impacts early in the planning process. The calculation of effective mesh size will give transportation planners a way to analyze the cumulative impacts of roads in districts, counties, and watersheds and can be used as an environmental indicator for ecological assessment of transportation system impacts.

## Introduction

### Overview

The impact of landscape fragmentation due to roads, urbanization, and other land uses has been identified as a major impact to wildlife and species of concern (Forman 1995; Forman et al. 2003). Impacts to wildlife include direct mortality (Mazerolle 2004; Riley et al. 2003), behavioral changes (Mazerolle et al. 2005), reduced dispersal abilities (Forman & Alexander 1998), and impediment to gene flow (Riley et al. 2006). Transportation planners have recognized the need to assess landscape fragmentation as a part of the environmental planning process. Recent changes in transportation planning regulations (Federal Transportation HR 3, SAFETEA-LU, Congress 2005) mandate that transportation planning incorporate considerations of wildlife conservation. This is due in part to the economies of scale that may be available through integrated regional planning, and to recognition that roads have cumulative impacts on the ecosystems they pass through that may not be correctly identified if planning and environmental assessment are done on a case by case basis.

There is a need for tools and analyses to assess habitat fragmentation at multiple spatial scales that can be easily used by transportation and land use planners. This is particularly the case in the State of California, a globally ranked hotspot of biodiversity, which is currently undergoing a rapid increase in human population density, urban growth and development of transportation infrastructure. This report presents the first results from applying a custom tool for calculating the effective mesh size to assesses the level of habitat fragmentation due to highways, local roads, rail, urban areas, agricultural areas, and natural fragmenting elements (i.e., rivers, lakes, and high alpine areas) in the State of California. By spatially overlaying different combinations of these fragmenting features, four "fragmentation geometries" were analyzed relative to boundaries relevant to planners: twelve Caltrans districts, 58 counties, and six nested spatial scales of watershed ranging from 9 to 6998 watersheds in the State.

We then examined how landscape fragmentation might impact two focal species that are important in California transportation planning: mule deer (*Odocoileus hemionus*) and mountain lion (*Puma concolor*). Deer are of concern in many states because they are often hit by traffic, making them a high-profile species for transportation planners. Mountain lion are of interest due to their large area requirements, which make them sensitive to ongoing landscape fragmentation. Mountain lion have been used as a focal species for modeling in the identification of important wilderness corridors in California (Beier et al. 2006; Hunter et al. 2003; Shilling et al. 2002; Thorne et al. 2006), and efforts are underway to preserve or restore some of these modeled wildlife corridors in Southern California (Beier et al. 2006).

**Landscape Fragmentation Metrics: Effective Mesh Size**

The scientific literature suggests a variety of landscape metrics for quantifying landscape fragmentation (e.g., Gustafson 1998; Haines-Young & Chopping 1996; Jaeger 2000; Riitters et al. 2005; Rutledge & Miller 2006). However, few methods have been developed for practical and intuitive assessment of landscape fragmentation by transportation and other land use planners, since most of these metrics can only be applied to specific aspects of landscape fragmentation. Li and Wu (2004) point out that the behaviors of many landscape metrics are not understood in sufficient detail, which may compromise their suitability for planning purposes. Jaeger (2002) compared 22 metrics with regard to their reliability for quantifying landscape fragmentation, and systematically investigated the eight most promising measures based on eight suitability criteria (intuitive interpretation, mathematical simplicity, modest data requirements, low sensitivity to small patches, monotonous reaction to different fragmentation phases (Forman 1995), detection of structural differences, mathematical homogeneity, and additivity). According to these criteria, only the *effective mesh size* ($m_{eff}$)was unreservedly appropriate as a fragmentation measure, while the suitability of the other measures was more or less severely limited (Jaeger 2000).

Effective mesh size is an expression of the probability that any two randomly chosen points in a region may be connected, i.e., not separated by barriers such as transportation infrastructure or urban areas (figure 1, Jaeger 2000). This measure has been widely applied in Europe and in several other countries. This includes many states in Germany such as Baden-Wuerttemberg (Esswein et al. 2004; Jaeger 2001; Jaeger et al. *in press-b*) where the resulting time series (1930-2004) have been used for environmental reporting (Ministerium für Umwelt und Verkehr Baden-Württemberg & Landesanstalt für Umweltschutz Baden-Württemberg 2003), Saxony (Walz 2005), Thuringia (Geologie 2004), Hesse (Roedenbeck et al. 2005), and Bavaria (Esswein et al. 2004). The effective mesh size metric was recently selected as one of 24 national core indicators for environmental reporting in the context of sustainability in Germany (Schupp 2005), and the corresponding calculations for the remaining states of Germany are under way. The German Federal Environment Agency has suggested tentative limits to the increase of landscape fragmentation in Germany based on the effective mesh size to start a discussion about environmental goals for the future degree of landscape fragmentation (Penn-Bressel 2005; UBA 2003). The effective mesh size has also been applied in South Tyrol (Italy) for environmental reporting on the level of municipalities (Moser et al. 2007), in Lombardy (Italy) (Padoa-Schioppa et al. 2006), and in Switzerland where it is used as an environmental indicator for monitoring sustainable development (Bertiller et al. 2007; Jaeger et al. 2006; Jaeger et al. in press-a). The European Environment Agency applied the effective mesh size to all European countries, preliminary results are presented in Bertiller et al. (2007), and is planning a more detailed investigation. The method has also been applied outside of Europe (Baldi et al. 2006). Environment Canada uses this measure for environmental reporting in their national report titled “Environmental Signals” (K. Lindsay, pers. comm.).

To analyze landscape fragmentation, it is first necessary to identify which landscape elements are relevant to fragmentation. The specific choice of fragmenting elements defines a so-called “fragmentation geometry”. We selected landscape elements shown to impede the movement of animal species, act as sources of emissions, or represent matrix, i.e., non-habitat (Forman et al. 2003; Trombulak & Frissell 2000). These included motorways, roads, railroads, areas of urban development, industrial zones, and agricultural fields. Large rivers and other water bodies also act as barriers to animal movement (Gerlach & Musolf 2000). Therefore, we included rivers and lakes in some fragmentation geometries.

The question of what is an appropriate way of accounting for mountain barriers (which include steep cliffs, rubble slopes, and glaciers) in the effective mesh size was first addressed in Switzerland by Jaeger et al. (in press-a). Holzgang et al. (2001), who in their study of wildlife corridors in Switzerland, considered large areas of rock impassable. This is particularly relevant for species that move along valleys where human activities are focussed. All areas above 2100 m were selected as high mountains (the treeline is between 1600 m and 2300 m in the Swiss Alps, Veit 2002), and this contour applied was applied as a fragmenting element in fragmentation geometries 2 and 3. Here, we present four different fragmentation geometries to allow for various interpretations of landscape fragmentation from different perspectives, and to illustrate the differences and implications of the various assumptions. The four fragmentation geometries were developed by combining highways, local roads, urbanized areas, agricultural lands, and natural fragmenting features (table 1).

The effective mesh size of these four fragmentation geometries is measured relative to different planning units, which may be at different spatial scales. The planning unit boundaries could be political boundaries or they could be based on ecological criteria such as ecoregions, dominant land cover, and watersheds. Planning units occur at a range of spatial scales, and are often hierarchically organized. For example, California Department of Transportation (Caltrans) districts are formulated along county boundaries, and contain from one to several counties. Thus, counties are nested within Caltrans districts, which are nested within the State of California. Similarly, watersheds are nested hierarchical entities with major watersheds containing multiple sub watersheds, which themselves nest watersheds at finer spatial scales, and so on. In California, six nested scales of watersheds have been identified (figure 2).

## Methods

### Effective Mesh Size Landscape Metric

The $m_{eff}$ expresses the possibility that any two randomly chosen points in the region under observation may or may not be connected. The more barriers (e.g., roads, railroads, urban areas) erected in the landscape, the less chance that the two points will be connected. It can also be interpreted as the ability of two animals of the same species – placed randomly in a region – to find each other (figure 1). The encountering probability is converted into the size of an area called the effective mesh size. The more barriers in the landscape, the lower the probability that the two points will be connected, and the lower the effective mesh size. If a landscape is fragmented evenly into patches all of size $m_{eff}$, then the probability of being connected is the same as for the fragmentation pattern under investigation.

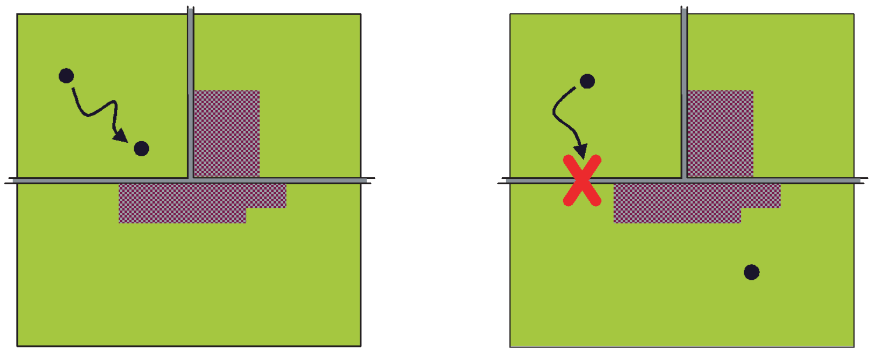


Figure 1. Two randomly chosen points are connected if and only if there are no barriers (e.g., roads, railroads, urban areas) between them (modified after Jaeger et al. *in press-b*).

One problem with this landscape metric, as pointed out by Moser et al. (2007), is that it assumes the unfragmented patches of land stop at the boundary of the planning unit (i.e. county, Caltrans district, or watershed), when in fact, the unfragmented area may extend far beyond the boundary of the planning unit. The effective mesh size described above uses the "CUT" procedure. An alternative implementation of the effective mesh size calculation to account for this is the effective mesh size based on the cross boundary connection (CBC) procedure, which accounts for the area of connected unfragmented areas that extend beyond the boundaries of a given planning unit that the effective mesh size is being calculated for.

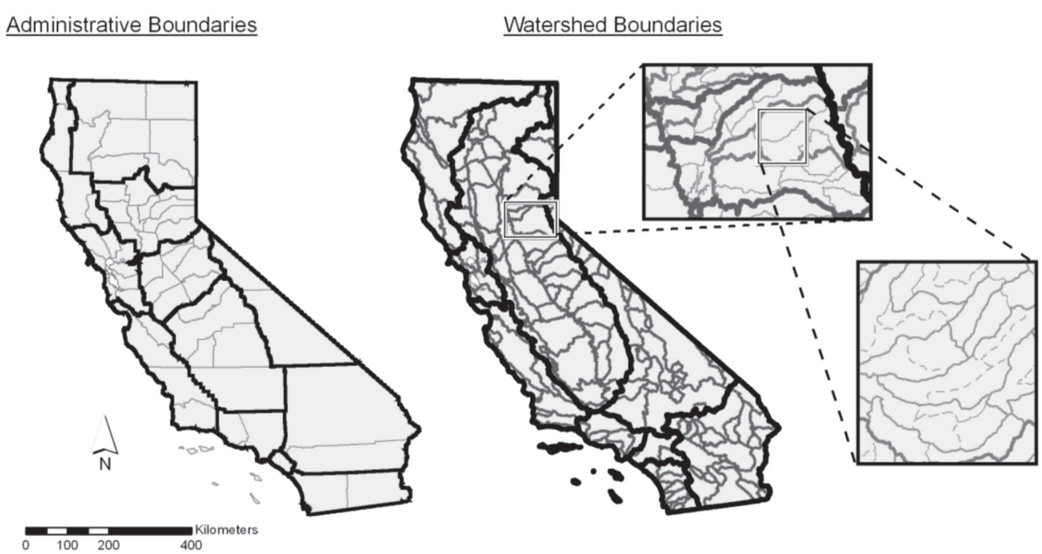



Figure 2. Administrative and watershed boundaries used as planning units to calculate effective mesh size for the State of California. Two spatial scales of administrative boundaries are shown on the left: counties (thin grey lines) nested within Caltrans districts (dark lines). Six spatial scales of watershed used in this analysis are shown on the right: hydrologic regions (thick black lines) and hydrologic units (thinner grey lines) zoomed-in to show hydrologic areas (medium thickness grey lines) and hydrologic sub-areas (thin grey lines), and zoomed-in finer to show super-planning watersheds (thin grey lines) and planning watersheds (dashed lines).

## Automated Effective Mesh Size Calculation Tool

A geographic information systems (GIS) automated tool for calculating effective mesh size was developed for use in ArcGIS 9.1 (ESRI 2005). This tool calculates both the effective mesh size CUT procedure and the CBC procedure based on GIS maps of a given fragmentation geometry and planning unit boundaries. This tool was written as a visual basic 6.0 .dll using the ArcObjects programming library, and can be obtained from the authors upon request.

The tool calculates the effective mesh size by first calculating the area of each planning unit from the planning unit layer and the area of each unfragmented patch from the fragmentation geometry layer. These two layers are then intersected while retaining the information about the area of each original planning unit and unfragmented area.

The CUT effective mesh size calculation was then calculated for each planning unit *j* using the formula as follows (Jaeger 2000):

$$m_{\text{eff}}(j) = \frac{1}{A_{tj}} \sum_{i=1}^{n} A_{ij}^{2}$$

where *n* = the number of unfragmented patches in planning unit *j*, $A_{ij}$ = size of patch *i* within planning unit *j*, and $A_{tj}$ = the total area of planning unit *j*.

The CBC effective mesh size calculation was also calculated for each planning unit *j* using the following formula (Moser et al. 2007):

$$m_{\text{eff}}^{CBC}(j) = \frac{1}{A_{tj}} \sum_{i=1}^{n} A_{ij} \cdot A_{i}^{cmpl}$$

where *n* is the number of unfragmented patches intersecting patch *j*, $A_{tj}$ is the area of planning unit *j*, $A_{ij}$ is the area of unfragmented patch *i* inside of patch *j*, and $A_{i}^{cmpl}$ is the complete area of unfragmented patch *i* including the area outside the boundaries of planning unit *j*.

## Planning Units

The effective mesh size using only the CBC procedure was calculated for four fragmentation geometries (described below) for every Caltrans District (12 total), county (58 total), and five spatial scales of watersheds: river basin (RB, 9 total), hydrologic unit (HU, 189 total), hydrologic area (HA, 578 total), hydrologic sub-area (HSA, 1040 total), super-planning watersheds (SPWS, 2309 total), and planning watersheds (PWS, 6998 total).

## Fragmentation Geometries

Four fragmentation geometries were created from the GIS database (Table 1). Fragmentation geometry 1 (FG 1) includes highways, major connector/arterial roads, railroads, and urban areas. Fragmentation geometry 2 (FG 2) includes all fragmenting elements in FG 1 plus all minor roads. Fragmentation geometry 3 (FG 3) included all elements from FG 2 plus agricultural areas. Fragmentation geometry 4 (FG 4) includes all elements from fragmentation geometry 3 plus natural fragmenting elements.

## GIS Database

*Transportation Infrastructure*

A GIS database of base layers was assembled in order to create four different fragmentation geometries. A 1:100,000 scale GIS data set of all roads for the State of California for 2005 was obtained from the California Department of Transportation (Caltrans). This data set included attributes distinguishing between highways, major connector/artery roads, and minor local roads. For the fragmentation geometries, major highways were buffered by 10 meters (on either side), major roads were buffered by 5 meters, and minor roads were buffered by 3 meters. A 1:100,000 scale GIS dataset of railroads was obtained from the California Spatial Information Library (CASIL) and were buffered by 3 meters for the fragmentation geometries.

*Land Use: Urban and Farmlands Data*

A GIS layer of urbanized areas was created by combining two data sets. The first data set is the Department of Forestry Fire Resources and Assessment Program statewide GIS layer of Footprint of Development derived from 2000 Census (housing density) and USGS National Land Cover Data (land use) at 30 m resolution. Since there has been a substantial amount of urbanization that has occurred in California since 2002—especially due to agricultural and rangeland conversion to urban areas—this map was updated using the California Farmlands Mapping and Monitoring program GIS dataset from 2004, which identifies urbanized areas, but only for agricultural counties. These two datasets were intersected using ArcGIS 9.1 and any area identified in either of the datasets as being urbanized, was assumed to be urbanized for the fragmentation geometry.

Table 1: Summary of the fragmenting elements used to define each fragmentation geometry. Note that each higher level of fragmentation geometry builds on the previous fragmentation geometry by adding additional fragmenting elements, as signified by the bold fragmenting elements

| Fragmentation Geometry | Fragmenting Elements Included |
|---|---|
| FG 1 | **Highways, major roads, railroads, urbanized areas** |
| FG 2 | **FG 1 and add minor roads** |
| FG 3 | **FG 2 and add agricultural areas** |
| FG 4 | **FG 3 and add lakes, major rivers, alpine areas above 3000 m** |

*Natural Fragmenting Features*

Lakes and major rivers were identified from the National Hydrologic Dataset. All lakes and permanently flooded areas were included in the fragmentation geometries. Only major rivers were included in the fragmentation geometries. Areas greater than 3000 m elevation were identified using a 30 m digital elevation model including all areas above 3000 m, the approximate elevation at which treeline begins in California.

### Focal Species

Large mammals are a primary concern to California transportation planners because of the dangers of animal vehicle encounters. We selected Mule Deer (*Odocoileus hemionus*) and Mountain Lion (*Puma concolor*) to illustrate how modeling the effective mesh size can inform planners about the extent to which landscape fragmentation may already be affecting wildlife. Range maps of each species were obtained from the California Wildlife Habitat Relationships Model (CWHR, CDF&G 2003). These range maps were spatially intersected with the effective mesh size maps calculated for planning watersheds based on fragmentation geometry 4. We used fragmentation geometry 4 because these species will react to fragmentation due to roads, rail, urbanized areas, agricultural areas, and natural fragmenting features. These maps were then analyzed based on thresholds for effective mesh size that relate to daily movement distances, home range sizes, and juvenile dispersal distances based on values estimated from the literature as described below.

A study of female mule deer with fawns in northern coastal California identified home ranges of on average 3 $km^2$, with a maximum of 5 $km^2$ (Taber & Dasmann 1957). Similar results were found in the central coast mountains of California. Eberhardt et al. (1984) reported juvenile movement distances were 14 km, and thus a squared area based on this estimates would be 14 km x 14 km = 196 $km^2$. Based on this information we selected a daily movement effective mesh size threshold of 5 $km^2$ and a dispersal movement threshold of 196 $km^2$.

Mountain lions have variable home range size and daily movement distances depending on the density of prey items, and are most abundant where prey densities are high. Home range for an adult male in California is often over 260 $km^2$ (Torres & Bleich 2000). A study in southern California identifies average nightly mountain lion movement to be 10 km (Beier et al. 1995). Squaring the nightly movement distance gives a 10 km x 10 km = 100 $km^2$ square area. Thus, effective mesh size thresholds for mountain lion used in this analysis were 100 km2 for daily movements, and 260 $km^2$ for home ranges.

## Results

### Fragmentation Geometries

Maps of the four fragmentation geometries show the spatial distribution of patch sizes bounded by fragmenting elements throughout the State of California (figure 3). Some similarities among the four maps can be seen. The spine of the Sierra Nevada, north coastal mountains and south eastern desert areas constantly have larger patch sizes, while the Los Angeles, San Francisco, and Sacramento metropolitan areas have consistently smaller patch sizes. However, many differences exist between these maps. The largest difference can be seen in the reduction in patch sizes throughout the State when adding minor roads to the fragmenting elements in fragmentation geometry 2. On the other hand, changes in patch size due to the addition of agricultural areas in Fragmentation Geometry 3 predominantly occur in the Central Valley region, where many of the agricultural areas in the State are located.

### Effective Mesh Size for Administrative and Watershed Planning Units

The effective mesh size within the entire State of California for FG 1 is 2962 $km^2$ (figure 4). By adding minor roads to the fragmenting elements, Fragmentation geometry 2 results in $m_{eff}$ decreasing to 1128 $km^2$. Adding agricultural areas to the fragmenting elements in fragmentation geometry 3 results in only a slight decrease in $m_{eff}$ to 1116 $km^2$. This slight decrease is due to the fact that the agricultural areas are covered by a dense network of minor roads. Finally, with the addition of natural fragmenting elements, $m_{eff}$ decreases to 789 $km^2$.

The effective mesh size was also calculated for each fragmentation geometry within each of the eight sets of planning units. The complete results for all these combinations are too massive to present completely, so summary statistics of the effective mesh sizes calculated are provided (table 2). The complete results may be obtained by contacting the authors.

Table 2 shows that by using finer and finer planning units the range of $m_{eff}$ increases for all fragmentation geometries. For example, for FG 1, the range of $m_{eff}$ for large river basins is 5,142 km$^2$, while the range for the much smaller planning watersheds is 20,885 km$^2$. This pattern holds true for all planning units and all fragmentation geometries.

Table 2: Planning unit area and effective mesh size summary statistics for the two nested administrative planning unit boundaries--Caltrans Districts and Counties--and six nested watershed planning unit boundaries--River Basins (RB), hydrologic units (HU), hydrologic areas (HA), hydrologic sub-areas (HSA), super planning watersheds (SPWS), and planning watersheds (PWS). For each of the boundaries the mean, standard deviation, median, minimum, and maximum planning unit area, and effective mesh size for the four fragmentation geometries (FG) are given. All values given in km$^2$. The $m_{eff}$ for the entire State of California for FG 1 is 2962 km$^2$, for FG 2 is 1128 km$^2$, for FG 3 is 1116 km$^2$, and for FG 4 is 789 km$^2$. Note that some planning units have an area of zero because they are located at the edge of the State and have an area less than 0.5 km$^2$.

| | | Caltrans District | County | RB | HU | HA | HSA | SPWS | PWS |
|---|---|---|---|---|---|---|---|---|---|
| **planning unit area** | **mean** | 34,022 | 7,054 | 45,459 | 2,165 | 709 | 395 | 177 | 58 |
| | **stdev** | 22,036 | 8,073 | 48,314 | 2,791 | 861 | 585 | 324 | 193 |
| | **median** | 28,541 | 4,017 | 29,715 | 1,129 | 422 | 193 | 109 | 32 |
| | **min** | 2,052 | 118 | 7,235 | 28 | 0 | 0 | 0 | 0 |
| | **max** | 72,240 | 52,061 | 46,525 | 18,219 | 8,282 | 7,871 | 6,692 | 6,692 |
| **FG 1** | **mean** | 2,237 | 1,714 | 1,782 | 2,615 | 2,176 | 1,845 | 2,649 | 3,423 |
| | **stdev** | 2,216 | 2,338 | 1,698 | 3,904 | 3,888 | 3,715 | 4,854 | 5,718 |
| | **median** | 1,604 | 920 | 1,619 | 1,143 | 673 | 502 | 830 | 1,256 |
| | **min** | 171 | 0 | 259 | 0 | 0 | 0 | 0 | 0 |
| | **max** | 6,620 | 12,092 | 1,606 | 18,436 | 20,885 | 20,885 | 20,885 | 20,885 |
| **FG 2** | **mean** | 869 | 689 | 660 | 909 | 715 | 607 | 1,028 | 1,478 |
| | **stdev** | 966 | 1,146 | 606 | 1,505 | 1,639 | 1,622 | 2,738 | 3,572 |
| | **median** | 470 | 242 | 394 | 354 | 153 | 103 | 143 | 181 |
| | **min** | 50 | 0 | 84 | 0 | 0 | 0 | 0 | 0 |
| | **max** | 2,829 | 5,064 | 571 | 10,447 | 14,891 | 14,891 | 14,900 | 14,900 |
| **FG 3** | **mean** | 857 | 676 | 649 | 895 | 703 | 597 | 1,019 | 1,471 |
| | **stdev** | 966 | 1,147 | 605 | 1,508 | 1,640 | 1,623 | 2,739 | 3,572 |
| | **median** | 455 | 221 | 376 | 332 | 133 | 94 | 134 | 173 |
| | **min** | 43 | 0 | 78 | 0 | 0 | 0 | 0 | 0 |
| | **max** | 2,813 | 5,058 | 569 | 10,445 | 14,889 | 14,889 | 14,898 | 14,898 |
| **FG 4** | **mean** | 610 | 466 | 521 | 716 | 554 | 452 | 666 | 890 |
| | **stdev** | 560 | 644 | 456 | 983 | 1,024 | 978 | 1,503 | 1,945 |
| | **median** | 420 | 175 | 366 | 258 | 117 | 74 | 112 | 147 |
| | **min** | 43 | 0 | 78 | 0 | 0 | 0 | 0 | 0 |
| | **max** | 1,722 | 2,615 | 425 | 4,821 | 7,883 | 9,097 | 10,137 | 10,175 |

**Relating Effective Mesh Size to Focal Species Movement Needs**

For mountain lion, 57% of its range in California has an effective mesh size that requires the animals to cross fragmenting elements on a daily basis or within their home ranges, leaving only 43% of the range with a large enough effective mesh size that they do not necessarily have to cross fragmenting elements within their home range (table 3). Fifteen percent of the mountain lion range is in the medium effective mesh size class, where individuals are less likely to encounter fragmenting elements with daily movements, although home ranges are very likely cross fragmenting elements. This leaves 42% of the mountain lion home range in the low effective mesh size class, where individuals would be expected to encounter fragmenting elements on a daily basis.

For mule deer, 44% of the range is has an effective mesh size larger than the threshold where deer would be expected to encounter fragmenting elements by dispersing juveniles or daily adult movements (table 3). Another 49% of its range is in the medium effective mesh size threshold category where deer would be expected to encounter fragmenting elements by juveniles, but adult daily movements would be less likely to encounter fragmenting elements. The remaining 7% of the range has an effective mesh size small enough that adult daily movements would likely encounter fragmenting elements.

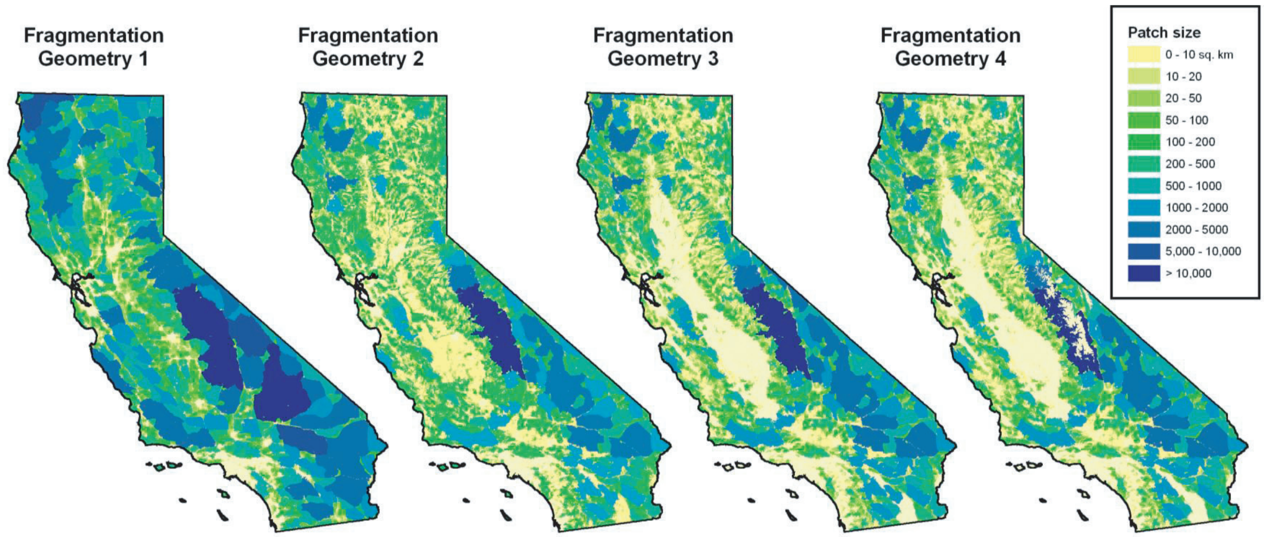



Figure 3. The four fragmentation geometries: (1) highways, major roads and urban areas; (2) highways, major roads, minor roads and urban; (3) highways, major roads, minor roads, urban and agriculture; (4) highways, major roads, minor roads, urban, agriculture, rivers, lakes and areas above 3000 m elevation (table 1). The categories show the sizes of the remaining patches.

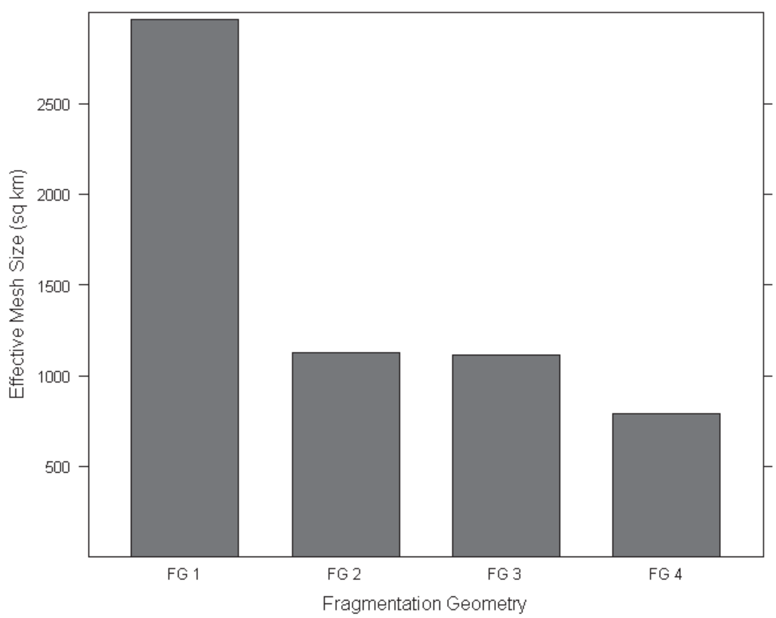



Figure 4. Effective mesh size within all of California for the four fragmentation geometries.

## Discussion

### Overview

Effective mesh size provides an easy to use and reliable method for quantifying landscape fragmentation useful for transportation planning. The metric produces a map of the spatial distribution of fragmentation, as well as quantitative data on the level of fragmentation present in different planning areas relevant to planners. Using effective mesh size as a landscape index permitted an assessment of the degree to which two species important to transportation planners are affected by roads in California. Such analytical techniques and tools are needed to improve the biological mitigation planning process.

The project took a multi-scale approach to assessing habitat fragmentation, which is important for both transportation planning and biological reasons. Different transportation planning efforts occur at different spatial scales. That is, a small road improvement project may only affect a fraction of a hectare of the landscape, but a major road project may affect tens to hundreds of hectares, while regional transportation planning efforts may affect thousands to millions of hectares. In addition, multi-scale analysis is important biologically because different animals respond to landscape characteristics at different spatial scales (Kotliar & Wiens 1990). A mountain lion will respond to habitat fragmentation at a much broader scale than will a small mammal. We recommend that tools developed for environmental assessment be flexible enough to allow for the analysis of potential impacts at a range of spatial scales (Thorne et al. 2007). The method described here allows for the flexibility to identify and analyze habitat fragmentation at scales that are relevant to a wide range of transportation planning efforts and animals that may be impacted.

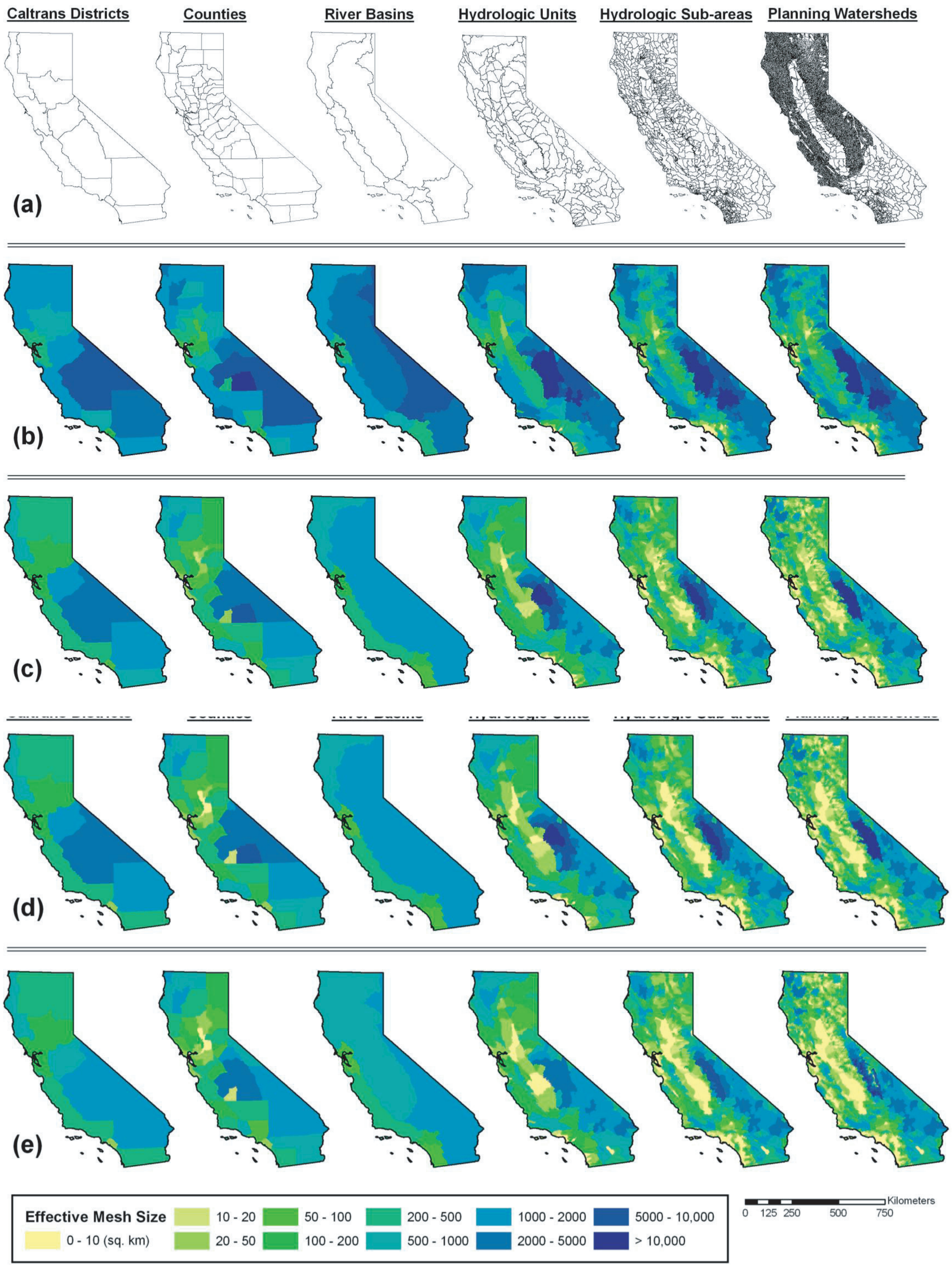



Figure 5. Effective mesh size within six different planning units for the four fragmentation geometries. (a) The two administrative planning units and four levels of watershed maps are shown and labeled across the top. The effective mesh size CBC metric is calculated for the different planning units (labeled across the top) based on: (b) Fragmentation Geometry 1, (c) Fragmentation Geometry 2, (d) Fragmentation Geometry 3, and (e) Fragmentation Geometry 4.

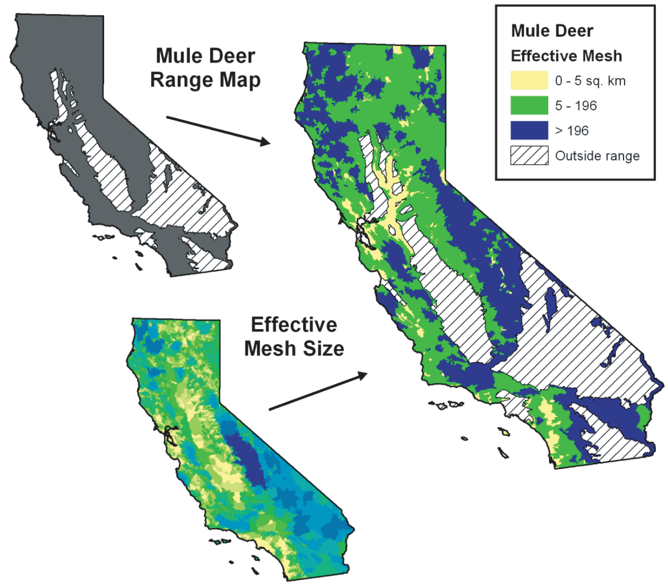



Figure 6. Mule deer range map overlaid with planning watershed level of effective mesh size (Fragmentation Geometry 4), show areas deer are more or less likely to encounter fragmenting elements (see also table 3).

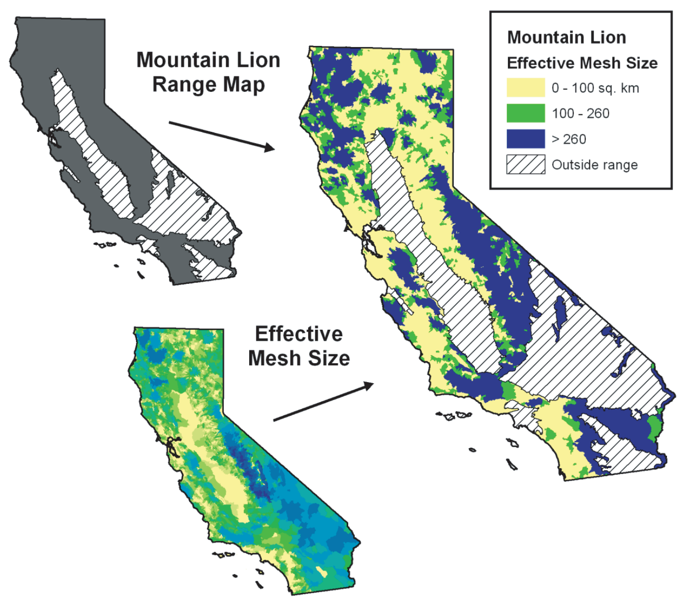



Figure 7. Mountain lion range map overlaid with planning watershed level of effective mesh size (Fragmentation Geometry 4), show areas mountain lion are more (0 - 100 km$^2$) or less likely (> 260 km$^2$) to encounter fragmenting elements (see also table 3).

Table 3: Effective mesh size suitability for mountain lion and mule deer ranges in the State of California. The area within and percent of the total range area for each of the suitability categories are given for each species. For mountain lion, high suitability has an effective mesh size greater than 260 km$^2$, medium is 100 – 260 km$^2$, and low is less than 100 km$^2$. For mule deer high suitability has an effective mesh size greater than 196 km$^2$, medium is 5 – 196 km$^2$, and low is less than 5 km$^2$. For these species high suitability relates to dispersal distances, medium relates to daily movement requirements, and low is generally unsuitable for the species.

| Effective Mesh Size Suitability | Mountain Lion | | Mule Deer | |
|---|---|---|---|---|
| | Area (sq km) | Percent | Area (sq km) | Percent |
| High | 116,783 | 43% | 123,708 | 44% |
| Medium | 40,484 | 15% | 139,244 | 49% |
| Low | 115,940 | 42% | 20,110 | 7% |
| Total | 272,758 | | 283,062 | |

### Relating $m_{eff}$ to Focal Species

Once landscape fragmentation has been quantified, any species for which there is a range map, and for which movement patterns can be obtained, can be assessed in similar fashion to the two presented here. The effective mesh size can be used to classify the landscape into regions where particular species are no longer able to move without encountering a fragmenting element. Depending on the species being studied, a different fragmentation geometry may be the most appropriate to use. In California, there are 294 terrestrial vertebrate species excluding birds, for which range maps are available (CDF&G 2003) and which can now be analyzed from the perspective of the landscape fragmentation indices, a future research goal of this group.

Animals exhibit different movement patterns, which can coarsely be classed into four categories: daily movement, home range, seasonal movement, and juvenile dispersal. We used this information to assess the "effective mesh size suitability" which relates $m_{eff}$ to the movement patterns for a particular species (table 3). In this case the daily (nightly) movement of mountain lion in southern California had been measured using radio collars, and the home range size estimate came from a study of desert mountain lion (Beier et al. 1995), which was potentially a larger estimate of area needed, and therefore a more conservative one. By classing the effective mesh sizes calculated for nearly 7000 watersheds in California into those below the daily movement patterns, those above the home range, and those in between, we were able to determine the level of habitat degradation imparted to mountain lion by roads in California. The results showed that 42% of the entire range is now below the threshold for daily movement patterns for this animal. We would expect mountain lion populations in this part of their California range to be in decline due to the necessity of frequent road crossings (table 3).

Effective mesh size could be used to identify areas that are prone to wildlife/vehicle collisions. Areas with very high meff would be expected to exhibit no fragmentation effects on deer populations, and not be prone to wildlife/vehicle collisions. Areas within the deer range that have very low $m_{eff}$ (< 5km$^2$) are likely to have low deer populations because the level of fragmentation is so high, and may be less prone to collisions. However, the areas with moderate levels of fragmentation (5 – 225 km$^2$) are likely to support viable deer populations, but these population are more likely to encounter roads. Thus, it is the areas that are large enough for the daily movement, but smaller than the dispersal movement requirements where there will be the highest possibility for wildlife collisions, and of greatest concern to transportation planners.

Another set of biological questions arises around a species' response to roads. Some species may have stronger road avoidance behavior, or may be less sensitive than others to roads (Jaeger et al. 2005). Many roads have some drainage structures, which may permit some species to move while the surface level roads prevent others from using the same landscape. Now that methods for quantifying effective mesh size have been developed, many road ecology research questions can be revisited using this landscape fragmentation index.

Population viability as impacted by increasing fragmentation exhibits critical thresholds, below which populations are prone to a much higher risk of extinction (Jaeger & Holderegger 2005; With & King 1999). As a consequence, better policies, decision-making procedures, and planning tools are needed that are based on the precautionary principle and on prospective simulation models, e.g., quantitative environmental standards limiting the degree of landscape fragmentation and precautionary assessment criteria.

Once the thresholds are crossed and the populations are declining, in most cases it is in practical terms impossible to return to the situation before the thresholds were crossed. Even in cases when it is in principle possible to reverse the trend and return to the situation before the thresholds were crossed, this is typically very difficult and much more expensive to implement the measures necessary for a recovery than before the thresholds were crossed.

### Implications of $m_{eff}$ for Transportation Planners

The results illustrate the utility of the effective mesh size metric, and raise questions about how to incorporate estimates of habitat degradation into transportation planning. This type of analysis can potentially be useful to identify contiguous suitable habitats split by roads which could become candidate locations for crossing structures. The data presented here represent an important step forward in analyzing and interpreting the current situation in California and other states, especially for comparative analyses of similar types of ecoregions. The results of this research are being provided to Caltrans for incorporation into a statewide database being developed to identify potential biological impacts due to planned future transportation projects (Thorne et al. 2007). This would then provide another metric for assessing the impact of these future transportation projects on habitat fragmentation and connectivity.

The long-term goal is to create comparative data for the whole of North America. These would serve as a basis for drawing up agreements about environmental standards such as limits, norms, and targets, and for creating measures towards limiting landscape fragmentation (Jaeger 2001; Penn-Bressel 2005; SRU 1994; UBA 2003). For this purpose, it is useful to establish time series for making comparisons with previous conditions, including comparisons with/without increase in traffic volume, and to identify changes in trends. The method used here is well suited for this purpose.

Incorporation of environmental indicators into environmental impact reports is potentially a major application for the type of data we report. A noteworthy example is the report on "The State of the Nation's Ecosystems – Measuring the

Lands, Waters, and Living Resources of the United States" which aims at using seven indicators of fragmentation and landscape pattern but suffers from the lack of data on these indicators (Center 2002; O'Malley et al. 2003), which could be partially addressed using $m_{eff}$. Assessing landscape fragmentation through time using meff is another application, and has already been implemented in the state of the environment report by the State Institute for Environmental Protection Baden-Württemberg (Ministerium für Umwelt und Verkehr Baden-Württemberg & Landesanstalt für Umweltschutz Baden-Württemberg, 2003) and in the report on the status of sustainable development in Baden-Württemberg (Renn et al. 2000), providing examples of how to measure and interpret time series of landscape fragmentation.

## Conclusions

Analyses of correlations between the degree of fragmentation and the presence of species can provide valuable information on the effects of transportation infrastructure. In the future, relationships with the absence or decreasing tendencies of species, especially listed species, may indicate to what degree the amount and loss of unfragmented areas reflect the situation of a species. Further refinements of the effective mesh size method should include the potential of mitigating fragmentation effects by crossing structures (Forman et al. 2003; Jaeger 2007; van der Grift 2005).

It has been called a cruel irony in road ecology that "the more important the question, the more uncertainty is associated with the answers that road science will be able to provide" (Roedenbeck et al. 2007). That is, while there is a large body of experience on how to study the project level effects, the effects on the larger scales are much more difficult to analyze and assess. The methods and results presented in this report provide a tool that is convenient to use for an assessment of the effects of road network on landscape fragmentation and connectivity on the regional and state scale, which can be applied in different places.

**Acknowledgements:** This research was supported by a UC Davis Sustainable Transportation Center faculty grant (A.M.B.). We thank Katie Benouar (Road Ecology Center, UC Davis) for project coordination and Mike McCoy (Information Center for the Environment, UC Davis) for technical support.

**Biographical Sketches:** Evan Girvetz is a doctoral student in the Graduate Group in Ecology at the University of California (UC) Davis (degree expected December 2007). His research focuses on using geographic information systems (GIS) integrated with quantitative analysis techniques to provide decision-support for answering real-world questions faced by land use planners and decision makers. He is currently a graduate student research fellow at the Road Ecology Center (UC Davis), and at the Information Center for the Environment (UC Davis).

Jochen A. G. Jaeger is a research associate in the Department of Environmental Sciences at the Swiss Federal Institute of Technology Zurich (ETH Zurich), Switzerland with Prof. Dr. Jaboury Ghazoul (Group for Ecosystem Management). He studied physics at the Christian-Albrecht University in Kiel, Germany and at the ETH Zurich, and received his Ph.D. from the Department of Environmental Sciences at the ETH Zurich. He held a position at the Center of Technology Assessment in Baden-Württemberg in Stuttgart, Germany. In 2001, he went to Carleton University in Ottawa, Ontario, Canada as a postdoctoral fellow with Prof. Dr. Lenore Fahrig. In 2003, Dr. Jaeger came back to ETH Zurich to work with Prof. Dr. K.C. Ewald. During the time April-June 2007 he worked as a visiting scholar at the Road Ecology Center at the University of California at Davis, U.S.A. His publications include the book *Landschaftszerschneidung* (2002). His research interests are in landscape ecology, quantification and assessment of landscape change, assessment of the suitability of landscape metrics, environmental indicators, road ecology, modeling, environmental impact assessment, urban sprawl, and novel concepts of problem-oriented transdisciplinary research.

James Thorne is a research scientist at the Information Center for the Environment, UC Davis. He got his PhD in Ecology at UC Davis in 2003, and has a masters in Geography from the UC Santa Barbara. His research interests include the integration of ecological data into planning, development and deployment of large datasets, and estimating the impacts of climate change.

Alison M. Berry is a plant scientist and Professor in the Department of Plant Sciences, and the director of the Road Ecology Center at UC Davis. As director of the Road Ecology Center she develops key research issues in road ecology, and builds graduate education and training opportunities. The UC Davis Road Ecology Center aims to facilitate interactions among UC Davis researchers and agency stakeholders that will lead to a new framework for research and technology transfer in road ecology.

## References

Baldi, G., J. P. Guerschman, and J. M. Paruelo. 2006. Characterizing fragmentation in temperate South America grasslands. Agriculture Ecosystems & Environment 116:197-208.

Beier, P., D. Choate, and R. H. Barrett. 1995. Movement Patterns of Mountain Lions During Different Behaviors. Journal of Mammalogy 76:1056-1070.

Beier, P., K. L. Penrod, C. Luke, W. D. Spencer, and C. Cabanero. 2006. South Coast Missing Linkages: restoring connectivity to wildlands in the largest metropolitan area in the USA. Pages 555 - 586 in K. R. Crooks, and M. Sanjayan, editors. Connectivity Conservation. Cambridge University Press, New York, NY.

Bertiller, R., C. Schwick, and J. Jaeger. 2007. Landschaftszerschneidung Schweiz: Zerschneidungsanalyse 1885-2002 und Folgerungen für die Verkehrs- und Raumplanung. ASTRA-Bericht. 229 pp. The Swiss Federal Roads Authority, Bundesamt für Strassen, ASTRA, Bern, Switzerland.

CDF&G. 2003. Caliornia Wildlife Habitat Relationship Database. California Department of Fish & Game, Sacramento, CA.

Congress, U. S. 2005. Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU).

Eberhardt, L. E., E. E. Hanson, and L. L. Cadwell. 1984. Movement and Activity Patterns of Mule Deer in the Sagebrush-Steppe Region. Journal of Mammalogy 65:404-409.

ESRI. 2005. ArcGIS 9.1. Environmental Systems Research Institute, Redlands, CA.

Esswein, H., J. Jaeger, and H.-G. Schwarz-von Raumer. 2004. Landschaftszerschneidung in Baden-Württemberg, Bayern und Hessen – Ein Ländervergleich. Pages 49-70 in A. f. Natur, and U. Baden-Württemberg, editors. Geografische Informationssysteme im Naturschutz und in der Planung. , Tagungsdokumentation.

Forman, R. T. T. 1995. Land mosaics: the ecology of landscapes and regions. Cambridge University Press, Cambridge, MA.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207-231.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter 2003. Road ecology: science and solutions. Island Press, Washington, DC.

Geologie, T. L. f. U. u., editor. 2004. Landchaftszerchneidung in Thuringen. Schriftenreihe der Thuringer Landesanstalt fur Umwelt und Geologie Nr. 66.

Gerlach, G., and K. Musolf. 2000. Fragmentation of landscape as a cause for genetic subdivision in bank voles. Conservation Biology 14:1066-1074.

Gustafson, E. J. 1998. Quantifying landscape spatial pattern: What is the state of the art? Ecosystems 1:143-156.

Haines-Young, R., and M. Chopping. 1996. Quantifying landscape structure: A review of landscape indices and their application to forested landscapes. Progress in Physical Geography 20:418-445.

Heinz Center. 2002. State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States. Cambridge University Press, New York.

Holzgang, O., H. P. Pfister, D. Heynen, M. Blant, A. Righetti, G. Berthoud, P. Marchesi, T. Maddalena, H. Muri, M. Wendelspiess, G. Dandliker, P. Mollet, and U. Bornhauser-Sieber. 2001. Korridore fur Wildtiere in der Schweiz - Grundlagen zur Uberregionalen Vernetzung von Lebensraumen. BUWAL, SGW und Vogelwarte Sempach, Schriftenreihe Umwelt Nr. 326, Bern.

Hunter, R. D., R. N. Fisher, and K. R. Crooks. 2003. Landscape-level connectivity in coastal Southern California, USA, as assessed through carnivore habitat suitability. Natural Areas Journal 23:302-314.

Jaeger, J. 2002. Landschaftszerschneidung. Eine transdisziplinäre Studie gemäß dem Konzept der Umweltgefährdung. Verlag Eugen Ulme, Stuttgart.

Jaeger, J., R. Bertiller, and C. Schwick. 2006. Umweltindikator Landschaftszerschneidung in der Schweiz: Zeitreihen zum Monitoring der Nachhaltigen Entwicklung (Monet) Naturschutz und Landschaftsplanung 38:347-350.

Jaeger, J., Esswein, H., Schwarz-von Raumer, H.-G., Müller, M. 2001. Landschaftszerschneidung in Baden-Württemberg - Ergebnisse einer landesweiten räumlich diffe¬renzierten quantitativen Zustandsanalyse. . Naturschutz und Landschaftsplanung 33:305-317.

Jaeger, J., and R. Holderegger. 2005. Thresholds of landscape fragmentation (in German: Schwellenwerte der Landschaftszerschneidung). GAIA 14:113-118.

Jaeger, J. A. G. 2000. Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. Landscape Ecology 15:115-130.

Jaeger, J. A. G. 2007. Effects of the configuration of road networks on landsacpe connectivity. Page in this volume in C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the 2007 International Conference on Ecology and Transportation (ICOET). Center for Transportation and the Environment, North Carolina State University., Raleigh, NC.

Jaeger, J. A. G., R. Bertiller, C. Schwick, K. Müller, C. Steinmeier, K. C. Ewald, and J. Ghazoul. in press-a. Implementing landscape fragmentation as an indicator in the Swiss Monitoring System of Sustainable Development (MONET). Journal of Environmental Management.

Jaeger, J. A. G., J. Bowman, J. Brennan, L. Fahrig, D. Bert, J. Bouchard, N. Charbonneau, K. Frank, B. Gruber, and K. T. von Toschanowitz. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. Ecological Modelling 185:329-348.

Jaeger, J. A. G., H. G. Schwarz-von Raumer, H. Esswein, and M. Müller, Schmidt-Lüttmann, M. . *in press-b*. Time series of landscape fragmentation caused by transportation infrastructure and urban development: a case study from Baden-Württemberg (Germany). Ecology and Society.

Kotliar, N. B., and J. A. Wiens. 1990. Multiple Scales of Patchiness and Patch Structure - a Hierarchical Framework for the Study of Heterogeneity. Oikos 59:253-260.

Li, H. B., and J. G. Wu. 2004. Use and misuse of landscape indices. Landscape Ecology 19:389-399.

Mazerolle, M. J. 2004. Amphibian road mortality in response to nightly variations in traffic intensity. Herpetologica 60:45-53.

Mazerolle, M. J., M. Huot, and M. Gravel. 2005. Behavior of amphibians on the road in response to car traffic. Herpetologica 61:380-388.

Ministerium für Umwelt und Verkehr Baden-Württemberg & Landesanstalt für Umweltschutz Baden-Württemberg, editors. 2003. *Umweltdaten 2003 Baden-Württemberg*. ISSN 0938-2178. Selbstverlag, Karlsruhe, Germany.

Moser, B., J. A. G. Jaeger, U. Tappeiner, E. Tasser, and B. Eiselt. 2007. Modification of the effective mesh size for measuring landscape fragmentation to solve the boundary problem. Landscape Ecology 22:447-459.

O'Malley, R., K. Cavender-Bares, and W. C. Clark. 2003. Providing "better" data: Not as simple as it might seem. Environment 45:8-18.

Padoa-Schioppa, E., M. C. Poggesi, and L. Bottoni. 2006. River basins as ecological units to evaluate landscape fragmentation. Pages 77-84. in B. Davies, and S. Thompson, editors. Water and the Landscape – The Landscape Ecology of Freshwater Ecosystems. IALE-UK.

Penn-Bressel , G. 2005. Begrenzung der Landschaftszerschneidung bei der Planung von Verkehrs¬wegen. GAIA 14:130-134.

Renn, O., C. Leon, and G. Clar. 2000. Nachhaltige Entwicklung in Baden-Wurttemberg. Center for Technology Assessment in Badeen-Werttemberg, Stuttgart, Germany.

Riitters, K., J. Wickham, R. O'Neill, B. Jones, and E. Smith. 2005. Global-scale patterns of forest fragmentation. Conservation Ecology 4:3.

Riley, S. P. D., J. P. Pollinger, R. M. Sauvajot, E. C. York, C. Bromley, T. K. Fuller, and R. K. Wayne. 2006. A southern California freeway is a physical and social barrier to gene flow in carnivores. Molecular Ecology 15:1733-1741.

Riley, S. P. D., R. M. Sauvajot, T. K. Fuller, E. C. York, D. A. Kamradt, C. Bromley, and R. K. Wayne. 2003. Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California. Conservation Biology 17:566-576.

Roedenbeck, I. A., H. Esswein, and W. Köhler. 2005. Landschaftszerschneidung in Hessen – Entwicklung, Vergleich zu Baden-Württemberg und Trendanalyse als Grundlage für ein landesweites Monitoring. Naturschutz und Landschaftsplanung 37:293-300.

Roedenbeck, I. A., L. Fahrig, C. S. Findlay, J. E. Houlahan, J. A. G. Jaeger, N. Klar, S. Kramer-Schadt, and E. A. Van der Grift. 2007. The Rauischholzhausen agenda for road ecology. Ecology and Society 12:11.

Rutledge, D. T., and C. J. Miller. 2006. The use of landscape indicies in studies of the effects of habitat loss and fragmentation. Naturschutz und Landschaftsplanung 38:300-307.

Schupp, D. 2005. Umweltindikator Landschaftszerschneidung – Ein zentrales Element zur Verknüpfung von Wissenschaft und Politik. GAIA 14:101-106.

Shilling, F. M., E. H. Girvetz, C. Erichsen, and B. Johnson 2002. A guide to wildlands conservation in the greater Sierra Nevada bioregion. California Wilderness Coalition, Davis, CA, USA.

SRU. 1994. Umweltgutachten. Sachverstandigenrat fur Umweltfragen, Metzler-Poeschel, Stuttgart, Germany.

Taber, R. D., and R. F. Dasmann. 1957. The Dynamics of 3 Natural-Populations of the Deer Odocoileus-Hemionus-Columbianus. Ecology 38:233-246.

Thorne, J. H., D. Cameron, and J. F. Quinn. 2006. A conservation design for the central coast of California and the evaluation of mountain lion as an umbrella species. Natural Areas Journal 26:137-148.

Thorne, J. H., E. H. Girvetz, and M. C. McCoy. 2007. A multi-scale and context sensitive state-wide environemtal mitigation planning tool for transportation projects in California. International Conference on the Environment and Transportation, Little Rock, AR.

Torres, S. G., and V. C. Bleich. 2000. Mountain lions: California's elusive predator. Outdoor California 6:4-6.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

UBA 2003. Reduzierung der Flächeninanspruchnahme durch Siedlung und Verkehr. Umweltbundesamt, Materialienband, UBA-Texte 90/03, Berlin, Germany.

van der Grift, E. A. 2005. Defragmentation in the Netherlands: A success story? Gaia-Ecological Perspectives for Science and Society 14:144-147.

Veit, H. 2002. Die Alpen Geookologie und Landschaftsentwicklung, Stuttgart.

Walz, U. 2005. Landschaftszerschneidung in Grenzräumen – Sachsen und die Sächsisch-Böhmische Schweiz. GAIA 14:171-174.

With, K. A., and A. W. King. 1999. Extinction thresholds for species in fractal landscapes. Conservation Biology 13:314-326.

# Is Strategic Environmental Assessment (SEA) an Effective Tool to Conserve Biodiversity Against Transport Infrastructure Development?

**Csaba Varga** (00-36-30-238-5646, varga.csaba@vnet.hu), Land Stewardship Advisory Service of BirdLife Hungary, Loportar u. 16., Budapest, H-1134 Hungary

**Abstract:** The European Union is at the threshold of a new development period. Hungary as a Member State of the EU was given an opportunity to frame its comprehensive development programs for the next seven years (2007-2013). One of these programs is the Transport Operative Program, which focuses on large-scale, large-volume national transport infrastructure developments including road, air, inland water, rail, and combined transport. The Program cover a defined period, however, it will assign the direction of developments for a longer time and foreshadow the vision of the whole transport system in future.

Under the related EU legislation a Strategic Environmental Assessment (SEA) must be accomplished for these kinds of programs. SEA is a specific procedure to identify and control environmentally harmful processes at the earliest and highest level of planning. SEA covers all fields of environmental issues including wildlife conservation and biodiversity maintenance.

In the course of the present research we examined the opportunities the SEA's institutionalized framework (regulations as well as measures) offers or might offer to mitigate the direct and indirect impacts of transportation via the nascent Hungarian Transport Operative Program.

The half-year-long study conducted between June and December, 2006 primarily aims at exploring opportunities lying in strategic-level assessment to conserve biodiversity at national and regional level and to treat habitat fragmentation.. Our study focused on determining what are the main issues that can be handled by the SEA and which ecological conflicts can be – at least partly - resolved at this level.

During the course of the research we used experience gathered by older EU Member States like the UK, Italy and Spain that have been formulated in the form of guidelines. The significance of our research is strengthened by fact that the overwhelming majority of one out of the nine European eco-regions (called Pannonian Biogeographical Region) can be found in Hungary. It is a great challenge for the country to meet Europe's controversial expectations: how to conserve this valuable area but at the same time carry out a large transport infrastructural development.

The results gained suggest that SEA is a satisfactory tool to indicate large-scale harmful processes, however, it does not guarantee certain and sizable mitigation of effects unless the its methodology will be developed further and it will be integrated more efficiently in the implementation process of the transportation strategies in future.

## Introduction

The European Union is at the threshold of a new development period. Hungary as a Member State of the European Union was also given an opportunity to frame its comprehensive development programs for the next seven years (2007-2013). One of these programs is the Transport Operative Program (TOP), which includes large-scale, large-volume nationwide transport infrastructure developments including road, air, inland water, rail, and combined transportation systems for the period marked above.

A primary concern during the elaboration of TOP was to ensure its conformity with the current Hungarian transportation policy as well as with the EU's official White Book on Transportation Policy, which was issued in 2001 and has once been revised since then. In practice, each Member State has the right to form their own strategy on the basis of their needs, however, the strategy has to fit to the current transportation and environmental policy trends. Environmental issues caused by transportation increasingly gain importance in European Union related policies and the White Book apparently also reflects this trend.

Strategic Environmental Assessment (SEA) is a relatively new procedure applied for certain development programs that should comply with the environmental requirements. The European Commission agreed Directive 2001/42/EC "on the assessment of the effects of certain plans and programs on the environment" – the 'SEA Directive' - on 27 June 2001. Since that date, the Directive has been adopted in the national legislation of the Member States, among them in that of Hungary. The objective of the Directive is: '*to provide for a high level of protection of the environment and to contribute to the integration of environmental considerations into the preparation and adoption of plans and programmes with a view to promoting sustainable development, by ensuring that an environmental assessment is carried out of certain plans and programmes which are likely to have significant effects on the environment*' (EC, 2001; Article 1).

Biodiversity has been decreasing steeply over a decade in several European countries. As a consequence, the conservation of biodiversity became an issue of high priority in the EU's environmental policy. EU Strategy for Sustainable Development (2001) set out a target by 2010: to halt the loss of biodiversity. Successful implementation of many of the priority objectives defined in the EU Biodiversity Strategy need sectoral considerations and the integration of biodiversity issues in other policies (EU Progress Report 2006). Beside the agriculture, transportation does not yet have a key role in the Strategy, although its fixed infrastructure might have a long-time effect on the affected habitats and wildlife.

### The Conflict

Transportation development has always been a major driving force as well as an important target for SEA. Not surprisingly, as transportation has serious impacts on the environment that have been widely known for a long time. At a regional and global scale these effects on ecosystems, on the nature reserves as well as on other protected nature values is being increasingly recognized among the other environmental concerns (TERM report 2002). This can only partly be put down to the generally growing endangerment of biodiversity, as underlying, there is fundamental dilemma: A primary objective of the European integration is the creation of a common market, which is in turn based on four guaranteed franchises: the free movement of goods, services, capital and workforce is greatly dependent on the existence of a highly developed and sophisticated transportation network that encompasses and interconnects the whole continent. At the same time, by creating the Natura 2000 network, the European Union has declared that the conservation of the common European natural heritage is also of key importance. Natura 2000 is Europe's ecological network, which connects all valuable nature areas all over the continent. As the pan-European transportation and ecological network necessarily cross each other, one of them has to be favored at their junctures. Unfortunately, the EU Biodiversity Strategy does not give feasible and executable propositions to resolve of the foreseeable conflicts. The related chapter of the document is not very specific, all it contains is that protected areas (with Natura 2000 areas), valuable but not protected nature areas as well as animals' migration routes have to be avoided by the transportation corridors. If the latter is not possible, at the crossing points of migration routes, conditions of safe passing of animals should be ensured. While the former suggestion for avoidance of vulnerable areas is often simply unfeasible, the latter cannot be translated into design terms at the level of strategies and thus it cannot be taken into consideration at the beginning of designing.

In the preparing phase of TOP, we examined what tools are at disposal to implement these propositions and to conserve biodiversity, and we also attempted to identify situations when the territorial overlaps are regarded as acceptable solution to the conflict between transportation corridors and nature.

## Methodology

This paper summarizes the findings of a half-year-long survey that was conducted between June and December, 2006. We primarily aimed at exploring theoretical and practical opportunities lying in strategic-level assessments to avoid further loss of biodiversity at national and regional level and also focused on managing habitat fragmentation. In this study several SEAs featuring transportation development and ecological assessments have been reviewed. As it turned out from the statements, the thematics of SEAs are similar to that of our research target, but the assessments have not a uniform and clear-cut methodology yet. The European countries adopted numerous different methods, among them qualitative analysis, ranking models, comparison of external expenses, risk assessment, multi-criteria assessment, matrices of impacts, cost-benefit analysis and the DPSIR model. Uniform methodology, however, exists neither at the same level of the assessment hierarchy, nor in the group of similar fields. Policies, programs and plans for different fields also prepared in different ways. Standalone strategic ecological assessments are relatively rare and information is hard to find on how the few exceptions are taken into account and how they are integrated (if ever) into the design process. If it functions, it functions on a non-systematic, case-by-case basis.

DPSIR model is listed among the SEA-related propositions issued by the EU as the most appropriate approach towards structuring and managing information on the environment. Consequently, the Hungarian SEA carried out for TOP also used a method based on the DPSIR model; a method called Strategic Assessment Methodological Principle. The environmental specialists examined to what extent the sustainability principles function at the different levels of interaction. The interactions include driving forces, pressures, state, impacts and lastly, responses. A complete environmental assessment has been implemented for the TOP, whose chapter on biodiversity and conservation of nature resources chapters are structured similarly in the SEA statement, according to the interactions. Apart from the ecology-specific findings and suggestions, this way we had an opportunity to review the specificities of the DPSIR model. Our primary concern was to find what is the scale and the depth of ecological processes that can be identified by this model. It was also important to find out what special tools are available for preventing and/or mitigating undesired changes, and how effective these are in practice. The study also aimed at learning how the most significant problems and conflict situations that are well-known and are listed in the SEA statement can be managed in the course of the professional consultation between designers and environmental specialists. We used the relatively unsophisticated cost-benefit analysis and a qualitative-type analysis as the main method of the research. The choice has proven adequate for drawing attention to the opportunities lying in the examined phenomena while at the same time it was sensitive enough to identify any specialties and difficulties in practice.

## Discussions

### Approaches

In practice, there are two conceptions of the role SEA plays in the design process. These are not in conflict but they are essentially different from each other. The first approach emphasizes SEA' similarities to environmental impact assessments (EIA) and considers SEA as the first step of a series of assessments, which is thus suitable for the geographic localization and prompt identification of problems right from the outset. This view is in line with the definition of SEA formulated by Sadler and Verheem in 1996, according to which "*SEA is a systematic process for evaluating the environmental consequences of proposed policy, plan or programme initiatives in order to ensure they are fully included and appropriately addressed at the earliest appropriate stage of decision making on par with economic and social considerations*".

The greatest advantage of this conception lies in its insistence that SEA precedes the environment impact assessment phase and thus it draws attention to conflict points even before the design of the given infrastructure elements pertaining to the policy, program or plan. This provides an opportunity for solving the problem in time.

According to the other approach, SEA is wholly new and independent form of supervision, and only its origin links it to EIA. Its tools are primarily suitable for seizing problems that can be interpreted predominantly at that strategic level. Consequently, environmental assessments following this conception are clearly biased towards processes present at landscape level, regional and global scale. These studies ascribe a relatively high relevance to impacts that are either indirect, synergistic or trans-boundary. Additional habitat loss along the transportation corridors caused by other infrastructure (industrial estates, warehouses, shopping centers etc.) is ranked as a critical issue, a major object of an SEA in this approach.

On the basis of the related literature it can be claimed that the first conception is much more widespread in practice. Presently, the transformation of a landscape in a smaller region is primarily determined by the development of the transportation network, most importantly roads and major ship-canals or other waterways. In a fragmented landscape connectivity will become a limiting factor for conserving biodiversity. We have increasingly more extensive knowledge on both habitat changes at landscape level and their significance in nature protection, thus the first approach is expected to gain more weight in future.

The scaling is apparently two central question of SEA: what processes can be managed by the SEA and which ecological conflicts can be – at least partly - resolved at this level. Two fields deserve our special attention which can hardly (or not at all) be treated at a lower level of design: the large-scale and longer ecological processes on the one hand, and the responsible planning process (implementation of transport policy that is more sensitive to wildlife conservation issues), on the other.

Accordingly, two features of SEA have to be highlighted from the perspective of this examination:

- It identifies the indirect and cumulative impacts of a planned strategy, program, plan prepared for a sizeable region – for a region or a whole country;
- Its findings can influence not only the program's implementation but – optimally – its content and logical structure, i. e. the direction of the development.

**Evaluation of Tools**

Every examined SEA used common tools or a combination of these for assessing the expected impacts on nature and on biodiversity. Methods can be classified on the basis of their similarity with each other and on the basis of their distinctive features. Theoretical toolkit that might be employed could be much larger than that is used in practice. In the research we collected the most frequently used tools, as well as we summarized their advantages and disadvantages. In the evaluation process we took into consideration the general methodological guidelines for SEA proposed by the EU, together with the methods featuring in sustainability assessments that are somewhat similar in nature to SEA.

*1. Habitat Analysis*

In the literature review preceding the research we found that it is the most popular and, in case of conservation issues, often exclusively used measure in SEA assessments. All methods classified as habitat analysis center around the comparison of the spatial distribution of vulnerable natural values with that of the designed infrastructure developments, and draft propositions for overlapping areas, be these plans for avoidance or – incidentally - for crossing. There are several methods for preparing a biodiversity map and also for confronting it against development plans. In a previous Hungarian strategic environmental assessment carried out for the development of national motorway system four alternatives were compared by measuring the length of road segments that cross national reserves and Natura 2000 areas for each alternative plan.

Identifying biodiversity hotspots requires a more refined method, but in most cases the results reflect the distribution of only a few, but veritably keystone species or habitats. For a complex evaluation of affected ecosystems enormous amount of data is needed. In the lack of available data everyday experience of field ecologists is usually ranked above the available methods.

As this tool has been used for a long time and in many forms in assessments at different levels, its advantages and disadvantages have become clear by now.

Table 1: Habitat Analysis Tool

| Disadvantages | Advantages |
|---|---|
| Extraordinary amount of data is needed for a regional or a national transport plan | Clear, widely understandable interpretation of expectable conflicts |
| Controversial results: habitat requirements of species can differ | Applicable also at lower levels of planning (this is rather an EIA-type of tool) |
| Avoiding all nature areas is unrealizable in a country that is rich in nature values | Indispensable for nature reserves of exceptionally high value (sanctuary-like areas) |
| Transportation lines are usually not fixed at this early level of planning, development elements are under continuous change during the planning phase: new analysis is needed again and again | |
| Efficiency of the tool is sometimes low mainly because several professional fields' requirements, maps have to be reconciled and often those maps are preferred that are less conflicting with the originally desired development goals | |

*2. Modifying the Strategy by Changing the Share of Various Transportation Sectors*

It has been well-known long ago that different transportation sectors have different ecological impacts and endanger wildlife to a different extent. Roads not only occupy huge strips of land from the landscape, but they are known to have several impacts that seriously damage the integrity and connectivity of habitats, moreover, even the life of certain animals (Trombulak and Frissell 2000). Generally, the least damage is assumed to be caused by railway and other means of fixed-line transportation. The various existing technical solutions are judged differently in any given transportation sector: a good example for this is the construction of high-speed railways especially in areas rich in natural resources.

Despite the hypothetically enormous advantages in exploiting the opportunities lying in strengthening the presence of more environment-friendly transportation sectors and technical solutions, this is a quite rarely used measure for economic reasons. It is obvious that in case of huge complex designs, the chances of shifting the emphasis on the basis of solely ecological considerations are very low. The success of the measure is also challenged by the fact that the most popular way of transport is usually the least nature-friendly, e.g. traveling by automobile. Well-founded proposals, however, play an enormous part in environmental consciousness-raising and in enlightening the interrelatedness of seemingly independent issues. In the process of TOP, nature conservation and environmental concerns emerging in connection with the plan of the Hungary's largest river, the Danube's transformation into a ship-canal can serve as a very good example for the role of consciousness-raising. The easement of shipping that has already been carried out in other countries in the planned way and that is otherwise rightly regarded as environment-friendly would presumably seriously imperil nature here due to the specific geomorphological characteristics of the Danube's Hungarian section. Although the decision not to canalize the river is presently questionable, the risk was mentioned in the final version of documents, and further measures have been taken to explore risk-related issues.

Table 2: Transportation Sector Tool

| Disadvantages | Advantages |
|---|---|
| Difficult to take into consideration in the course of the design: generally high-speed rails and ship-canals do, traditional railways and in-land shipping do not cause conflicts | Decreasing the share of the most harmful transportation sectors : it can indirectly exert its benign effect through improving the state of other environmental elements like water and air |
| Limited applicability: this tool can be applied only in certain cases | Highly effective and efficient tool alone: no roads no serious ecological problems |
| At best only partial management of ecological conflict situations possible: other measures are always needed | Decreasing the need of costly mitigation and acting longer |

*3. Evolving and Applying Sustainability Criteria*

Sustainability criteria include among others the conditions for the conservation of the natural environment and the preservation of biodiversity. Sustainability helps to decide among different values and the criteria draw attention to issues that might stir conflicts and mark areas that are especially sensitive.

Another opportunity lying in employing sustainability criteria is that with their aid, environmental and conservation principles can be integrated directly into the design process. The criteria most frequently feature in distinct planning and so-called Good Practice guidelines. These guidelines are able to exercise strict control from the first planning phase to the implementation and maintenance phase (i. e. monitoring and indicators?)?. In the Hungarian SEA, minimum sustainability criteria have been determined concerning development priorities, but unfortunately, these have not been included in TOP.

Table 3: Sustainability

| Disadvantages | Advantages |
|---|---|
| It can hardly be integrated into a given design system | Fits tightly to strategic level assessments |
| High resistance against it from the engineering and transportation planning side | Fits better to the modern conservation paradigm |
| No immediate impacts | It can help communication between different partners |
| Long learning curve | Facilitate joint thinking |

*4. Indicators*

In theory, indicators are indispensable elements of any strategy. They can play an important role in the comparison of various alternatives, or of similar indicators reported by other countries, and also in the evaluation of programs by comparing status indicators measured before and after a given program. In the field of nature conservation, effect indicators are supposed to be the most expedient, but at present these are not yet available. The European Environmental Agency have developed some result-type indicators that reflect nature-related effects of transportation and transportation infrastructure development'. These can be used comparatively on larger (European or regional) scales. However, indicators for areas destroyed by roads, for the fragmentation of nature areas and for the proximity of protected nature reserves are not yet veritably expedient in comparing a whole country's alternative development programs and thus they do not facilitate the decision among them. The key problem lies in the enormous data input required for the calculation of the indicators, as well as in the simplifying nature of calculation that masks qualitative differences. Consequently, indicators do not feature in the Hungarian SEA for TOP.

**Special issues in the Hungarian Case Study**

Hungary is struggling to make up a considerable leeway in economy and infrastructure development. This effort is subsidized by the EU, among other supporting the transportation development. At the same time Hungary (partly due to the leeway) has still significantly more natural values than the older Member States. With the accession the country enriched EU' natural heritage with the majority of an additional biogeographical region, the Pannonian region. Maintaining and conserving the values of this region are also subsidized by European funds.

There are two remarkable special issues worth mentioning from our case study. In Hungary, areas located closely around settlements are in many cases of high, sometimes European-level ecological value. In the past, these areas were inappropriate for house-building or cultivation and served as a boundary for the settlement's further expansion, while nowadays these are - in many cases – the last natural values within the settlement's authority. By-pass roads built primarily for environmental reasons (in order to decrease noise and air pollution, high risk of accident inside the settlements) effect just these areas the most fatally. Balancing environmental protection and conservation objectives does not yet seem to be manageable in the framework of the strategic analysis as the settlements' interests is also inevitably justified. Decisions made at lower levels of design – again drawing on the Hungarian experience – have given rise to many conflicts.

Compensation could be offered in cases where damaging nature areas is inevitable. Application of compensation in Hungary is regulated by a decree on Natura 2000. Practically, the decree adopts the „no net effect" principle of the EU's biodiversity strategy for the affected areas. Still, compensation is a highly disputed measure among ecologists and conservationists, as the criteria for inevitability of natural damage are not defined in an exact and transparent way. Western European examples show that compensation can easily become a simple economic consideration (i. e. it is „cheaper" to compensate for than to avoid damage), and this practice can in turn cause serious damage to nature. In the final analysis, compensation does not create new value, all it tries to do is to substitute - with more or less success - an existing value doomed to devastation. The main impediment of realizing the modern "dynamic" conservation paradigm is also closely connected to the institution of compensation: there are very limited space for the creation of sizeable and valuable new habitats, Hungarian land use suits no longer the natural dynamics of ecological processes.

**Conclusions**

We have to come to terms with the fact that major developments of transportation networks will necessarily affect negatively the natural environment to be protected. In most cases of a well-thought design, there are environmentally acceptable solutions, but even these are compromises at the best that result in only a moderate" degradation of the of habitats. Apart from gaining much more thorough scientific knowledge about the phenomena, the theoretical guidelines will have to be clarified in order to elaborate solutions that would keep damages done to the wildlife at a still tolerable level in the long run. The first step would be the clear and unambiguous articulation of different policies, and as concerns the professional fields themselves, coordination and cooperation should be heightened. Developing compromises, cooperation and dialog is declared and intended to be SEA's key responsibility. As concerns the policies, conservationists necessarily have to establish a realistic, an optimistic and a pessimistic vision about the transportation networks. These visions will have to determine those target states of damaged or endangered habitats similarly positioned by the transportation lines whose evolution is acceptable for conservationists. In current practice, it too often occurs that two significantly different propositions are worked out for the same issue, where the conditions are completely alike in both cases. Without setting target states and delineating the appropriate method to reach these, different and in many cases, ad-hoc solutions will continue to be given to current and future conflicts, depending on the knowledge and jurisdiction of the commissioned expert of exert group. This, as we have experienced many times, has already undermined the trust of designers in conservation experts.

In the field of transportation development, the lack of standalone and unified environmental policy could also be felt in the reviewed documents, as well as in the argumentation supporting the TOP.

This is well reflected in the wording of TOP: there are contradictory environmental and sustainability targets and unrealistic, and hence not too detailed commitments. Presenting by-pass roads as a progressive step „successfully" masks the fact that probably conservation areas are being damaged, while the amount of emitted pollutants and noise will even grow due to the increasing traffic and speed on that road – the only thing that will change is the location of the emission.

Transport infrastructure generates regional development, moreover, this is one of its major objectives. Regional development requires additional areas, often in the zone of newly built roads and railways. Facilities directly linked to transportation infrastructure are intrinsically inseparable from them, and amplify their negative effects on the environment. As at the level of EIA the permitting procedure of roads and that of other facilities are separated in time and in administrative process, this relationship has to be taken into consideration and their synergistic impacts has to be handled in SEAs. For the time being, this important objective is not being attained by the predominantly adopted approach of regarding SEA as one form of impact assessment.

Concluding, we can claim that SEA in its present form is yet a weak tool for conservation biodiversity. The study has revealed that theoretically, SEA offers many opportunities, while in practice only some of them have proven really effective. Consequently, it is imperative to improve its methodology and to widen its usability, and it should be integrated more efficiently in the whole implementation process of the transportation strategies in future.

**Acknowledgments:** The author thanks Katalin Gyertyán and Kornél Nádas (Hungarian Ministry of Economy and Transport) for their administrative support, Zsolt Szilvacsku (BirdLife Hungary Land Stewardship Advisory Service), Ágnes Mészárosné Kiss (Hungarian Institute of Transportation Science) for their advice and suggestions.

**Biographical Sketch:** Csaba Varga is a conservation consultant for BirdLife Hungary Land Stewarship Advisory Service and coordinator of projects including ecological impacts of transportation. He obtained M.Sc. in ecology in 1994, and he has been involved in environmental impact studies ever since. Csaba's current research focus include scaling issues of ecological impacts of transportation and implementation of adaptive management of roadside habitats.

## References

Trombulak, S. and Frissell, C.A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* Vol. 14: 18–30.

Sadler, B. and Verheem, R.1996, Strategic Environmental Assessment – status, challenges and future directions. Ministry of Housing, Spatial Planning and the Environment of the Netherlands, The Hague, The Netherlands.

## Bibliography

Byron, H. J., Treweek, J. R., Sheate, W. R., Thompson, S. 2000. Road developments in the UK: an analysis of Ecological Assessments in Environmental Impact Statements produced between 1993 and 1997.

Geneletti, D. 2003. Biodiversity Impact Assessment of roads: an approach based on ecosystem rarity. *Environmental Impact Assessment Review* Vol. 23: 343 -365.

Treweek, J. R., Hankard, P., Roy, D. B., Arnold, H. and Thompson, S. 1998. Scope for strategic ecological assessment of trunk-road development in England with respect to potential impacts on lowland heathland, the Dartford warbler (Sylvia undata) and the sand lizard (Lacerta agilis). *Journal of Environmental Management* Vol. 53: 147-163.

Sheate, W. R. 1995. Transport policy: a critical role for strategic environmental assessment. *World Transport Policy & Practice*, Vol. 1: 17-24.

Venturelli, R. C., Galli, A. 2006. Integrated indicators in environmental planning: Methodological considerations and applications. *Ecological Indicators* Vol. 6: 228–237.

Gyorsforgalmi úthálózat és a f?úthálózat kiemelt beruházásainak hosszú távú közúthálózat-fejlesztési programjának környezeti vizsgálata [Strategic Environmental Assessment of longer-scale development of motorway and highway network in Hungary]. 2005. Prepared by UVATERV Ltd. and KTI, Budapest.

Strategic Environmental Assessment for the Hungarian Transport Operative Program. 2006. Prepared by Respect Co.Hungarian Transport Operative Program. 2006. Ministry of Economy and Transport, Budapest.

A sustainable Europe for a better world: A European Union Strategy for Sustainable Development. 2001. Published by: Commission of the European Communities, Brussels.

European Directive 2001/42/EC “on the assessment of the effects of certain plans and programmes on the environment”. 2001. Published by: Commission of the European Communities, Brussels.

Europe’s biodiversity - biogeographical regions and seas. Published by: EEA (European Environment Agency). http://reports.eea.europa.eu/ [consulted in 07/10/2007]

Keep Europe moving - Sustainable mobility for our continent. Mid-term review of the European Commission’s 2001 Transport White Paper. 2006. Published by: Commission of the European Communities, Brussels.

Paving the way for EU enlargement. Indicators of transport and environment integration. TERM 2002, Environmental issue report. Published by EEA 2002. Copenhagen. http://reports.eea.europa.eu/ [consulted in 04/18/2007]

Progress towards halting the loss of biodiversity by 2010. EEA Report, No 5/2006. Published by EEA. 2006. Copenhagen. http://reports.eea.europa.eu/ [consulted in 04/20/2007]

The SEA manual. A sourcebook on strategic environmental assessment of transport infrastructure plans and programmes. 2005. Published by European Commission, DG TREN, Brussels.

White paper. European transport policy for 2010: time to decide. 2001. Published by: Commission of the European Communities, Brussels.

# Patch Occupancy Models and Black Bear Management in the Southeastern Coastal Plain: A Potential Tool?

**Jay E. Clark** (931-308-7570, jayclarkmusic@bellsouth.net), Department of Forestry, Wildlife and Fisheries, University of Tennessee, Knoxville, TN 37996 USA
**Frank T. van Manen**, U.S. Geological Survey, Southern Appalachian Field Branch, Knoxville, TN 37996 USA
**Joseph D. Clark**, U.S. Geological Survey, Southern Appalachian Field Branch, Knoxville, TN 37996 USA

## Abstract

Habitat fragmentation in the southeastern Coastal Plain is widely regarded as a central issue in the management of black bear (*Ursus americanus*) populations. Further habitat loss and fragmentation, and increases in human density, may influence the persistence of black bears throughout this region. Therefore, tools to evaluate these impacts are needed to encourage and allow for an integrated, regional-scale approach to management. Stochastic patch occupancy models (SPOMs) represent a group of metapopulation models that are based only on the occupancy status and size and distribution (i.e., connectivity) of habitat patches. Application of such models may provide wildlife managers and landscape planners with useful tools to evaluate the potential impacts of future land-use changes (e.g., construction of new highways) on the persistence of wildlife populations at a regional scale and to determine how those impacts may be mitigated (e.g., establishing corridors). We developed a SPOM for the area encompassing the entire range of the Florida black bear (*U. a. floridanus*) and applied the model to quantify colonization and extinction rates of habitat patches across the network. We adjusted interpatch distances using least-cost distance analyses to account for characteristics of the landscape (i.e., roads and land-cover types) and their potential effects on dispersal among patches. The best-fitting model incorporated effects of land-cover type and roads, including type of road. Using the parameter estimates of the best model, we performed a 25-year simulation of patch incidence to assess the potential for natural recolonization of unoccupied patches and to identify patches that may become extinct over the 25-year period. The simulation predicted only limited population expansion but also predicted low potential for extinction, thus occupancy patterns exhibited high stability. To demonstrate the potential utility of our model to managers and landscape planners, we applied our models to hypothetical management scenarios. We demonstrated how our model could be used to guide restoration efforts by identifying those patches within an assemblage that, if restocked, would maximize recolonization potential for surrounding patches. We also demonstrated how our model could be used to assess impacts on connectivity among existing bear populations resulting from changes in landscape structure and composition (e.g., highway upgrades). Additionally, we applied the parameter estimates of the best model, tested the validity of its application, and performed simulations for the area encompassing the entire range of the federally threatened Louisiana black bear (*U. a. luteolus*) and populations of the American black bear (*U. a. americanus*) in Arkansas. Although SPOMs may prove to be a valuable tool for regional-scale management of black bears in the southeastern Coastal Plain, we caution that the methodology used to develop our model has not been attempted for large carnivores and the reliability of our predictions has not been thoroughly tested. Thus, we emphasize that our model should be used in conjunction with other available information and not provide the sole basis for making management decisions.

# The Use of Habitat Suitability Indices (HSIs) for Evaluating Impacts to, and Assessing Mitigation for, Terrestrial Wildlife Habitat for Transportation Projects

**Rick Black** (801-743-7831, rick.black@hdrinc.com), Senior Environmental Scientist, HDR Engineering, Inc., 3995 South 700 East, Suite 100, Salt Lake City, UT 84107, Fax: 801-743-7878 USA

**Abstract**

Habitat Suitability Indices were used to evaluate terrestrial wildlife habitat impacts for a newly proposed 35-mile highway that runs through five different habitat types.

Typically for transportation projects, detailed impact analysis of terrestrial wildlife is limited to federally listed Threatened and Endangered species, or even State sensitive species. Terrestrial wildlife habitats are usually addressed by acreage of impacts, at best, but often only qualitatively. The quality of the habitat or the importance of the habitat is often not addressed. However, if mitigation is required for the identified impacts to these habitats, it is often difficult to quantify appropriate mitigation measures for ambiguous impacts.

For the Mountain View Corridor EIS, Habitat Suitability Indices (HSIs) were used to help quantify and qualify the terrestrial wildlife habitat the proposed 35-mile highway might impact. Utah State Division of Wildlife Resource Agency personnel and United States Fish and Wildlife Agency personnel were consulted with at the onset of the analysis to properly identify analytical methods. Together with environmental scientists, habitat types and species to represent these habitat types were identified and agreed upon.

The model provided a quick and efficient means of data collection, leading to an index of wildlife habitat quality within the project corridor. Output results were then used by the NEPA team (including agency personnel) to help shape alternatives and select alternatives to be carried through the NEPA analysis process.

If through the NEPA process, mitigation for non-federally-listed terrestrial wildlife habitat is proposed or required, this model will help establish the proper mitigation for the impacts.

# Using Tools to Support Decision-Making for Multiple Benefits in Transportation and Conservation

**Shara Howie** (703-797-4811, shara_howie@natureserve.org), Sector Relations Manager, NatureServe, 4001 Discovery Drive, Suite 2110, Boulder, CO 80303 USA
**Kimberly Majerus** (708-283-4346, kimberly.majerus@dot.gov), Natural Resource and GIS Analyst, FHWA-Resource Center, 19900 Governors Drive, #301, Olympia Fields, IL 60461 USA
**Shari Schaftlein** (202-366-5570, shari.schaftlein@dot.gov), Team Leader, FHWA Project Development and Environmental Review Office, Washington, DC USA

**Abstract:** One of the challenges faced by transportation and environmental practitioners is to keep pace with policy and technology advancements and capitalize upon new tools and methods as they become available. Several existing efforts and new initiatives are underway to improve practices in the use of tools within transportation program delivery. For example, the FHWA Headquarters Project Development and Environmental Review Office, FHWA Division Offices, state departments of transportation, NatureServe, and Defenders of Wildlife hosted workshops in Arizona, Arkansas, and Colorado to bring together transportation and environmental practitioners to discuss ways to link efforts for conservation and transportation planning. One result from the workshops is an expanded awareness of available information, data, and tools that can support the integration of conservation and transportation efforts and transportation program and project delivery. Another result from the workshops is evidence of the importance of face-to-face interactions between professionals in transportation and environmental and resource agencies. This paper includes a discussion of the approaches used in the workshops and successes and lessons learned. Several other existing efforts and new advancements that are moving forward to expand the use of data and tools in transportation decision-making are also discussed. The purpose of this paper is to highlight examples of specific types of expertise, data, and tools that can immediately be used to assist transportation and environmental practitioners achieve their goals and meet their requirements.

## Introduction

Transportation programs and projects include many environmental responsibilities. It is an on-going challenge to harmonize long-standing federal, state, and local requirements with emerging requirements and best available science and technology. During the past years, several Congressional Directives, FHWA initiatives, and Presidential Executive Orders have emerged to support environmental efforts and improve timely delivery of transportation projects. Examples include: Eco-Logical: An Ecosystem Approach to Infrastructure, Environmental Streamlining and Stewardship, Context Sensitive Solutions, and Planning and Environment Linkages. Various other complimentary initiatives are underway at the federal, state, and local levels, for example, Cooperative Conservation and watershed management. Transportation legislation, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), includes changes in environmental review processes at both the long-range transportation planning and project levels (SAFETEA-LU 2005).

As background material for this paper, the following summary highlights some of the content for SAFETEA-LU and the Code of Federal Regulations (CFR 2007) for long-range transportation planning and the content of the plan as:

- Develop the long-range statewide transportation plan, as appropriate, in consultation with State, tribal, and local agencies responsible for land use management, natural resources, environmental protection, conservation, and historic preservation
- Include a discussion of potential environmental mitigation activities (at the policy and/or strategic-levels). *[23 CFR 450.214(j) and 450.322(f)(7)]*, developed in consultation with Federal, State and Tribal wildlife, land management, and regulatory agencies
- Compare transportation plans to State/Tribal conservation plans or maps, and to inventories of natural or historic resources, if available *[23 CFR 450.214(i)]*
- Fulfill the long-range planning factor to: “protect and enhance the environment, promote energy conservation and improve quality of life” expanded to also include “promote consistency between transportation improvements and State and local planned growth and economic development patterns” *[23 CFR 450.206 and 450.306]*

Several benefits arise from meeting these requirements and improving practices for the use of information and tools to support transportation decision-making. Throughout all stages of transportation program delivery, transportation and environmental practitioners are benefiting from interdisciplinary approaches to decision-making that support transportation activities as well as environmental goals. These integrated approaches provide benefits for:

- Compliance with existing and new requirements
- Better outcomes and results
- Avoidance of late-process surprises and engineering re-work
- Better interaction between environmental and transportation offices
- Facilitation of multi-purpose goals
- Improved mitigation and demonstration of sequencing *(avoid, minimize, compensate for unavoidable impacts)*

- Larger scale mitigation strategies developed in advance of projects
- Reduced duplication of efforts, including information and data sets
- Fewer delays in environmental reviews to support streamlining of efforts
- Reduced costs

These benefits can be accomplished through improved practices in the use of information, expertise, and tools to integrate environmental information and expertise more fully into transportation program delivery.

## Expertise, Data and Tools

Many sources of expertise, data, and tools can be utilized to support existing and new efforts for transportation. The Transportation Research Board (TRB) suggests that in order to meet environmental requirements, transportation and natural resource agencies will have to rely on advanced geospatial tools and a more collaborative approach to all transportation activities (Transportation Research Board 2006). Computer tools, GIS, and maps are particularly powerful tools for facilitating integration of information, people, and decision-making for planning and projects.

### Expertise

Transportation decision-making relies upon various experts working together. Transportation and environmental expertise is available at the national, Tribal, state, and local levels within both the public and private sectors. An ongoing challenge is to identify the expertise that is needed and use interdisciplinary approaches to coordinate expertise into the decision-making process.

Including expertise in the selection and use of information and data helps ensure the credibility of the decision-making process and the outcomes. In fact, with the Internet providing a conduit for vast quantities of unfiltered information, the need for knowledgeable people to select what information is credible and to make the best use of this information will continue to increase. The assistance of transportation and environmental experts can help define information needs as well as information sources.

Using appropriate experts for interpretation and analysis of data can be critical for ensuring successful planning and project outcomes. For example, a coordinated examination of the methods used to assess the sensitivity of an ecological feature could reveal that the potential for an adverse impact is much lower than originally thought and options to avoid an adverse impact become available. Interdisciplinary approaches can help clarify how to develop and deliver information with the most useful content and format to be shared with the diversity of individuals involved in all aspects of transportation decision-making. Agreements on methods for analyzing data in planning will aid in downstream agreements on methods to be used in NEPA and project delivery and to meet the requirements of SAFETEA-LU Section 6002, Environmental Process Provisions.

Some information is most usable in computer format as data. Some information is most useful in other formats such as hardcopy maps or reports or photographs. Several types of analyses, maps, inventories, surveys, aerial photographs, plans, and reports exist and are available. The following section focuses on examples of environmental data that have been identified as useful for transportation practitioners and their responsibilities.

### Data and Methods

Although many sources of data exist, it is essential that data is selected and used based on how well the data matches information needs within the decision process. It is important to include the proper expertise in data selection and use. Some data can be useful at a broad-brush scale for some screening and scoping decisions, while other data needs to be at a finer scale for use in detailed design tasks. The scale, quality, and credibility of data are important so that data can be used effectively by the experts participating in the planning and decision-making processes.

Prior to developing new environmental data, a worthwhile step is to conduct a review of already existing data. There are some excellent sources of environmental data that are directly relevant to the needs of transportation and environmental practitioners. The following sections describe examples of sources for environmental data and uses of the data.

In some cases, environmental practitioners and the staff of transportation agencies and their consultants have already compiled environmental data from various existing data sources (such as environmental agencies) and they can also be “data producers.” In other cases, coordination with environmental agencies and organizations reveals other available data sources and “data producers.” Examples of coordinated efforts to develop and share data as well as the use of data “clearinghouses” are highlighted in later sections of this paper.

Data and inventories on threatened and endangered species, ecological resources, and environmentally sensitive areas are available and in use to support transportation responsibilities at the project level. The data includes information about the species and habitats that exist in a region, their condition or conservation status, the location of sensitive or other important features, and how these resources are likely to be affected by proposed activities. This type of data exists in every state in the state natural heritage programs and in a centralized national database managed by NatureServe, a conservation non-profit organization that provides coordination for the network of state natural heritage programs. For more than 30 years, NatureServe has worked in partnership with its international network of member programs (known in the U.S. as state natural heritage programs) toward its joint mission of collecting, managing, and applying data on rare and endangered species, and threatened ecosystems. NatureServe provides national coordination and technical support for the development and use of scientifically-based standards, data and tools that are used by the member programs and integrates these data into a national view. The data is updated continually and is accessible to federal and state agencies, as well as private and non-governmental organizations and the public.

The state natural heritage programs locally collect, analyze and distribute their data, and provide local expertise to local, state, and region-wide efforts. Today, the data housed at NatureServe's central database along with data aggregated from the individual state natural heritage programs' databases collectively is the most comprehensive, standardized inventory on at-risk species and ecosystems that exists for North America. Transportation offices in many states are benefiting from the use of this data and expertise. The state natural heritage programs function by carrying out field inventories, collaborating with federal and state agencies, and others to collect data in the state, and manage their data according to consistent national standards. They serve as a 'clearinghouse' of data on plants, animals and ecological communities that are legally protected, or otherwise of conservation concern. Since the mission of NatureServe and its member programs is to maintain and expand this database over time, inventories and results of studies done across the state can be integrated into their data management system, and therefore be easily utilized by all.

A keystone of the natural heritage data includes the conservation rank. Using expert methodology, each species and ecological community is assigned a conservation rank that reflects its rarity at a global, national, and state scale. For example, if a species was ranked G1 after evaluating all defined factors, it would indicate that the species is critically imperiled across its entire range (i.e., globally). For species, the factors that are considered in assessing conservation status include:

- total number and condition of occurrences (e.g., populations)
- population size
- range extent and area of occupancy
- short- and long-term trends in the above factors
- scope, severity, and immediacy of threats
- number of protected and managed occurrences
- intrinsic vulnerability
- environmental specificity

This standardized method of ranking species has been developed in collaboration with many conservation organizations including the International Union for the Conservation of Nature (IUCN) Species Survival Commission (http://www.iucnredlist.org). The conservation status ranks for species and ecological communities are utilized by many federal agencies as a tool to prioritize conservation activities and assist in identifying actions that could prevent at-risk species from becoming listed for protection under the Endangered Species Act. In fact, a majority of the methodologies developed and utilized by NatureServe and its member programs is created in close collaboration with other partners including federal and state agencies, and other conservation organizations.

The following summary describes ways to access online data developed by NatureServe and its network of member programs.

- Access to generalized data for species and ecological data across North America is available on NatureServe Explorer (www.natureserve.org/explorer). Precise species locations are also available by contacting NatureServe directly. NatureServe is in the process of rolling out newly developed web services that will provide on-line access to more precise species and ecological data at a national scale.
- An increasing number of natural heritage programs are developing analytical products that map out environmentally sensitive areas, and provide other web-based conservation services such as environmental review tools. Access to local web portals for individual natural heritage programs is available at: (http://www.natureserve.org/visitLocal/index.jsp).

Activities for federal, state, and regional conservation plans have been a particular focus in recent years. These plans can be used to provide important environmental and ecological data and an ecological context for the transportation community. A few types of plans and efforts are summarized below.

The Endangered Species Act directs the U.S. Fish and Wildlife Service (USFWS), Department of Interior; and the National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA) to develop and implement recovery plans to promote the recovery and conservation of threatened and endangered species. These agencies support several other efforts as well. These recovery plans are available from the USFWS at: http://www.fws.gov/endangered/recovery/index.html and the NMFS at: http://www.nmfs.noaa.gov/pr/recovery. The goal of the Endangered Species Act is the recovery of listed species to levels where protection under the Act is no longer necessary.

Another important effort has been The Nature Conservancy's work to identify and map priority biodiversity areas within each ecoregion of the country. These "ecoregional plans" summarize conservation priorities, and include information on both plants and animals that are legally protected or are of conservation concern (http://www.nature.org/tncscience/). Still another regional planning approach focuses on what is variously termed green space, open space, or green infrastructure. A strategy, plan, or map for high priority areas for environmental values and conservation is developed as a "greenprint." Approaches to greenprints often focus on connecting existing green space and environmental and habitat areas together with new locations by identifying potential locations for connections and including these in the greenprint and strategy. Greenprints can extend across a geographic area of any size. A statewide example is Maryland (www.dnr.state.md.us/greenways/greenprint/). An example that includes multiple states is the U.S. Environmental Protection Agency's Southeastern Ecological Framework (http://www.geoplan.ufl.edu/epa/). At the state level, each state has completed a State Wildlife Action Plan (http://www.wildlifeactionplans.org/). All of these plans identify species in need of special attention, and many include maps of priority habitats or areas for wildlife conservation, and can help chart the course for wildlife conservation at local, state, and national levels.

In addition to environmental information and plans, a variety of other data sources exist in online data clearinghouses at the national, regional, state, and local levels. Environmental agencies are commonly data producers and data sources for environmental data. Geo-spatial datasets for transportation, infrastructure, and environmental topics can be accessed through the National Spatial Data Infrastructure (NSDI). This is a nationwide GIS data clearinghouse of free, downloadable data from federal, state, and local sources at: www.geodata.gov.

Links to other examples of state-based sources of information and data can be found through Defenders of Wildlife's Biodiversity Partners website (www.biodiversitypartners.org). Many other online data clearinghouses and data sets are available. The U.S. Geological Survey provides several types of data and also sponsors the National Biological Information Infrastructure (www.nbii.gov).

This paper illustrates that several existing sources of information and data are available to transportation and environmental practitioners. Proper use of environmental data can be highly beneficial to support the integration of the information and people that are part of the transportation decision process. Using data in combination with software tools can be powerful since it can support the use of available data and provide a framework to guide the decision-making process. The discussion below summarizes how demonstrations of computer tools were included in the workshop setting as a way to show tools in action and facilitate discussion about how to use tools to support transportation decision-making. The discussion also highlights several topics and insights about advancements in tools and their use.

**Tools**

A variety of tools, some generic and some custom-built, are now available to transportation agencies. These tools make environmental and ecological data, analyses, and expertise more accessible than ever before. Expertise is needed to effectively define the need for tools and select tools that best match processes and decisions.

Several important concepts emerge in considering how technology can enable the integration of environmental and natural resource information and data into transportation planning and project delivery processes and vice versa. Transparency and accountability are keys for information and analyses to be credible and to stand-up to legal and political scrutiny. Such transparency can be supported by the use of analytical tools and can thereby assist in facilitating trust between a diversity of participants involved in an interdisciplinary process. In contrast, "black box" approaches to using computer tools can sometimes trigger mistrust between participants.

Because planning and project delivery involves a balance among multiple values, use of analytical tools should be based on clearly defined assumptions and values. A whole class of optimization techniques that are embodied in tools are becoming available to vastly improve the efficiency of evaluating various 'what-if' scenarios, and help practitioners decide among them. Using an iterative process for using tools and identifying alternative scenarios for meeting multiple goals has been found to be worthwhile. Examples of tools and their uses are provided below.

NatureServe Vista is an example of a decision-support tool specifically designed to help to integrate various types of data, and conduct evaluations of planning and project delivery scenarios (www.natureserve.org/prodServices/vista/overview.jsp). This GIS-based software supports the creation and use of maps of environmental, infrastructure, socio-economic, biological and non-biological features in a selected area of interest. Maps can be used individually or combined within GIS analyses. Based on the distribution and characteristics of mapped features, a "value map" can be generated from GIS analyses depicting areas of greater and lesser importance or sensitivity.

An option within the tool allows the selection and assignment of different scores and weights for features within maps that can be used in calculations using GIS analyses. An example of a credible and scientifically based environmental scoring system was previously described as the conservation ranking system. These options and tools assist with decision-making for particular interests, requirements, or priorities, and with integrating these together to support multipurpose goals. Use of tools and maps can be focused on an individual feature or resource such as a legally protected species or can be expanded to integrate with any other features that can be mapped such as streams, wildlife areas, wetlands, historic resources, and socio-economic factors.

The map outputs can show high priority locations for conservation. Areas that are considered irreplaceable can also be shown. Early awareness of these priorities can support the selection of the best locations to serve the purposes of development and conservation. Maps can also be used to help accomplish mitigation to avoid adverse impacts to priority areas and avoid high compensatory mitigation costs.

In addition, NatureServe Vista supports an iterative decision-making process because many different scenarios can be analyzed and compared by using the tool. Evaluation of scenario results can help inform planning and project level decisions. The system also supports an open, transparent decision-making process with tools that can be used to document and report on the assumptions made at every decision point. Figure 1 below illustrates the type of results produced after running a specific scenario using NatureServe Vista to support analyses and decision-making toward defined goals.

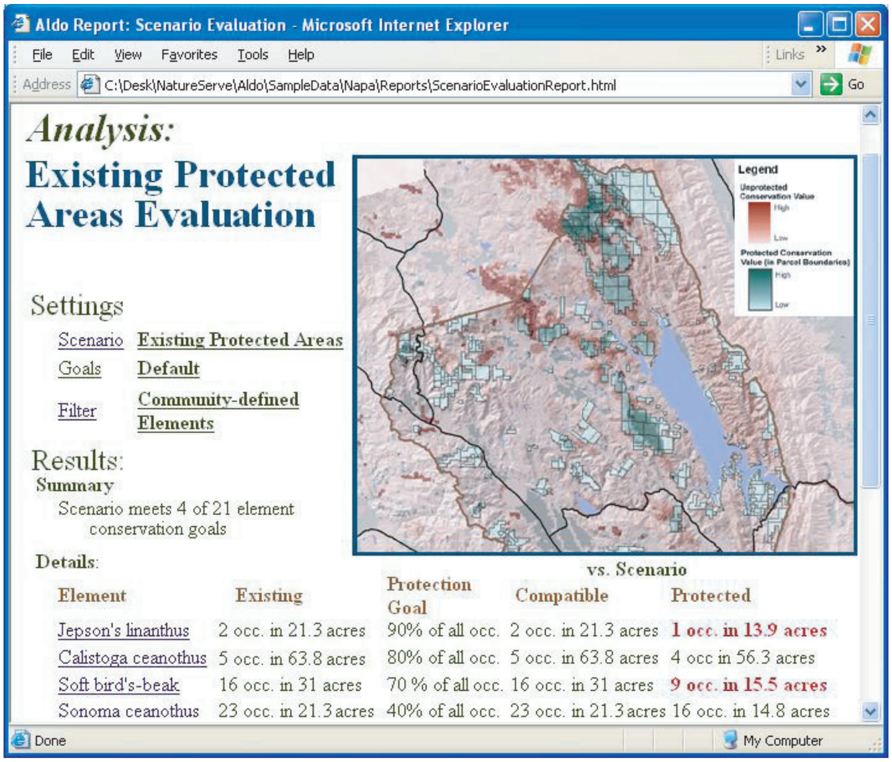



Figure 1. Results from NatureServe Vista Scenario Evaluation Analysis. (Source: Comer 2006)

The map output in figure 1 and various types of alternative scenarios that generated map outputs using NatureServe Vista were demonstrated and discussed in the workshop setting. Workshop demonstrations also showed how data outputs from one tool can be used as inputs to other tools as a “toolbox approach.” A toolbox approach matches data and tools to individual needs and also supports interdisciplinary approaches. Computer advancements have pursued a toolbox approach so that decision support systems can support multiple goals for environmental and infrastructure and mission priorities (Goran et al. 1999, Majerus and Rewerts 1994, Sydelko and Majerus 1999).

One of the purposes of the workshop was to demonstrate a “toolbox” approach by using several example tools including NatureServe Vista, CommunityViz (www.communityviz.com/), and Quantm (http://www.quantm.net/). Demonstrations of a toolbox approach highlighted that CommunityViz is a GIS-based tool that provides a means to visualize analyses of land use alternatives and understand their potential impacts from environmental, economic, and social perspectives. Through the use of 3-D simulation, scenarios can be visualized from different angles. This feature supports decision-processes and enables citizen participation in planning processes. Quantm is a planning system for corridor and route Optimization. Quantm addresses complex route planning issues, transportation route alignment options, and consideration of alternatives. The workshop demonstrations showed that it is possible to utilize results from NatureServe Vista, Quantm and CommunityViz as data flows between tools. This approach leverages the uniqueness of data outputs generated from each tool to support evaluations of alternative land use and transportation scenarios. A toolbox approach maximizes flexibility in the use of tools by offering options to support decision-making for particular interests, requirements, or priorities as well as interdisciplinary approaches to balancing multi-purpose goals.

Other example tools were researched and discussed as part of the workshops. Details are summarized in the ‘other tools’ presentations and handouts for Day 2 for each state’s workshop at: http://www.defenders.org/habitat/highways/workshops/home.html. Case studies illustrating other successes in the use of GIS tools are documented in the Transportation Research Board’s Circular on ‘Environmental GeoSpatial Information for Transportation’ (Transportation Research Board, 2006).

The use of computer tools and GIS continues to advance at the national, state, and local levels. The following section offers a few examples of state natural heritage programs working with transportation agencies to support state, regional, and local planning and project efforts:

1. **Colorado**

    a. The Colorado Department of Transportation (DOT) partnered with The Nature Conservancy, U.S. Fish and Wildlife Service, Colorado Division of Wildlife (CDOW), and the Colorado Natural Heritage Program on a range-wide impact analysis on short-grass prairie. Impact analysis utilized the Gap Analysis Project (GAP) vegetation layer, predictive habitat layer (source: CDOW), nesting sites, and element occurrences. Breeding bird atlas data and expert opinion were utilized to develop 'presumed presence' maps of federally listed and potentially federally listed species. These maps were used to determine areas of impact or potential impact based on proposed transportation routes and plans. For unavoidable adverse impacts, the maps were the basis of developing recommendations for habitat areas as compensatory mitigation. Colorado DOT worked with the U.S. Fish and Wildlife Service on the mitigation effort, and the Conservancy helped purchase or conserve these lands through easements. See figure 2 below for an illustration of the type of analysis done for the shortgrass prairie in Colorado.

    b. Pikes Peak Council of Governments is working with the Colorado Natural Heritage Program and others on the use of the NatureServe Vista decision support tool to assist in transportation planning activities with a focus on two counties in Colorado.
2. **Nevada** – Nevada Natural Heritage Program supplies Nevada DOT with sensitive species data for all DOT projects and efforts, such as gravel pit operations, bridge widening, and new construction. Turn around time in answering Nevada DOT requests is usually hours. In exchange, Nevada DOT provides funding to the Nevada Natural Heritage Program.
3. **Virginia** – Virginia DOT has a cooperative agreement with the Virginia Natural Heritage Program for the sharing and use of natural heritage data. In addition, the Virginia Natural Heritage Program staff works with Virginia DOT staff to address the effects of storm water runoff, sinkhole filling and collapse, surveys along roads to assist in protection efforts, and habitat fragmentation and management of habitat corridors.

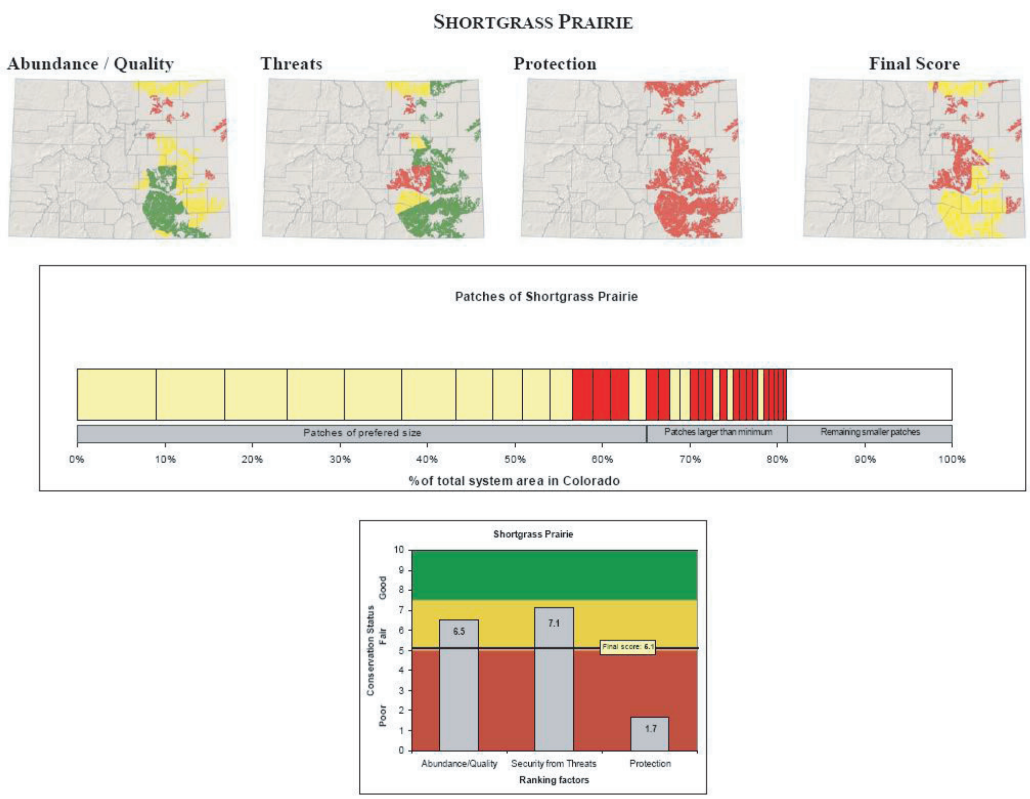



Figure 2. Analysis for shortgrass prairie in Colorado. (Source: Rondeau 2007)

One example of efforts underway by FHWA is the Planning and Environment Linkages (PEL) initiative. The PEL initiative represents an approach to transportation decision-making that considers environmental, community, and economic goals during the long-range transportation planning stage and carries them through to project implementation. An FHWA website offers a summary of PEL as well as links to information, case studies, and research findings available at: http://www.environment.fhwa.dot.gov/integ/index.asp.

## Conclusions/Next Steps

Expertise and data and tools are readily available and can immediately assist transportation and environmental practitioners meet their requirements and accomplish multiple goals. Interdisciplinary approaches are highly beneficial to supporting both existing practices and advancements underway for the use of tools in transportation decision-making. Transportation practitioners are already experiencing the benefits of integrating environmental information and expertise into long-range transportation planning and project delivery. Benefits include: 1) improved planning and project decisions and outcomes; 2) more effective environmental mitigation; 3) selection of sites for compensatory mitigation in advance before they are converted to other purposes or before land costs increase; 4) improved processes for environmental approvals and permits; and 6) savings in cost and time.

To achieve these benefits, some recommended next steps to both support and improve decision-making include:

- Initiate workshops and coordination between transportation and environmental and conservation practitioners to move forward to support an informed process for defining collective goals and outcomes in planning, project development, design, construction, operations, and maintenance.
- Identify and implement a process for tracking identified environmental and conservation priorities and commitments and ensuring the priorities are taken into account at all levels of transportation decision-making.
- Demonstrate and promote successes in interdisciplinary and collaborative processes and projects, and in use of data and tools.
- Work with local, state, and federal agencies and conservation organizations toward identification and development and use of key environmental and biological datasets needed to inform transportation planning and project delivery.
- Develop guidance on how to coordinate with local agencies and organizations to develop and supply standardized data on endangered and imperiled natural resources in order to compile best available data.
- Initiate effort to develop toolkits and question and answer (Q&A) summaries on how to meet SAFETEA-LU provisions for long-range transportation planning.
- Encourage and pursue efforts to integrate transportation and conservation planning. (For example, conduct annual statewide interdisciplinary planning meetings.)
- Develop or refine standards and methods for sharing of data to support long-range planning processes and implementation of projects.
- Evaluate the need for tools, and apply the use of tools to both support and document transportation decision-making processes.
- Promote and implement the multi-agency initiative for 'Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects' (Eco-Logical 2006) within planning and project delivery.
- Participate in the FHWA *Eco-Logical* grant solicitation available at: http://www.environment.fhwa.dot.gov/eco-logical/eco_index.asp. Supported by FHWA with seed funding to implement Eco-Logical efforts at the planning and project levels.

**Biographical Sketches:**

Shara Howie is currently a Sector Relations Manager for NatureServe's Conservation Services Division and works out of the Western Regional Office of NatureServe located in Boulder, Colorado. Shara has over 12 years of experience supporting the development and maintenance of conservation data and data management systems. Shara has years of experience as a project manager supplying U.S. and Canadian federal agencies and other organizations with conservation data, analyses and other conservation services in collaboration with NatureServe's international network of member programs (Natural Heritage Programs). Shara is currently working on projects with Parks Canada, the Canadian Wildlife Service, Federal Highway Administration, the National Park Service, and The Nature Conservancy. In the past, Shara worked extensively with the Department of Defense, USEPA and other federal agencies, and she specializes in the facilitation of data sharing between organizations. Before joining NatureServe in 2001, Shara worked for The Nature Conservancy's Science Division for 10 years and the Smithsonian's Botany Department for 3 years. Shara has a Bachelor's Degree in Biology from George Mason University.

Kimberly Majerus is a natural resource and GIS analyst with the FHWA-Resource Center near Chicago, Illinois. She partners with FHWA Divisions and HQ to deliver technical assistance and customized sessions to support transportation state and environmental offices nationwide. A 20 year career includes the Illinois Department of Transportation and Corps of Engineers and University of Illinois as project manager, environmental unit head, and GIS lab coordinator as well as President of the Illinois Environmental Council (IEC), not-for-profit organization. Kimberly's experience includes 10 years of participation in nationwide, multi-agency programs and projects toward integrated efforts and decision support systems for multi-purpose goals and benefits. B.S. and M.S. degrees earned at University of Illinois at Urbana-Champaign.

Shari Schaftlein has been the Team Lead for Program/Policy Development in FHWA's Project Development and Environmental Review Office in Washington, D.C. for the past 3 ½ years. Activities that she champions include: the Context Sensitive Solutions (CSS) Program, the Center for Environmental Excellence, the National Liaisons, the Executive Order on Streamlining and Stewardship, SAFETEA-LU Rollout, the Green Highways Partnership, and Linking Planning and NEPA. She serves as the FHWA representative on the NCHRP 25-25 Panel on AASHTO Standing Committee on Environment (SCOE) Quick Response Research and is a Member of Transportation Research Board (TRB) ADC10-Environmental Analysis Committee. Prior to FHWA, she worked in the Washington State Department of Transportation, Environmental Office for 11 years, where she held the positions of Water Quality Program Manager, Streamlining Initiatives Manager, and Deputy Director. She has also held environmental management positions with the West Michigan Environmental Action Council in Grand Rapids, and the Quileute Tribe in La Push, WA. Degrees include a B.S. and M.S. in Environmental Science from Indiana University.

## References


Code of Federal Regulations (CFR) 2007. Title 23: Highways. Available at: http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?&c=ecfr&tpl=/ecfrbrowse/Title23/23tab_02.tpl

Comer, Pat, Ph.D. 2006. Approaches to Biodiversity Conservation Planning. Presented at Arizona Linking Transportation and Conservation Planning Workshop, slide 24. Available at: http://www.defenders.org/habitat/highways/workshops/az/presentationsday1/approaches-to-biodiversity-conservation-planning.pdf

Eco-Logical 2006. Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects. Multi-agency initiative and guide. DOT-VNTSC-FHWA-0601. FHWA-HEP-06-011. 83 pages. Available at: http://www.environment.fhwa.dot.gov/ecological/eco_index.asp

Goran, William D. and Jeffery P. Holland, John W. Barko, and Andrew J. Bruzewicz .1999. Plans for the Land Management System (LMS) Initiative. ERDC/CERL Technical Report 99/60. 75 pages

Majerus, Kimberly A. and Chris C. Rewerts. 1994. PRISM Decision Support System for Integrated Natural and Cultural Resource Management at Fort Polk, Louisiana. In proceedings: GRASS GIS User's Conference. Work sponsored by Legacy Resource Management Program

Rondeau, Renee. 2007. Scorecard for Matrix Ecological Systems in Colorado. Presented to Colorado Department of Transportation in follow-up meeting to Colorado Linking Transportation and Conservation Planning Workshop (August 2006). Available at: https://transfer.natureserve.org/download/longterm/Measures-Scorecards/

Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) 2005. Links to information on SAFETEA-LU Sections 6001 and 6002: http://www.environment.fhwa.dot.gov/integ/related.asp

Sydelko, Pamela J. and Kimberly A. Majerus, Jayne E. Dolph, & Tom N. Taxon. 1999. A Dynamic Object-Oriented Architecture Approach to Ecosystem Modeling and Simulation. In Proceedings of the 1999 American Society of Photogrammerty and Remote Sensing (ASPRS) Annual Conference. pages 410-421. Work sponsored by Strategic Environmental Research and Development Program (SERDP)

Transportation Research Board (TRB) 2006. TRB of The National Academies. Environmental Geospatial Information for Transportation. Transportation Research Circular, Number E-C106, November 2006. Available at: http://onlinepubs.trb.org/onlinepubs/circulars/ec106.pdf

State Connectivity Examples

## Arizona's Wildlife Linkages Assessment

**Bruce Eilerts** (602-712-7398, beilerts@azdot.gov), Section Chief/Planning Program Manager, and
**Siobhan Nordhaugen** (602-712-6166, snordhaugen@azdot.gov), GIS/Special Projects Consultant,
Arizona DOT, 206 South 17th Avenue, Mail Drop 043R, Phoenix, AZ 85034, Fax: 602-712-3492
USA

**Abstract**

With the release of the Arizona's Wildlife Linkages Assessment, November 2006, the Arizona Wildlife Linkages Workgroup is working to integrate and incorporate wildlife concerns and habitat connectivity needs into the forefront of transportation and regional planning processes to address habitat fragmentation due to highways and other human development.

Arizona, ranking third nationally for biodiversity, is home to nearly 900 vertebrate wildlife species. The phenomenal growth of Arizona's human population, economy and infrastructure present challenges to the maintenance of natural ecosystems and wildlife populations that constitute an important part of the State's wealth. In particular, roads, urbanization, canals, railways, energy corridors and activities of illegal migrants and border security operations not only destroy habitat, but create barriers that isolate wildlife populations and disrupt ecological functions such as gene flow, predator-prey interactions, and migration. Addressing each of these potential barriers one-at-a-time is expensive and inefficient. In each landscape, we must address all these factors concurrently to successfully maintain or restore linkages between habitats and conserve the wildlife and natural ecosystems that Arizona's residents and visitors rely on and benefit from.

Road kill has become a common sight along many Arizona roadways - conspicuous evidence of habitat fragmentation. The results of these often-fatal encounters have far-reaching effects. Wildlife-vehicle collisions cause human deaths and injuries, millions of dollars in property damage, loss of game and non-game animals, and sometimes expose the State to liability. Working together, federal, state, county and private stakeholders can minimize these social costs while enhancing opportunities for movement of wildlife between Arizona's habitat areas.

The Arizona Wildlife Linkages Workgroup (AWLW) is a collaborative effort formed by the Arizona Department of Transportation, Arizona Game and Fish Department, Bureau of Land Management, Federal Highway Administration, Northern Arizona University, Sky Island Alliance, USDA Forest Service, U.S. Fish and Wildlife Service and the Wildlands Project to address habitat fragmentation through a cohesive, systematic approach. Through this partnership and commitment, a series of successful statewide workshops were conducted in order to facilitate "buy-in" to the process and gather information from local experts to identify: 1) large blocks of protected habitat; 2) wildlife movement corridors (potential linkage zones) between as well as through them; and 3) factors threatening to disrupt such linkage zones.

In November 2006, after several years of refinement, the AWLW has produced the Arizona's Wildlife Linkages Assessment along with a map to graphically display the areas of concern. AWLW expanded upon the original workshop information and has worked to further define existing conditions, record biotic communities, list species that depend on particular linkages, identify land ownership within those linkages, and detail anticipated in addition to known threats. Currently, more than 150 potential linkage zones have been identified throughout Arizona.

The potential linkage zones were prioritized based on biological importance and the existing, as well as anticipated, threats and opportunities for preservation and/or restoration. This prioritization was used to identify several key linkages for additional analysis and development of site-specific linkage designs. In most cases, only a fraction of the land in a potential linkage zone will need to be conserved. To date, eight have been completed. Each linkage design includes a map of critical land to be conserved, recommendations for structures to facilitate wildlife crossing of roads, railroads, canals, and other human caused barriers, and management recommendations for multiple-use landscapes.

Even prior to official release, statewide planners have been utilizing this Assessment for projects including bond initiative development, regional growth concerns and transportation project development. The Assessment provides a starting point for detailed consultation and coordination by providing a common reference point. With early consideration, the opportunity is created to resolve environmental issues pertaining to wildlife connectivity and wildlife-vehicle collisions while reducing project development costs. Furthermore, the formation of the AWLW has facilitated discussions and partnerships to help ensure a unified approach to wildlife linkage preservation and management while reinforcing the commitment and efficiency of wildlife connectivity measures undertaken by all stakeholders. Recognized as

an important component, this Assessment is considered in the Governor's Growth and Infrastructure Initiative. Overall, utilization of this Assessment is a strategy that promises to benefit all of Arizona.

This was only the first step in a continuing process of defining and elevating the awareness of critical habitat connectivity areas. Substantial work has begun on identifying and mapping additional linkage zones within habitat blocks. It is anticipated that this will double the current number of linkage zones. As new linkage zones are added, road construction programs are updated and development in the State progresses, this evaluation and resulting prioritization will be revised and updates issued. Also, linkage designs will be developed for each potential linkage zone. Another eight linkage zones have recently received funding for linkage design analysis and the work is underway. A website and workshops are being developed to promote the utility of the Assessment.

# Conserving the Connections: A Nationwide Inventory of State-Based Habitat Connectivity Analysis

**Jesse Feinberg** (Phone: 202-682-9400 x119, jfeinberg@defenders.org) Conservation Policy Assistant, Habitat and Highways Campaign, Defenders of Wildlife, 1130 17th Street, NW, Washington, DC 20036, Fax: 202-682-1331 USA

**Abstract:** Habitat fragmentation is among the most serious threats to species and biological diversity. Highways can divide wildlife habitat into smaller patches, reducing or prohibiting necessary wildlife movement between core habitat areas for foraging, mating, and other life functions.

Defenders of Wildlife reviewed all 50 states to identify those that are working to address habitat connectivity in the context of transportation planning. The goal of these plans is to facilitate interagency cooperation in order to enhance wildlife connectivity while continuing to expand and improve transportation infrastructure. We found that eleven states have completed, or are currently completing, a statewide habitat connectivity analysis, which will allow them to incorporate wildlife habitat and linkage needs into highway project planning. An additional eight other states are working on connectivity issues but on a regional scale or without a direct link to transportation planning.

This analysis provides a snapshot of the status of connectivity planning across the nation. By comparing lessons learned and successful methods, states considering connectivity planning can draw from the experience of others, while states with existing plans can use this information to improve as plans are updated.

## Introduction

As highways and associated development continue to expand, many wildlife species must face the difficult challenge of crossing unnatural and often dangerous environments, particularly highways, as they attempt to move between habitat areas. A new or expanded highway through natural areas will destroy, degrade or fragment ecologically important habitats. Human-caused habitat fragmentation is the isolation of wildlife habitat caused by manmade barriers like highways disrupting the natural landscape (Gore et al. 2001). Fragmentation is among the most major threats to the health and viability of many species, as well as to biodiversity as a whole, and contributes to the loss of habitat connectivity. Habitat connectivity is defined as "the degree to which the landscape facilitates animal movement and other ecological flows" (Forman, et al. 2003).

In recent years, many state departments of transportation (DOTs) and resource agencies, as well as federal agencies, have recognized the severity of the impacts of highways on habitat and wildlife populations. Some states have taken steps beyond required federal regulations by creating state-specific habitat connectivity analyses. These analyses identify the most important habitat areas and wildlife movement corridors across the state as they intersect with existing and proposed highways. By integrating wildlife movement patterns, protected natural areas, and transportation infrastructure into one statewide plan, states can use this data to begin to reverse the trend of fragmented habitats and reduced wildlife populations. As of spring 2007, eleven states have created, or are in the process of creating, a statewide habitat connectivity analysis by identifying the most important natural linkage areas which connect core habitat for vulnerable wildlife, and integrating this data into transportation planning. Eight other states profiled here are taking steps to improve connectivity, but are not considered a full connectivity plans as they either do not encompass the entire state, or the analysis is not integrated with transportation planning. In total, nineteen plans are profiled.

Where the information is available, Defenders of Wildlife has examined and inventoried the features of each of the existing and in-progress plans, such as sponsoring organizations, methodology, data sources, legislative support, funding, action, and implementation. By inventorying each analysis, we can compare plans and successful methods, as well as share data. Those states which have yet to conduct their own analysis can draw from the collective knowledge and experience of the currently participating states in order to create their own successful connectivity plan. States which have already conducted analyses can examine the successes and conclusions of others, which may assist in maximizing the efficacy of existing plans as they are implemented and updated over time.

Some of the plans discussed are currently being organized or analyzed at the time that this inventory was conducted and written. As such, some of these plans, in particular those identified as in progress, will warrant being revisited in coming years.

## Habitat Connectivity

Connectivity can be defined as the "...degree to which landscape characteristics facilitate or impede the ability of an organism to move within a landscape and acquire resources" (Fahrig and Merriam 1985). A loss of connectivity due to human-induced separation of natural areas is associated with restricted or severed wildlife movement between habitats. These isolated patches of habitat often cannot support large numbers or many kinds of species if movement corridors connecting these areas are fragmented by a highway or other development. Increasing connectivity between core habitat patches can help alleviate this problem. According to Bennett, 2004, reconnecting these patches of habitat will assist local wildlife population viability in five distinct ways:

1. It allows individual animals access to a larger area of habitat – for example, to forage, to facilitate the dispersal of juveniles or to encourage the recolonization of 'empty' habitat patches.
2. It facilitates seasonal migration.

3. It permits genetic exchange with other local populations of the same species.
4. It offers opportunities for individuals to move away from a habitat that is degrading or from an area under threat.
5. It secures the integrity of physical environmental processes such as periodic flooding that are vital to the requirements of certain species.

(Bennett 2004)

More broadly, Bennett is referring to the needs of species in order to survive and remain healthy such that biodiversity may be maintained. Biodiversity is the variety of living organisms, species, habitats and ecosystems which comprise life on Earth, as well as all the natural processes which occur between species and within these systems (Meffe, et al. 1997). Allowing for species diversity to be maintained in the face of increased human development is certainly a challenge, but is vital for the long-term sustained ecological integrity of natural areas and processes upon which both humans and wildlife rely. Reconnecting important habitat otherwise fragmented by development such as highways is a key step in preserving biodiversity and essential ecological processes.

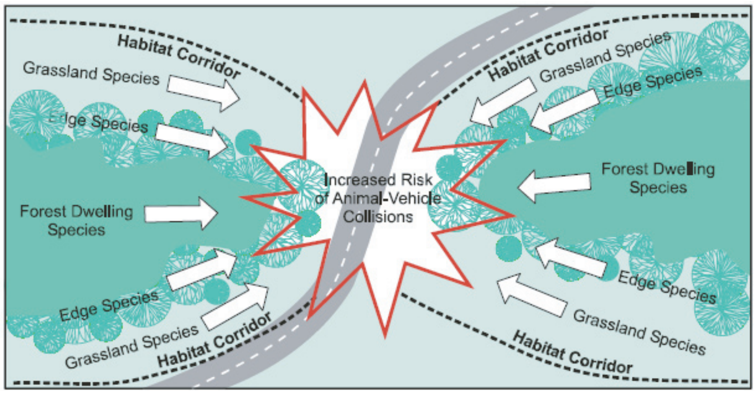



Figure 1. Representation of a wildlife corridor fragmented by a highway (Donaldson and Weber 2006).

Reconnecting natural landscapes fragmented by a highway may be accomplished through a combination of preserving core habitat areas and the natural corridors or linkages connecting them. Beier and Noss (1998) conducted an extensive review of literature on habitat corridors, and concluded that corridors indeed provide landscape connectivity when core habitats are fragmented by development such as highways. They define the term corridor as "a linear habitat…that connects two or more larger blocks of habitat and that is proposed for conservation on the grounds that it will enhance or maintain the viability of specific wildlife populations in the habitat blocks" (Beier and Noss, 1998). While a corridor is considered a travel route for wildlife, a linkage may be described as a travel route which can also support low density wildlife (Servheen et al. 2003). However, for the sake of this inventory, both terms may refer to the same basic idea of natural land and structural connections which serve to bridge fragmented core habitats.

If a natural land corridor is disturbed or destroyed, engineering manmade wildlife crossing structures to traverse a highway may also partially alleviate the effects of fragmentation. These structures can include under and overpasses, extending bridges to allow passage beneath them, and installing widened aquatic culverts for both fish and other wildlife passage. Some of these structures have been extensively studied and their successes documented, such as underpasses in Canada's Banff National Park (Clevenger and Waltho 2000) and suggested practices discussed (Forman et al. 2003, West 2006).

**Habitat Connectivity Analyses**

More than simply identifying and conserving valuable habitat areas, state-based habitat connectivity analyses, also sometimes referred to as wildlife linkage analyses or other similar phrases, stress the importance of permeability across landscapes and through highway systems. Properly considered and implemented habitat connectivity analyses identify ecologically intact core habitats in need of preservation or restoration, and also pinpoint wildlife movement corridors as they intersect with highways. Connectivity analyses identify and prioritize those areas most important for a variety of wildlife conservation needs and enables DOTs, resource agencies, conservation partners, and others to make better decisions regarding transportation planning, design and mitigation. Ultimately, data can then be used to reduce animal-vehicle collisions, thus improving the safety of the traveling public and the viability of wildlife (Austin et al. 2006). Producing statewide or regional plans for habitat connectivity is an essential component to the development of a comprehensive system of conserved corridors and effective wildlife crossing structures.

The mapping of ecologically significant areas is certainly not a new practice. Many states have implemented various plans and programs to conserve valuable habitat and green areas. However, the creation of statewide habitat connectivity plans which addresses wildlife movement in the context of highways is a fairly recent development, garnering political traction in the 1990s. Florida, one of the first states to address the issue of connectivity as it relates to highways, initiated a study in 1990 to map the biologically rich areas in the state. The resulting 1994 report was titled "Closing the Gaps in Florida's Wildlife Habitat Conservation System". The Florida Game and Fresh Water Fish Commission mapped the state's land cover and wildlife habitat needs, while the Florida DOT assisted in creating a wildlife occurrence geographic information system (GIS) database (AASHTO NCHRP 25-25 2004). Although "Closing the Gaps" was not specifically created in order to integrate transportation and conservation planning, it was the first iteration in a series of Florida's statewide efforts to address wildlife linkage needs. This early effort likely was initiated due to a myriad of factors, including Florida's well-studied biological diversity, rapid land and highway development in recent decades, and political will to have more control over growth patterns and wildlife health.

As the creation of these plans is not mandated by law, each was produced a little differently. Of the nineteen states inventoried here, most have taken different approaches to identifying wildlife connectivity threats, formulating, and then implementing connectivity plans. Many of these states' efforts are collaboratively negotiated with different partners, while some have made an effort to consult with a combination of state and federal agencies, universities, nonprofit organizations, and the private sector. These plans are produced with different methodologies and partners, with varying budgets and political support, and are in varying stages of adoption and implementation.

Despite the multiple avenues by which a state may go about producing a connectivity analysis, a fully comprehensive habitat connectivity plan will likely contain a combination of some important elements:

- aerial photos
- land ownership maps
- vegetation maps
- topographic maps
- wildlife habitat or range maps
- Monitoring wildlife behavior
- Roadkill information
- Existing and planning highways
  (Ruediger 2007)

Inclusion of these elements will provide planners with access to a wide range of data with defined ecological priorities paired with fairly spatially precise maps.

Planning connectivity on a statewide basis as it relates to highway infrastructure often can help participating states conserve not only natural resources, but time and money as well. Instead of constructing wildlife crossings and several miles of exclusionary fencing on a project-by-project basis, by using a habitat connectivity plan agencies can be assured they are conserving and mitigating in areas most in need of connectivity. Statewide connectivity mapping allows states to make the most fiscally sound mitigation investments with their limited dollars, and to avoid developing altogether those areas most critical for wildlife habitat. Some states, such as Vermont and Virginia, also boast that their connectivity plans will allow for a more efficient permit review process, as planning will provide a stronger degree of predictability than currently available (Austin et al. 2006, Donaldson and Weber 2006).

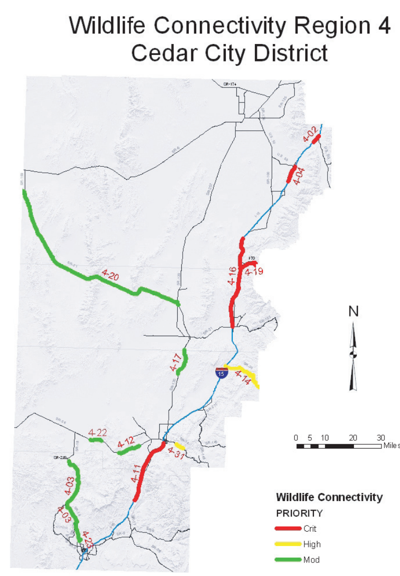



Figure 2. A map from Utah's statewide connectivity plan with priority highway segments (West 2006).

States would also benefit from integrating connectivity analyses into their respective State Wildlife Action Plan (SWAP). Each SWAP is a comprehensive wildlife conservation plan that addresses species in greatest conservation need and their major threats, as well as proposed conservation actions to address these threats. Allowing for wildlife migration and dispersal through the promotion and support of habitat connectivity is a major component to conserving species sited in the SWAPs. If each SWAP, which must be revised every ten years, adopts the findings and priorities of state-wide habitat connectivity plans, states would possess a fully integrated plan addressing vulnerable species, threats, connectivity through highways, and actions to be implemented.

This inventory examines eleven statewide habitat connectivity analyses. In a separate section, eight more states are profiled. These eight plans deal with reconnecting natural areas for wildlife; however, they are not considered statewide habitat connectivity plans because they are one or more of the following:

1. Analysis does not cover the entire state or the connectivity analyses is project-specific
2. Analysis is connectivity-oriented but not integrated with transportation plans
3. Connectivity is being integrated into highway projects, but without a statewide plan

Many other states not examined in this inventory have also made significant efforts to reduce or even reverse the trend of habitat fragmentation. However, this inventory examines comprehensive efforts for habitat connectivity and wildlife linkages in relation to highways, or at a minimum, reconnecting fragmented habitats. Proactive and successful state and city efforts such as Washington DC's Green Infrastructure program, Florida's Efficient Transportation Decision Making tool, New Jersey's Landscape Project, or other various open space programs were considered but could not be included in this assessment as interlinked habitat and highway connectivity were not their primary focus.

Below is an inventoried summary of each statewide habitat connectivity plan currently completed or in progress.

## Statewide Habitat Connectivity Analyses

Alaska (Completed)

Description: One of the first states to address this issue, FHWA Alaska Division and the Alaska Department of Transportation and Public Facilities received a grant from FHWA Headquarters in 1992 to fund a habitat connectivity study. However the study did not take place until 2003.

Plan Name: Alaska Habitat Connectivity Project

Year: 2003 (research), 2004 (published)

Partners: FHWA Alaska Division, Alaska Department of Transportation and Public Facilities, FHWA, Environment and Natural Resources Institute of the University of Alaska Anchorage

Process: Five months of research, and two partnership workshops to share data and identify species of concern.

Contents: A "'toolbox' of information that may be used by the Alaska Department of Transportation & Public Facilities to assess the effects of existing and proposed roads on habitat quality and connectivity" (DiBari 2004). More specific information is not readily available.

Application: No evidence that Alaskan agencies have made a concerted effort to implement.

Website: http://www.akhcp.org (website currently offline)

Contact: Alaska Department of Transportation and Public Facilities

Arizona (Completed)

Description: The Arizona Wildlife Linkages Workgroup was built upon the cooperative 2002-2006 partnership between FHWA, Arizona DOT, Arizona Game and Fish Department and the U.S. Forest Service to study elk-movement across State Route 260, which resulted in the construction of a series of wildlife crossing structures. (FHWA Exemplary Ecosystems Initiative 2003). The Workgroup then took the lead in producing the Wildlife Linkages Assessment.

Plan Name: Arizona's Wildlife Linkages Assessment

Year: 2003 (Arizona Wildlife Linkages Workgroup formed), December 2006 (Assessment published)

Partners: Arizona DOT, Arizona Game and Fish Department, Bureau of Land Management, FHWA, U.S. Forest Service, U.S. Fish and Wildlife Service, Northern Arizona University, Wildlands Project, Sky Island Alliance

Process: In April, 2004 the Wildlife Linkages Workgroup organized and facilitated the Missing Linkages Workshop. More than 100 biologists and planners attended the workshop to identify "missing linkages" (critical connectivity areas). Subsequent workshops expanded and refined data and maps.

Contents: Identifies, prioritizes, and maps over 150 wildlife linkages.

Application: As the website states: "This non-binding document and map will serve as an informational resource to planners and engineers, providing suggestions for the incorporation of these linkage zones into their management planning to address wildlife connectivity at an early stage of the process".

Website: http://www.azdot.gov/Highways/OES/AZ_WildLife_Linkages/assessment.asp

Contact: Bruce D. Eilerts, Arizona Department of Transporation
Siobhan E. Nordhaugen, Arizona Department of Transporation
Ray Schweinsburg, Arizona Game and Fish Department

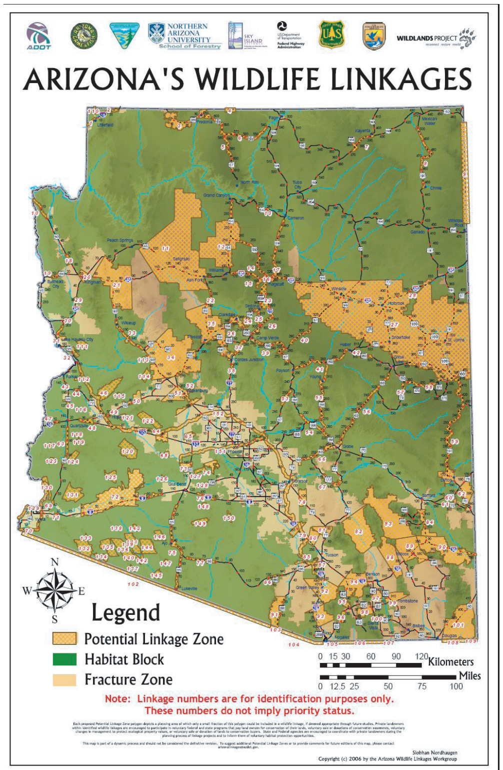



Figure 3. Arizona's Wildlife Linkages Assessment (Arizona DOT).

<u>Colorado</u> (Completed)

Description: Using a FHWA grant, Colorado produced a statewide habitat connectivity plan. The non-profit Southern Rockies Ecosystem Project was instrumental in bringing partners onboard in order to create the Linking Colorado's Landscapes connectivity analysis. Linking Colorado's Landscapes has not been adopted in its entirety by the state, nor has every key state agency joined as a partner in determining priority areas, notably the Colorado Division of Wildlife.

Plan Name: Linking Colorado's Landscapes

Year: 2003 (partnership began), 2006 (publication of Linking Colorado's Landscapes)

Partners: Southern Rockies Ecosystem Project, Colorado DOT, FHWA, The Nature Conservancy, Colorado State University

Process: Southern Rockies Ecosystem Project hosted a series of interagency workshops across the state to identify priority wildlife linkages. Colorado State University then created maps overlaying landscape characteristics, wildlife movement patterns, preferred habitats, and Colorado DOT animal-vehicle collision data and transportation planning data (Southern Rockies Ecosystem Project 2006).

Contents: 176 identified wildlife linkages across the state, with 23 linkages designated as high priority for both wildlife and safety.

Application: Colorado DOT is beginning to implement some of linkage analysis' findings, identifying 13 wildlife crossing areas on I-70.

Website: http://www.restoretherockies.org/linkages.htm

Contact: Julia Kintsch, Southern Rockies Ecosystem Project

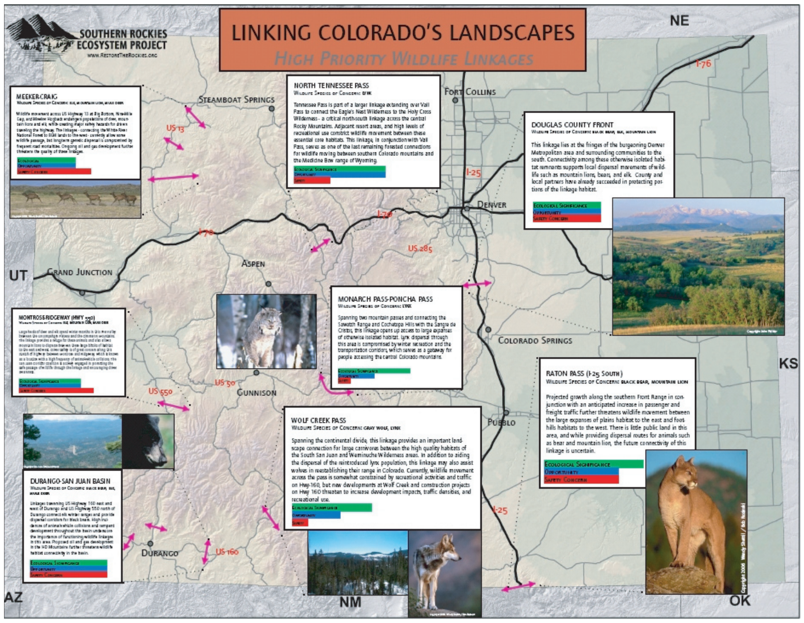



Figure 4. High priority wildlife linkages in Colorado (Southern Rockies Ecosystem Project 2006).

<u>Idaho</u> (In Progress)

Description: For several years, Idaho Transportation Department Region 6 has been conducting a linkage analysis and building a roadkill database under a special FHWA grant. Idaho has since received FHWA grant money to conduct a habitat connectivity analysis on a statewide scale (Tim Cramer, personal communication).

Plan Name: Currently unnamed

Year: In Progress 2006-2007

Partners: Idaho Transportation Department, Idaho Fish and Game, FHWA, U.S. Fish and Wildlife Service, Bureau of Land Management, U.S. Forest Service, American Wildlands, GeoData Services Inc.

Process: Currently partners are surveying existing databases and meeting with local interested parties as well as state, federal, and local governments. The plan will also include many sources of data, including aerial photos, U.S. Geological Survey maps, climate, local zoning, development changes, Census data, Gap Analysis project data, wetland inventories, games census data, fire records, and more (Kim Just, personal communication).

Contents: Unknown

Application: Plan will be used to draw conclusions for what types of procedures and structures will be most effective for wildlife mobility in particular areas.

Website: N/A

Contact: Kim Just, Idaho Transportation Department

<u>Maine</u> (In Progress)

Description: In early 2006, Maine formed a working group to discuss the creation of a statewide habitat connectivity plan which would stem from the locally-oriented Beginning with Habitat Program.

Plan Name: Beginning with Habitat Connectivity Project

Year: In Progress

Partners: Maine Department of Conservation, Maine Department of Inland Fisheries and Wildlife, Maine Department of Transportation, Maine State Planning Office, Maine Department of Environmental Protection, U.S. Fish and Wildlife Service, The Nature Conservancy, Maine Audubon, and others

Process: A two-tiered approach: mapping core habitats and the natural areas connecting them on a broad landscape level by consulting habitat permeability models; identify and monitor specific species and track their habitat use and movement patterns. Once modeling is complete, Beginning with Habitat will implement these connectivity plans in several pilot towns (Steve Walker, personal communication).

Contents: The project is proposed to include a protocol to analyze connectivity between habitat areas, develop connectivity maps, conduct a demonstrative case study for local planners.

| | |
|---|---|
| Application: | "To ensure wildlife habitat connectivity in Maine by improving the knowledge and tools available to local planners through the Beginning with Habitat program" (Department of Inland Fisheries and Wildlife, and Department of Conservation). |
| Website: | http://www.beginningwithhabitat.org/ |
| Contact: | Steve Walker, Maine Department of Inland Fisheries and Wildlife |

New Hampshire (In Progress)

| | |
|---|---|
| Description: | New Hampshire DOT is currently engaged in a pilot project with partners to develop a predictive model for determining wildlife movement which can be applied across the state. Currently only a pilot project, the goal is to expand the model into a developed GIS map of habitats frequented by wildlife and the areas where they most often cross highways (AASHTO NCHRP 25-25 2004). |
| Plan Name: | Currently unnamed |
| Year: | In Progress |
| Partners: | New Hampshire DOT, New Hampshire Fish and Game Department, New Hampshire Audubon Society, others |
| Process: | NHDOT has contacted Fish & Game Conservation Officers, local road agents, conservation commission members, and NHDOT maintenance patrol foremen to collect anecdotal evidence of crossings and road kills and record that information in a database. Partners will then compare this field data with the predictive habitat and wildlife crossing modeling that the New Hampshire Audubon Society produced. |
| Contents: | Plans call for the development of a GIS layer of important wildlife habitat areas and locations of frequent wildlife crossings to be used as a planning and design tool for future projects (AASHTO NCHRP 25-25 2004). |
| Application: | The New Hampshire State Wildlife Action Plan calls for a statewide landscape connectivity analysis my mapping wildlife corridors and buffers. The project described here may fulfill this need when completed. |
| Website: | N/A |
| Contact: | New Hampshire DOT |

New Mexico (Completed)

| | |
|---|---|
| Description: | In February 2003 the New Mexico legislature passed House Joint Memorial 3, which asked officials to determine mitigation strategies to reduce vehicle-wildlife collisions. The result of this directive was the June 2003 two-day Critical Mass workshop, which brought together about 100 New Mexico DOT employees, private consultants, federal and state biologists, and conservation groups. (MacCarter 2003-2004). |
| Plan Name: | Critical Mass |
| Year: | June 2003 (Critical Mass workshop held) |
| Partners: | New Mexico DOT, New Mexico Department of Game and Fish, federal and state biologists, Wildlands Project, Tijeras Canyon Safe Passage Coalition, private consultants, others |
| Process: | In June 2003 New Mexico Department of Game and Fish and New Mexico DOT hosted a two-day Critical Mass workshop to identify and prioritize wildlife linkages most threatened by highways across the state. Among others, Tijeras Canyon was identified as a high priority linkage. Following this workshop, the conservation organizations The Wildlands Projects and Tijeras Canyon Safe Passage Coalition have partnered with the state to begin implementing priority wildlife crossing structures. |
| Contents: | Identified and prioritized wildlife linkage areas as they cross highways. |
| Application: | Critical Mass's findings have not been implemented into transportation planning with regularity. New Mexico still mainly deals with wildlife linkage and habitat connectivity issues on a project-by-project basis, such as elk-proof fencing on U.S. 64 (Mark Watson, personal communication). |
| Website: | http://wildlife.state.nm.us/conservation/criticalmass/index.htm<br>http://www.safepassagecoalition.org/ |
| Contact: | New Mexico Department of Game and Fish |

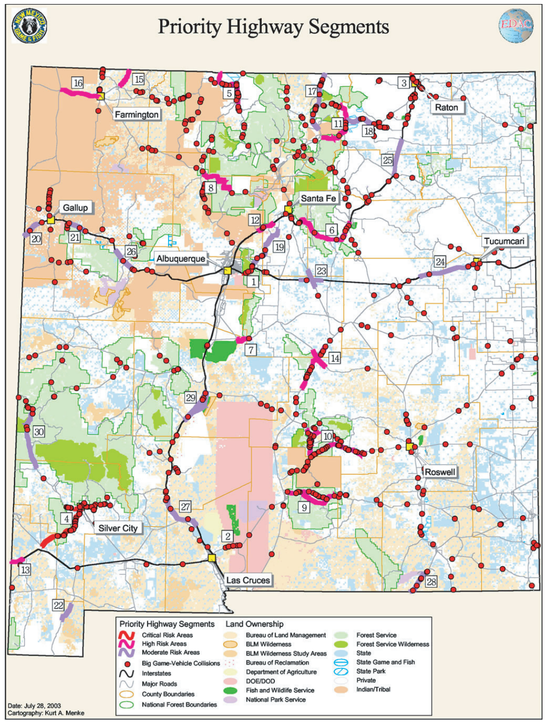



Figure 5. Priority highway segments map for New Mexico (New Mexico Department of Game and Fish 2003).

<u>Oregon</u> (In Progress)

Description: This in progress statewide habitat connectivity plan will identify potential wildlife linkage areas by studying the movement needs of a number of focal species. These areas will then be evaluated and prioritized based upon the availability of conservation opportunities and the needs of the wildlife.

Plan Name: Oregon Wildlife Movement Strategy

Year: In Progress, scheduled for completion likely early 2008

Partners: Oregon Department of Fish and Wildlife, Oregon DOT, U.S. Fish and Wildlife Service, Bureau of Land Management, others

Process: Agency experts will identify and begin to prioritize linkages. During the summer and fall of 2007, Oregon Department of Fish and Wildlife and partners will hold a series of workshops to bring together biologists, engineers, land managers and planners to discuss the prioritized linkages and how the Movement Strategy's findings will be incorporated into their work. The state is also evaluating wildlife collision incidents in order to map hotspot areas, which will then be included in the linkage assessment (Mindy Trask and Audrey Hatch, personal communication).

Contents: The Oregon Wildlife Movement Strategy will provide prioritized wildlife linkage information, including mapping of hotspots.

Application: Can be used throughout the state to be incorporated into transportation planning.

Website: http://www.dfw.state.or.us/conservationstrategy/StakeholderRequest.pdf

Contact: Audrey Hatch, Oregon Department of Fish and Wildlife
Melinda Trask, Oregon Department of Transportation

<u>Utah</u> (Completed)

Description: A multi-partner collaborative process created a detailed map of connectivity areas, with descriptions and recommendations for each. This statewide plan is now being implemented into highway planning as Utah's highways are expanded and built.

Plan Name: Wildlife Connectivity Across Utah's Highways

Year: 2006 (published)

Partners: Utah DOT, Utah Division of Wildlife Resources, U.S. Forest Service, U.S. Fish and Wildlife Service, several private consulting and conservation groups

Process: A two day workshop occurred on May 11-12, 2004 for experts to determine connectivity areas. Participants determined which species were at risk, and to what degree, on the state's highways. Also discussed and later published was the feasibility of several suggested mitigation practices, including fencing, various forms of wildlife crossings such as over and underpasses, and infrared sensors (West 2006).

Contents: Contains a detailed description of identified linkage areas, listing the conservation issues for each as well as its priority, species of concern, comments, and recommendations. Each connectivity region is mapped. The plan also contains a discussion of various mitigation methods.

Application: The identified linkages are integrated with the state's transportation planning and current projects. Utah DOT engineers, project managers, environmental managers, and long-range planners are aware of the information in Wildlife Connectivity Across Utah's Highways and use it often (Paul West, personal communication).

Website: http://www.udot.utah.gov/main/f?p=100:pg:9114202191868033625::::V,T:22337,1566

Contact: Paul West, Utah Department of Transportation

Vermont (Completed)

Description: In recent years, Vermont has constructed wildlife crossings as part of its highway projects but has done so without a statewide connectivity plan to help guide priority action areas. Partners set out to identify and prioritize the most important habitat areas for wildlife as they come in contact with highways, and to create tools to make this process easier and more accurate.

Plan Name: Wildlife Linkage Habitat Analysis

Year: May 2006 (published)

Partners: Vermont Agency of Transportation (VTrans), Vermont Fish and Wildlife Department

Process: Researchers incorporated multiple data layers into a GIS map, including ecological value of habitat near roadways, roadkill data, development density, land use data, the amount of core habitat surrounding a potential linkage, and more (Austin et al. 2006).

Contents: Partners created two products. The first product is a centralized database of wildlife road mortality and road crossing locations as well as related habitat data for key selected species throughout the state. The second product is the GIS-based Wildlife Linkage Habitat Analysis.

Application: These planning tools are now available for VTrans and Vermont Fish and Wildlife Department to use. VTrans is currently using this new tool during early project development to assess wildlife hotspots, which will help determine the best practice to reconnect severed wildlife linkages (Glenn Gingras, personal communication).

Website: http://www.aot.state.vt.us/TechServices/EnvPermit/Documents/Wildlife_Linkage_Habitat_Report_5_15_06.pdf

Contact: John Austin, Vermont Fish and Wildlife Department
Kevin Viani, Vermont Agency of Transportation
Forrest Hammond, Vermont Fish and Wildlife Department

Virginia (Completed)

Description: Virginia's Department of Conservation and Recreation created a GIS mapping analysis of the state's natural core habitat areas and the corridors which connect them together for Virginia DOT's use.

Plan Name: Virginia Natural Landscape Assessment (VANLA)

Year: December 2006 (report published)

Partners: Virginia Department of Conservation and Recreation, Virginia Department of Transportation

Process: Except for technical discussions on GIS mapping capabilities, VANLA was created by Virginia's Department of Conservation and Recreation without the input of Virginia DOT.

Contents: The mapping analysis uses land cover data to determine appropriate designations of landscape core and corridor areas. Cores, habitat fragments, and natural landscape blocks have been mapped.

Application: VANLA has not been officially adopted or implemented by Virginia DOT. However VANLA was designed to be both relevant and applicable to Virginia DOT project planning and environmental analysis, and may prove useful to both agencies if it is adopted in coming years.

Website: http://www.virginiadot.org/vtrc/main/online%5Freports/pdf/07-r14.pdf
http://www.dcr.virginia.gov/natural_heritage/vclnavnla.shtml

Contact: Bridget Donaldson, Virginia Transportation Research Council
Joseph Weber, Virginia Department of Conservation and Recreation

## Other Connectivity Work

California (Multiple plans, some In Progress)

Description: Currently no official statewide habitat connectivity analysis exists for California. Many of the state's potential habitat connectivity corridors have been identified and mapped, but without the official input of some key agencies. An important wildlife connectivity identification effort occurred at the November 2, 2000 Missing Linkages workshop at the San Diego Zoo, which brought together one hundred sixty scientists, conservationists, land managers and planners. 232 problem areas and potential linkages were identified (South Coast Wildlands 2006). Negotiations are currently underway to consider the creation of an official statewide habitat connectivity model.

Plan Name: N/A

Year: March 2007 (first meeting of interagency partners and others to create official plan)

Partners: Department of Fish and Game, CalTrans, California Department of Parks and Recreation, South Coast Wildlands, others

Process: California agencies are holding preliminary meetings with partners to determine if the state will create an official plan.

Contents: An official statewide plan would likely include new research as well as previously identified linkages from sources like the South Coast Missing Linkages Project.

Application: Linkages from the Missing Linkages workshop, as well as from other sources, have been incorporated into the design of some particular road projects, such as Freeways 118 and 101 (Lauren 2006).

Website: N/A

Contact: Kristeen Penrod, South Coast Wildlands Project

Florida (Multiple plans, some In Progress)

Description: Florida does not have one official statewide plan, but does have at its disposal many different datasets, biological surveys, and wildlife plans which have been used in different capacities to date, including the Cooperative Conservation Blueprint, Critical Lands/Waters Identification Project, Closing the Gaps, Florida Ecological Greenways Network (GeoPlan), Florida Natural Areas Inventory, and the Century Commission. This abundance of biological data and planning has proven difficult to consistently integrate with transportation planning, as no singular overarching statewide directive combines these numerous plans and data sets into one unit.

Plan Name: N/A

Year: N/A

Partners: Different plans and datasets have included partners such as Florida Game and Fresh Water Fish Commission, Florida DOT, Florida Fish & Game Commission, University of Florida, Florida Fish and Wildlife Conservation Commission, Florida Department of Environmental Protection, U.S. Fish and Wildlife Service

Process: N/A

Contents: Varies for each plan or dataset, but no single statewide habitat connectivity plan exists. Some efforts such as the Cooperative Conservation Blueprint and Conservation Land and Water Identification Project are underway to unify the plans.

Application: N/A

Website: N/A

Contact: N/A

Maryland (Completed)

Description: In 2001 Maryland launched the GreenPrint program to identify important unprotected natural areas, link these areas through a system of natural connections, and acquire or purchase conservation easements for the highest priority areas (GreenPrint Program 2006). Maryland DOT is not a partner so GreenPrint's direct application to transportation planning may be limited.

Plan Name: GreenPrint

Year: 2001 (GreenPrint program created)

Partners: Maryland Department of Natural Resources

Process: GreenPrint uses a computer tool developed to help identify and prioritize areas in Maryland for conservation and restoration. Elements considered include the variety of natural resource in an area, how a given place fits into a larger system, ecological importance, a regional or landscape-level view for wildlife conservation. The tool will also designate land as a “hub” (a large core habitat) or a “corridor” (a wildlife travel linkage).

Contents: Identify important unprotected natural lands in the state, link these lands through a system of corridors or connectors, and save those lands through targeted acquisitions and easements (GreenPrint Program 2006).

Application: A number of large parcels have been purchased through this program

Website: http://dnr.maryland.gov/greenways/greenprint/

Contact: Maryland Department of Natural Resources

<u>Massachusetts</u> (Completed)

Description: Both Massachusetts's BioMap and the Conservation Assessment and Prioritization System (CAPS) are used to identify lands in critical need of conservation protection. They are not integrated with the state's transportation plans.

Plan Name: BioMap, and Conservation Assessment and Prioritization System

Year: BioMap: On Going
CAPS: 2003, 2004, 2005 (final technical reports published)

Partners: BioMap: Massachusetts Division of Fisheries and Wildlife, Executive Office of Environmental Affairs
CAPS: University of Massachusetts

Process: BioMap: Biologists select populations to map based on elements such as habitat and resource requirements, threats, and conservation needs. Species habitat and supporting natural landscapes are mapped using GIS software (BioMap 2002).
CAPS: Uses GIS mapping to assess to the ecological integrity of developed and undeveloped areas in the state.

Contents: BioMap: A map of areas in need of strategic land protection
CAPS: A comprehensive land cover map with ecological integrity designations, and a list of priority areas for conservation

Application: Both are used by the state when considering land purchases or other methods for conservation.

Website: BioMap: http://www.mass.gov/dfwele/dfw/nhesp/nhbiomap.htm
CAPS: http://masscaps.org/

Contact: BioMap: Natural Heritage & Endangered Species Program - Massachusetts Division of Fisheries & Wildlife

CAPS: University of Massachusetts, Department of Natural Resources Conservation

<u>Montana</u> (Completed)

Description: Montana is not currently working on creating a statewide habitat connectivity plan. However the rapid assessment process which enabled the identification and prioritization of wildlife crossing structures along U.S. Route 93 in western Montana is noteworthy. The process is now being used selectively in other states such as Wyoming.

Plan Name: N/A

Year: 2003 (finalized)

Partners: U.S. Forest Service, U.S. Fish and Wildlife Service, U.S. Department of Transportation, Montana Department of Transportation, Montana Fish, Wildlife & Parks; the Salish and Kootenai tribal governments, Rocky Mountain Elk Foundation, GeoData Services Inc., American Wildlands, University of Montana (Brown 2006)

Process: As an alternative to a lengthy and expensive – though likely more thorough - study, an interagency team assessed wildlife movement patterns, animal-vehicle crash data, and landscape characteristics such as topography and vegetation over two days to determine likely wildlife movement-highway intersection hotspots (Ruediger, Lloyd and Wall 2003). Planners then took this data into consideration when designing U.S. Route 93.

Contents: A map of U.S. 93 with 48 potential wildlife linkages identified, and a brief description of the landscape and local wildlife in each linkage area (Ruediger, Lloyd and Wall 2003). One over-crossing and 39 large under-crossing structures are currently in design (American Wildlands 2005).

Application: Montana DOT is installing wildlife crossing structures on U.S. 93 to allow wildlife safe passage.

Website: http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1194&context=jmie/roadeco

Contact: Pat Basting, Montana Department of Transportation
Bill Ruediger, Wildlife Consulting Resources
Josh Burnim, American Wildlands

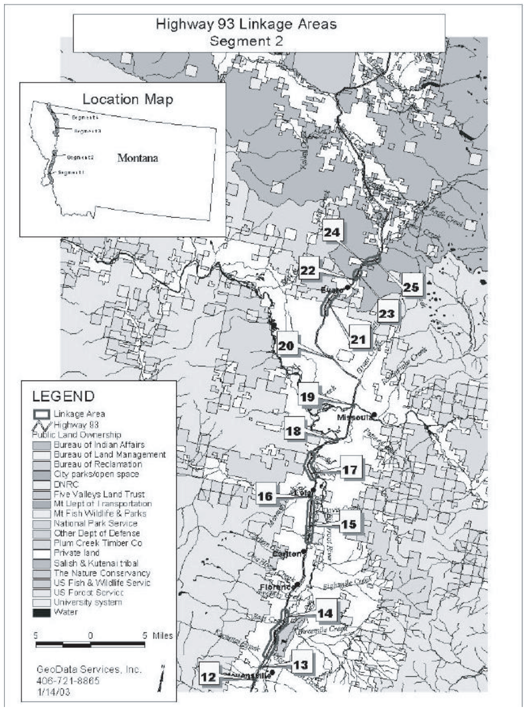



Figure 6. A map from the U.S. 93 rapid assessment (Ruediger, Lloyd and Wall 2003).

North Carolina (In Progress)

Description: North Carolina is currently involved with three projects which relate to wildlife linkages. First, the Ecosystem Enhancement Program, in cooperation with the North Carolina GAP project, is analyzing habitat cores and corridors needed for vulnerable species. Second, the Department of Environment and Natural Resources is working on four multi-county projects to identify key conservation sites and corridors, with the intention of sharing this data with North Carolina DOT. Third, the state is beginning a statewide conservation planning effort similar to Maryland's (Linda Pearsall, personal communication). Fragmentation of habitat from highways and wildlife linkages are not being addressed directly through these programs at this time.

Plan Name: North Carolina Ecosystem Enhancement Program (the first of three programs)

Year: July 2003 (Ecosystem Enhancement Program begins)

Partners: Department of Environment and Natural Resources, U.S. Fish and Wildlife Service, NC Wildlife Resources Commission, North Carolina Museum of Natural Sciences, Audubon, North Carolina Zoological Park, others

Process: Unknown

Contents: Unknown

Application: Unkown

Website: http://www.nceep.net

Contact: Linda Pearsall, Department of Environment and Natural Resources

Washington (Completed)

Description: Washington State does not have a statewide connectivity plan. The state is committed to enhancing wildlife connectivity along the I-90 Snoqualmie Pass, however, as the highway is upgraded. After several years of deliberations, appropriate wildlife crossing structures and their locations were selected, and the state has allocated money to begin installing a series of under and overpasses and extended bridges to allow for habitat connectivity in this ecologically unique area.

Plan Name: I-90 Snoqualmie Pass Wildlife Habitat Linkage Assessment

Year: 1998 (assessment began), May 2000 (assessment published)

Partners: U.S. Forest Service, Washington State Department of Transportation, I-90 Wildlife Bridges Coalition, others

Process: Under a cooperative agreement between the U.S. Forest Service and Washington State DOT, a comprehensive habitat connectivity assessment was produced for the I-90 Snoqualmie Pass area.

Contents: Researchers included a least-cost path model to identify potential linkage areas for sensitive species, GIS analysis of ungulate roadkill, monitoring of existing wildlife crossing structures to assess effectiveness, camera documentation of wildlife found near I-90, and winter snow tracking to determine common crossing locations and species distribution (Singleton Lehmkuhl 2000).

Application: As of December 2006 the Governor's 2007-2009 calls for $525 million to be used for I-90 construction. This cooperative partnership is designed to enhance both transportation utility and wildlife connectivity. Yet the I-90 project is not part of a broader-scale statewide connectivity plan. Without a statewide habitat connectivity plan in place to prioritize project areas, it is difficult to determine if mitigation dollars are all best spent on this one project or perhaps dispersed amongst a few priority areas.

Website: http://www.wsdot.wa.gov/research/reports/fullreports/489.1.pdf
http://www.i90wildlifebridges.org/

Contact: Patty Garvey-Darda, U.S. Forest Service
Jen Watkins, I-90 Wildlife Bridges Coalition

<u>Wyoming In Progress</u>

Description: Wyoming has no system-wide connectivity plan like many of the states analyzed in this inventory. Despite this, agencies have partnered on several highway projects in order to install wildlife crossing structures in important wildlife habitat areas (Bill Ruediger, personal communication).

Plan Name: N/A

Year: N/A

Partners: Wyoming Game and Fish Department, Wyoming Department of Transportation

Process: Conservation and mitigation determinations are decided on a project-by-project basis between the Wyoming Game and Fish Department and Wyoming DOT.

Contents: N/A

Application: Wyoming has installed wildlife crossing structures on particular highway projects in order to maintain connectivity for wildlife which use and inhabit the surrounding habitat.

Website: N/A

Contact: Wyoming Game and Fish Department
Wyoming Department of Transportation

## Conclusion

In order to be successfully implemented, a habitat connectivity plan must be:

- detailed
- spatially explicit
- agreed upon by the parties affected
- incorporated into long-term statewide transportation and conservation plans
- have the political and financial backing of state officials

Of the most comprehensive plans included in this inventory, some of these common threads of success emerged. An important factor to a plan's success often begins with a partnership between the state department of transportation and the land and wildlife management agencies during the process of identifying and prioritizing critical natural resources and sensitive habitat areas. It is difficult for a connectivity plan to succeed and be implemented on a wide scale without the support of state transportation and fish and game agencies in partnership with land management agencies. States which take meticulous care to identify valuable resources, but did not do so in partnership with all relevant agencies such as the DOT or Forest Service, may have difficulty in sustaining large-scale conservation efforts if the transportation department's plans are not integrated with these conservation plans. As new projects are proposed, agencies' plans may conflict if they are unaware of each other's long term goals. For a statewide habitat connectivity plan to be successful and implementable, an open and continuous relationship between multiple partners appears to be of crucial importance, in particular between state agencies but also between federal partners and knowledgeable non-profits.

It should also be noted that a successful plan does not necessarily have to map out the specific location of every natural resource sited anywhere near a possible highway project in order to be useful. If a plan maps the general locations of important habitats and (more specifically) the common movement corridors of key species, then planners will be able to apply this general research when scoping transportation projects. A finely detailed analysis may not be necessary until the specific project has been decided upon. At that stage, planners may anticipate the ecological factors most likely to be present in the project area, and can plan accordingly to avoid the area, or to take appropriate mitigation measures if the project is deemed to not have an alternative.

As the science supporting the benefits of habitat connectivity in relation to highway systems expands, so too does the practice of states seeking proactive solutions to issues associated with wildlife movement across state highways. States need to continue to make strides in seeking to protect ecologically valuable blocks of habitat across the landscape and the crucial linkages between them while not comprising the needs of human mobility. Embracing interagency cooperation, creating these statewide habitat connectivity plans have allowed participating states to conserve time, money and natural resources, while improving safety for travelers due to reduced wildlife getting onto the road. As the states inventoried here continue to expand upon and approve their planning processes, states which are currently considering beginning a similar project can look to the myriad plans of state peers for inspiration and practical solutions in order to conserve the connections for people and wildlife.

**Biographical Sketch:** Since June 2006, Jesse Feinberg has been a Conservation Policy Assistant with the Habitat and Highways program at Defenders of Wildlife. A Washington, DC based non-profit, Defenders of Wildlife is a conservation organization dedicated to the protection of all native wild animals and plants in their natural communities. Before joining Defenders Jesse worked at the Wisconsin Department of Natural Resources in the Community Financial Assistance and Communications Departments, and received his Bachelors degree at the University of Wisconsin-Madison in international studies and communication arts.

## References

AASHTO Center for Environmental Excellence. 2004. NCHRP 25-25 (04) Environmental Stewardship Practices for Highway Construction and Maintenance. Washington, DC. http://environment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/3_4.aspx

American Wildlands. 2005. Guide to Transportation Planning and Projects Affecting Wildlife in the U.S. Northern Rockies. American Wildlands. Bozeman, MT.

Austin, J., K. Viani, and F. Hammond. 2006. Vermont Wildlife Linkage Habitat Analysis: A GIS-Based, Landscape-level Identification of Potentially Significant Wildlife Linkage Habitats Associated with State of Vermont Roadways. Vermont Agency of Transportation, Montpelier, VT. http://www.aot.state.vt.us/TechServices/EnvPermit/Documents/Wildlife_Linkage_Habitat_Report_5_15_06.pdf

Beier, P. and R. Noss. 1998. Do Habitat Corridors Provide Connectivity? *Conservation Biology* 12:1241–1252.

Bennett, G. 2004. Linkages In Practice: A Review of Their Conservation Value. The International Union for the Conservation of Nature and Natural Resources, Switzlerand. http://www.iucn-ce.org/documents/econets/Linkages_in%20Practice-final.pdf

Brown, J. 2006 Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects. Federal Highway Administration, Washington, DC. http://www.environment.fhwa.dot.gov/ecological/eco_3.asp

Clevenger, A., N. Waltho, and M. Hourdequin. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology* 14:47-56.

Cramer, Tim. 2007. Idaho Transportation Department. Rigyb, ID. Personal Communication.

DiBari, J. 2004. A Scoping Analysis to Assess the Effects of Roads in Alaska on Habitat Quality and Connectivity. University of Alaska, Anchorage, AK. http://www.dot.state.ak.us/stwddes/dcsenviron/assets/pdf/habitatconnectivityrpt.pdf

Donaldson. B. and J. Weber. 2006. Use of a GIS-Based Model of Habitat Cores and Landscape Corridors for the Virginia Department of Transportation's Project Planning and Environmental Scoping. Virginia Transportation Research Council, Charlottesville, VA. http://www.virginiadot.org/vtrc/main/online%5Freports/pdf/07-r14.pdf

Environmental and Enhancement Group. 2004. Arizona Department of Transportation Environmental and Enhancement Group Annual Report FY 2004, Phoenix, AZ. http://www.adotenvironmental.com/EEG_common/documents/files/reports/eeg_annual_r eport_fy_2004.pdf

Fahrig L. and G. Merriam. 1985. Habitat patch connectivity and population survival. *Ecology* 66:1762-1768.

Federal Highway Administration. 2003. Comprehensive Approach to Wildlife Protection on State Route 260. Washington, DC. http://www.fhwa.dot.gov/environment/ecosystems/az.htm

Forman, R. T. T., D. Sperling, J.A. Bissonette, et al. 2003. *Road Ecology: Science and Solutions*. Island Press, Washington, D.C.

Gore, J., J.J. Claar and B. Ruediger. 2001. Why Did The Bear Cross The Road? It Didn't! In: *Proceedings of the 2001 International Conference on Ecology and Transportation*. Center for Transportation and the Environment, NC State University, Raleigh, NC

Gringas, Glen. 2007. Vermont Agency of Transportation. Montpelier, VT. Personal Communication

Just, Kim. 2007. Idaho Transportation Department. Boise, ID. Personal Communication.

Hatch, Audrey. 2007. Oregon Department of Fish and Wildlife. Salem, OR. Personal Communication.

Lauren, W. August 25, 2006. Report identifies 'missing linkages' in wildlife corridors. *The Malibu Times*. http://www.scwildlands.org/articles/082506_MalibuTimes.pdf

MacCarter, J. S. 2003-2004. Share With Wildlife Update. New Mexico Department of Game and Fish, Santa Fe, NM. http://www.wildlife.state.nm.us/publications/documents/share_w_wildlife_update_winter2003.pdf#search=%22june%202003%20%22New%20Mexico%20Carnivore%20Worki ng%20Group%22%22

Maine Department of Inland Fisheries and Wildlife, and Department of Conservation. 2004. Habitat Connectivity: Landscape-level Planning to Increase Connectivity between Important Habitats – A Proposal to the Maine Outdoor Heritage Fund. Augusta, ME.

Maryland Department of Natural Resources. 2006. GreenPrint Program. Annapolis, MD. http://www.dnr.state.md.us/greenways/greenprint/greenprint.html#wha

Massachusetts Division of Fisheries and Wildlife. 2002. BioMap. MA. http://www.mass.gov/dfwele/dfw/nhesp/nhbiomap.htm

Meffe, G. K., C.R. Carroll, and contributors. 1997. *Principles of Conservation Biology*. Sinauer Associates, Sunderland, MA.

New Mexico Department of Game and Fish. 2003. Priority Highway Segments Map. Sante Fe, NM. http://wildlife.state.nm.us/conservation/criticalmass/index.htm

Pearsall, Linda. 2007. North Carolina Department of Environment and Natural Resources. NC. Personal Communication.

Ruediger, B., J. Lloyd and R. Wall. 2003. A rapid assessment process for determining potential wildlife, fish and plant linkages for highways. In: *Proceedings of the 2003 International Conference on Ecology and Transportation*. Center for Transportation and the Environment, NC State University, Raleigh, NC

Ruediger, B. and M. DiGiorgio. 2007. Safe Passage: A User's Guide to Developing Effective Highway Crossings for Carnivores and Other Wildlife. Wildlife Consulting Resources and Southern Rockies Ecosystem Project, Denver, CO

Ruediger, Bill. 2007. Wildlife Consulting Resources. MT. Personal Communication.

Servheen, C., J. Waller and P. Sanderstrom. 2003. Identification and Management of Linkage Zones for Wildlife Between the Large Blocks of Public Land in the Northern Rocky Mountains. U.S. Fish and Wildlife Service. Missoula, MT.

Slesar, C., S. Morse and J. Austin. 2003. Vermont Agency of Transportation Wildlife Crossing Team; Building an inter-agency planning tool to address ecological connectivity in Vermont. Montpelier, VT. http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1002&context=jmie/terc

Singleton, P. and J. Lehmkuhl. 2000. I-90 Snoqualmie Pass Wildlife Habitat Linkage Assessment. Washington State Department of Transportation, Olympia, WA.

Southern Rockies Ecosystem Project. 2006. Denver, CO. http://www.restoretherockies.org/

Trask, Melinda. 2007. Oregon Department of Transportation. Salem, OR. Personal Communication.

Walker, Steve. 2007. Maine Department of Inland Fisheries and Wildlife. Augusta, ME. Personal Communication.

Watson, Mark. 2007.New Mexico Department of Game and Fish. Sante Fe, NM. Personal Communication.

West, P. 2006. Wildlife Connectivity Across Utah's Highways. Utah Department of Transportation, Salt Lake City, UT. http://www.udot.utah.gov/main/f?p=100:pg:1133421010011270926::::V,T:,1566

West, Paul. 2007. Utah Department of Transportation. Salt Lake City, UT. Personal Communication

White, P. 2007. Getting Up To Speed: A Conservationist's Guide to Wildlife and Highways. Defenders of Wildlife,Washington, DC.

# Integrating Wildlife Crossings into Transportation Plans and Projects in North America

**Patricia C. Cramer** (435-797-1289, pcramer@cc.usu.edu), USGS Utah Cooperative Research Unit, Utah State University, College of Natural Resources, Logan, UT 84322-5290 USA
**John A. Bissonette** (435.797.2511, john.bissonette@usu.edu), USGS Utah Cooperative Research Unit, Utah State University, College of Natural Resources, Logan, UT 84322-5290 USA

**Abstract:** Results are presented of a North American survey designed to learn how transportation departments mitigate transportation corridors for wildlife and give examples of how wildlife mitigation measures can be incorporated into long range plans and in routine everyday actions. The objective is to promote greater understanding of the potential for incorporating wildlife movement needs into transportation programs and projects. Research results presented include data from a continent-wide telephone survey conducted over a two year period (2004-2006) to learn of accomplishments in wildlife passage and how wildlife and ecosystem needs have been incorporated into the transportation planning process. Telephone interviews were conducted with 410 transportation and ecology professionals in every state and province. Based on research data and the mandates of the SAFETEA-LU legislation the case is made that greater efforts in long term transportation plans and everyday retrofits are necessary to provide for wildlife and ecosystems needs. Some efforts have already been accomplished and can be adapted continent-wide. There are greater than 580 terrestrial and 10,000 aquatic wildlife and fish passages in North America that were specifically built as wildlife and fish crossings, and millions of other bridges and culverts constructed for other purposes but which could be used by wildlife. Placement of these structures has grown so rapidly that over 500 new terrestrial passages are projected to be built in the next 10 years. The almost exponential increase in passage construction each decade is an indication of the growing awareness of the need to mitigate new and existing transportation infrastructure for wildlife permeability. There is also a greater awareness that early planning for wildlife and ecosystems is critical to accomplish these mitigation activities. The inclusion of wildlife and ecosystem needs early in the development of long range transportation plans has not been the traditional paradigm as was learned over the course of the survey. The majority of transportation planners who participated in the survey indicated their state's consideration of wildlife and ecosystems, in the form of consultations with natural resource professionals and referencing Geographic Information Systems (GIS) maps and other data, did not occur until the project development stage. This late consideration does not typically allow adequate time to avoid important wildlife corridors and to install mitigation measures. The majority of those working with transportation and ecological concerns recognized the need to incorporate wildlife mitigation needs early in the programming, planning, and design processes, as learned from the web-based priorities survey. The survey revealed that early planning for wildlife and ecosystem needs was the number one priority in dealing with roads and wildlife. This early level planning has also been mandated in the U. S. SAFETEA-LU Transportation Act of 2005. Examples are presented of instances where long range planning included wildlife and ecosystems needs, and suggest how this can be accomplished on a state and province-wide basis. We also present how everyday opportunities can be used to facilitate wildlife movement over and under roads and railways. Knowledge of successful accomplishments can help build upon opportunities in the movement toward a more proactive transportation planning paradigm.

## Introduction

There is an overall consensus among scientists, practitioners, and the general public that roads and their accompanying vehicle traffic pose a serious threat to wildlife and that it is necessary to take action to mitigate those effects (Trombulak and Frissel 2000, Forman et al. 2003, Gunderson et al. 2005, Weigel 2005). Scientists have documented road and vehicular effects from global warming to genetic isolation in insects (Forman 1999, Trombulak and Frissel 2000, Bissonette 2002, Angermeier et al. 2004, Keller et al. 2003). The effects that involve mortality from collisions with vehicles and modifications of animals behavior as described by Trombulak and Frissel (2000) are two effects that can be partially mitigated through alterations of existing road and rail structures and better planning for wildlife in future transportation projects. Traditional transportation planning does not begin to incorporate wildlife and ecosystem needs until late in the planning stages when a specific project has begun the planning and development stages, typically only five years or less to the time of project construction. This later stage of planning allows little time or funding for changes to the proposed projects that would accommodate ecosystem and specific species needs. As a result, transportation system planning, development and construction has in most cases exacerbated the ecological effects of roads, railways, and traffic when in fact there may have been opportunities to help minimize or eliminate these impacts under another planning paradigm.

The new paradigm for transportation planning has begun to develop, due in part to a greater understanding of ecological effects of roads, traditional environmental protection laws such as the U. S. National Environmental Policy Act (NEPA) and the Canadian Fisheries Act, and the recent United States 2005 Transportation Act known as SAFETEA-LU. Traditionally, environmental concerns were viewed as only those related to regulations and laws that required developers of infrastructure to apply for permits and meet specific requirements, such as those pertaining to the U. S. Clean Water Act, Endangered Species Act, and NEPA. With the passage of SAFETEA-LU, long range transportation plans at the state and regional level, which are traditionally set for a 20 to 30 year time frame, are required to be developed in 'consultations with resources agencies, such as those responsible for land-use management, natural resources, environmental protection, conservation and historic preservation, which shall involve, as appropriate, comparisons of resource maps and inventories.' SAFETEA-LU also requires these consultations have 'Discussion of potential environmental mitigation activities and potential areas to carry out these activities, including activities that may have the greatest potential to restore and maintain the environmental functions affected by the plan' (SAFETEA-LU Section 6001). This legislation sets the stage for more open discussions when long range planning is carried out and creates a strong incentive for natural resource agencies to identify natural areas and wildlife populations in greatest need of protection. SAFETEA-LU also instructs states to create participation plans that identify a process for stakeholder involvement. This early level planning and consultation requires coordination of data sources and working relationships among agencies that may have not been fostered in the past. As states begin to work toward this new paradigm, it would be most instructive to examine examples of how these relationships have been developed in specific projects and places where wildlife mitigation has become a standard option for transportation projects. This paper presents examples of how early planning and coordination among stakeholders across North America has helped ameliorate the effects of existing and future transportation projects. Our objective is to promote greater understanding of the potential for incorporating wildlife movement needs into transportation programs and projects.

## Methods

### Telephone Survey of Wildlife Crossings

Knowledge of wildlife mitigation activities across North America was largely gathered through a continent-wide telephone survey of transportation and natural resource professionals. The objective of this survey was to learn of state and provincial efforts to mitigate roads for wildlife with wildlife crossings and the process of incorporating wildlife needs into transportation planning (See Cramer and Bissonette 2005 for further details). The survey was carried out from July 2004 through March 2006. Crossings were defined as a new or retrofit passage over or below a roadway that were designed specifically or in part to assist with wildlife movement. Structures in place solely for other purposes such as water flow or recreationists' use that later had fencing attached to them to funnel wildlife to them were not considered wildlife crossings.

### Web-based Survey of North American Priority Ranking

North American priorities for the research and practice of transportation ecology dealing with wildlife movement and roads were also used in this research. Our research team of six ecologists and three engineers generated a list of 25 priorities dealing with safely accommodating wildlife movements within transportation systems (Bissonette 2006). The list was then presented in an on-line survey for participants to rate the priorities in April of 2006. Through our contacts generated from the above telephone survey and other transportation-related work, we invited 497 transportation ecology-related professionals to rate the 25 priorities. These priorities were then ranked according to participants' ratings.

## Results

### Wildlife Crossings

Telephone survey interviews with 410 individuals and ongoing communications with transportation and natural resource professionals reveal there are a minimum of 592 terrestrial wildlife crossings and over 10,000 aquatic wildlife crossings in North America (figure 1). The first well-documented wildlife passages were installed in the 1970's. Since that time each decade has had a doubling in the number of wildlife passages when compared to the previous decade. There are projected to be over 500 new terrestrial passages built for wildlife in the next 10 years. These are intended to mitigate the entire network of approximately 7.2 million kilometers of roads in North America (Forman et al. 2003, Gunderson et al. 2005)

### Planning Stages

In order to formally organize the continuous transportation planning process, we segmented the process into long range plans (20-30 years), State Transportation Improvement Plans (5 years), and project plans (near future), based on a similar survey conducted by the U. S General Accounting Office (United States General Accounting Office 2004). Telephone survey participants who were knowledgeable about transportation planning in their state (we present only U.S. individual state results) were asked 1. "How does your state consider ecosystem conservation during the creation of the long-range transportation plans? 2. . . .during the State Transportation Improvement Program (STIP) process? and 3. . . .during Project Development?" The consideration of ecosystem conservation was defined as: A – the incorporation of local plans that have considered ecosystem conservation; B – the use of resource agency personnel as stakeholders in developing transportation plans; C – the consideration of input from environmental interest groups; D - planning agency or resource agency personnel conducting site visits to determine or confirm the location of ecological resources; E – the use of resource agency data to determine mitigation requirements, develop alternative locations, or to avoid planning projects with unacceptably high ecosystem impact; F – the use of geographic information systems (GIS) to determine ecological resource locations; and G - provide funding to ecological impact studies. These actions were taken from those described by transportation agencies in the GAO study (United States General Accounting Office 2004). The majority of respondents representing 28 states indicated their states did not consider wildlife or ecosystem conservation until the project planning phase. Respondents in eight states responded that their planning began considering wildlife and ecosystem conservation at a level equivalent to the State Transportation Improvement Planning process, and respondents in fourteen states stated they began their consideration of wildlife and ecosystem needs at the long range (20 years or more) planning process (table 1). This long range planning was conveyed as not necessarily consistent state-wide long range planning for ecosystem conservation, but also included long range planning for specific road projects or specific geographic areas, specific case studies for future planning models, or new legislation for mandated long term planning.

## Priorities

Four hundred and forty-four participants rated the priorities related to roads and wildlife on the April 2006 web-based survey. The number one ranked priority was the need to “Incorporate wildlife mitigation needs early in the U.S. DOT/ Canadian MoT programming, planning, and design process.”

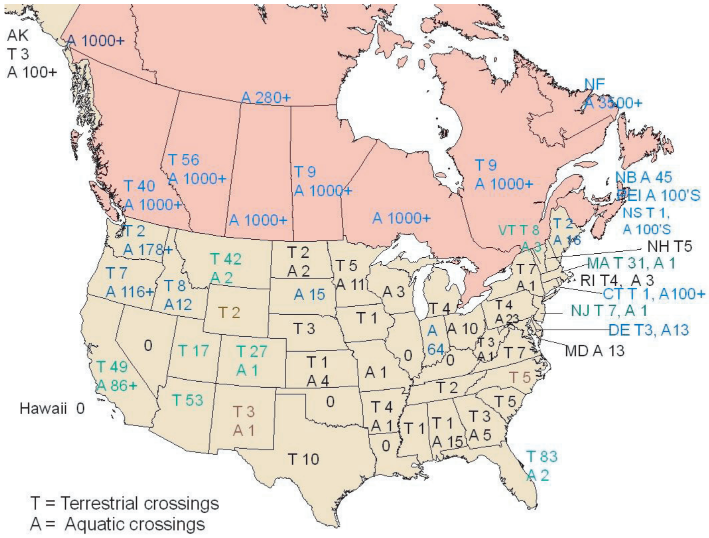



Figure 1. Estimated number of terrestrial (T) and aquatic (A) wildlife crossings in North American states and provinces as taken from NCHRP 25-27 telephone survey.

Table 1: The point in the planning process when telephone survey participants indicated their state began considering ecosystem conservation

| **Planning Stages** | | |
|---|---|---|
| **Long Range (20+ years)** | **STIP (5 + years)** | **Project (5 years or less)** |
| Arizona | Idaho | Alabama |
| California | Louisiana | Alaska |
| Colorado | Minnesota | Arkansas |
| Florida | Pennsylvania | Connecticut |
| Idaho | Rhode Island | Delaware |
| Illinois | Wisconsin | Georgia |
| Indiana | West Virginia | Hawaii |
| Kansas | Wyoming | Iowa |
| North Carolina | | Kentucky |
| New Mexico | | Massachusetts |
| Oregon | | Maryland |
| South Carolina | | Maine |
| Vermont | | Michigan |
| Washington | | Missouri |
| | | Montana |
| | | Mississippi |
| | | North Dakota |
| | | Nebraska |
| | | New Hampshire |
| | | New Jersey |
| | | Nevada |
| | | New York |
| | | Ohio |
| | | Oklahoma |
| | | Tennessee |
| | | Texas |
| | | Utah |
| | | Virginia |
| Total = 14 | Total = 8 | Total = 28 |

## Discussion

Responses to this survey indicate a traditional lack of consideration of wildlife and ecosystems early in transportation planning but also the occurrence of a transition to a new paradigm for transportation planning that is beginning to include these considerations earlier in the planning processes. We learned these planning processes are not as clearly defined as the three stages presented to participants. There is more of a continuum of planning with multiple stages and inputs from a plethora of stakeholders. There are also a multitude of opinions about how states are planning for wildlife and ecosystems. Regardless of our efforts to standardize the questions and predicted answers, the responses were more often a reflection of the individual participant's reality than what may take place across a state. As a result, we present here generalized responses and present examples to better elucidate the new changes to the traditional transportation planning paradigm. This is also a reflection of the nature of planning for long range programs. While long range transportation plans may include statements that the state transportation department would like to be "good stewards of the environment and to follow state and federal NEPA environmental rules," there are typically no definitive statements on specifically how ecological concerns will be planned for or how input from natural resource agency personnel will be incorporated and accommodated in plans. We found that when a specific ecological place such as a more pristine area or transportation corridor is considered, then ecological concerns are more easily defined and accommodated. This is particularly true with large transportation corridors. Corridor planning may be only briefly addressed in the long range plan, but then undergoes a planning process that includes many separate projects over a long span of highway. These plans could be considered a type of long range plan because they occur on 15 to 20 year time frames. As many as a dozen respondents noted this type of corridor planning and indicated that personnel from natural resource agencies are part of the long range planning committees for these corridor plans. If respondents mentioned this type of planning as the first stage that wildlife and ecosystem conservation needs were considered, then their states were classified as beginning ecological planning at the State Transportation Improvement Program stage.

Most states typically began their ecological considerations when planning for the better defined projects. Participants mentioned that wildlife and ecosystems were considered when NEPA requirements began to be taken into account. It appears that provisions of section 6001 of the SAFETEA-LU Act make it much more clear as to at what stage ecological considerations must begin, and exactly what those actions should be.

Another factor in the recording of the transition from traditional to a new planning paradigm was the timing of this survey. It is worthwhile to note the survey was conducted during a transition period where transportation planning was conducted under guidance of the 1998 Transportation Act (TEA 21) to the beginning months of the 2005 Transportation Act, SAFETEA-LU. This was also a critical time when individual states were creating their Comprehensive Wildlife Conservation Plans, which were completed in October of 2005, and later became known as Wildlife Action Plans. As a result, many if not most respondents gave responses that talked of past planning actions and then how the "new" methods were being incorporated into planning stages.

The telephone survey also gave us the opportunity to learn how states deal with transportation planning and ecological concerns over a variety of situations. It may be more instructive to report these exemplary and day to day examples of integrating wildlife and ecological concerns into transportation planning than to give a more academic collection of data and analysis. We present our findings in the form of ten steps. These steps represent processes that are most common to successful mitigation projects and are representative of the newly developing paradigm of transportation planning.

1. **Take stock of state/provincial situation**
   In states where there is an active program of mitigating for wildlife within transportation corridors, a common theme often is a recent event that helped catalyze support among agencies for coordinating efforts. These events are usually workshop-type meetings where members of state and federal agencies, non-profit organizations and zoological parks, consulting companies, academic institutions, and the general public come together to identify wildlife and landscape linkages, zones of connectivity and places where roads bisect those areas, or specific road related mortality workshops to identify the necessary steps to begin to address the issue. Examples of these events include wildlife connectivity-linkage workshops in many western states in the past five years (Utah, Arizona, New Mexico, California, and parts of Oregon, Idaho, and Montana), the Northeast's wildlife and roads bi-annual meetings, and Ontario's recent (2007) Ecopassage Forum to address wildlife mortality province-wide.

2. **Locate or generate databases, maps, and plans that could help with transportation and conservation**
   All states recently completed Wildlife Action Plans which help to identify species in areas that are most in need of protection or sensitive to development, among other priorities. Prior to 2006 when these were finalized, certain states had begun to address these issues in similar documents. Florida is among the leaders in mapping where they believe wildlife and overall landscape linkages should be maintained or restored and made those maps widely available, along with documents of where sensitive species reside and the lands important to their survival. With the use of the State Wildlife Action Plans, connectivity maps of landscape linkages, and accurate and updated Geographic Information Systems (GIS) databases there will be a number of resources for transportation agencies to cross reference at early planning stages.

3. **Bridge relationships**

   One of the common comments participants provided was the lack of communication among agencies until there was an almost crisis situation where the agencies became pitted against one another and sometimes the public. In situations where agencies are working cooperatively together and in conjunction with the public and outside organizations, the common denominator appears to be a proactive effort to communicate and work together long before there is a specific transportation project beginning construction. Vermont Agency of Transportation and Vermont Department of Fish and Wildlife have both a memorandum of agreement and a regular working relationship that involves quarterly meetings, field courses, and other activities to find ways to work together in assisting terrestrial and aquatic wildlife movement regardless of what transportation projects are being planned. We suggest similar avenues for state and federal agencies to build communication and relationship bridges long before there is a specific regulatory reason to do so.

4. **Bring data and natural resource professionals into long range planning centered on a specific area or issue**

   In states where there was an indication that wildlife and ecosystems needs were considered early in the long range planning process, in almost every instance it was when there were specific issues transportation planning could most easily examine, such as a specific ecologically sensitive area (such as the San Diego area of California and Illinois' Critical Trends Assessment identified areas), the availability of distinct GIS layers that could show what the concerns were (such Florida's ETDM planning portal), a demonstration project for future planning (such Colorado's Front Range MPO long range plan), and interagency initiatives such as Oregon's support of the Collaborative Environmental Transportation Streamlining (CETAS) which considers environmental issues relative the larger transportation picture, and the nationwide Eco-Logical approach. Long range plans may be the one common denominator for all states but they are not the only means whereby wildlife and ecosystems concerns can be addressed early on.

5. **Begin multi-agency cooperation years ahead of project**

   If transportation and natural resource professionals can begin cooperating with one another for periods of years ahead of project development, there are multiple opportunities to negotiate differences within the transportation time frames. One common challenge among state transportation departments is the need to move the regulatory permitting process along at a faster pace than the state and federal wildlife agencies can accommodate. An increasingly popular answer to this problem is for state transportation agencies to pay for biological-oriented liaison positions within their state office of the U.S. Fish and Wildlife Service in order to more adequately address their concerns within transportation time constraints. Another approach is for transportation and natural resource professionals and other stakeholders to begin negotiating ecological considerations in large projects five to twenty years ahead of construction. One drawback to this early planning is that many natural resource agency personnel and budgets are already stretched to their limits and cannot afford this early level planning even though it may prevent more time intensive reactions to plans that went on without them. If such agencies could prioritize involvement in transportation planning there may be many more opportunities to mitigate for ecological concerns. An example of a multi-year, multi-partner planning strategy that has become an exemplar of wildlife crossings is the coordinated effort to mitigate for wildlife on US 93 across the Flathead Indian Reservation. The Salish-Kootenai Tribe who owns and resides on the reservation, the Montana Department of Transportation, and U.S. Federal Highways worked together for years in negotiating the plans for an upgrade to the road that will also result in upwards of 42 wildlife crossings.

6. **Set up pre-construction and continuous scientific monitoring and coordination**

   The states with the most successful wildlife mitigation across transportation corridors programs are also the states with strong scientific involvement in these mitigation efforts that result in monitoring and adaptively managing mitigation projects. A critical step in transportation planning is to involve scientists in pre-construction monitoring of the situation and post-construction monitoring to ascertain if the structures were effective. One of the best scientifically documented wildlife mitigation projects is the Payson State Road 260 project across the Tonto National Forest in Arizona. Not only were wildlife biologists involved in planning and pre and post construction monitoring and their results incorporated into an adaptive management scenario to improve on future crossings, but the U.S. Forest Service also supported several engineer positions to oversee the construction of wildlife mitigation structures and the overall construction project to make sure the project was conducted in the environmentally sensitive methods agreed upon.

7. **Reach out to non-agency partners**

   The public and non-profit environmental organizations can also help planning efforts. Citizen scientists are helping to gather data on wildlife moving near the road and wildlife mortality hotspots in places such as Crows Nest Pass on Highway 3 in Alberta, and along State Highway 75 in Idaho. These efforts can help identify specific places in need of mitigation. Non-profit organizations can also help to raise support for transportation projects years before construction such as the I-90 Coalition has done for a series of passage to be built in an upgrade to Interstate 90 across Washington. They can help educate the public on the need for mitigation efforts and even lobby congressional delegates for funding of these efforts such as Colorado's Southern Rockies Ecosystem Project has done for an overpass near Vail, Colorado.

8. **Find everyday opportunities in bridge and culvert replacements**

   There are over 200,000 bridges in the United States that will need to be replaced in the next 10 years (MacDonald and Smith 1999) and thousands more culverts that will also need to be replaced. These replacements present opportunities to allow for aquatic and terrestrial wildlife movement. If the states' surveys of culverts and bridges and the long range and STIP transportation plans can be coordinated along with identification of wildlife linkage areas, we can identify hundreds of opportunities in every state where wildlife crossings can be incorporated into projects that are already scheduled. The next logical step would be to make those structures wildlife friendly by such efforts as extending bridges over riparian area's 100-year flood plains to encompass upland for terrestrial movement, and making adjustments to stream culverts to allow a more natural flow to allow for aquatic organisms to travel up and down stream. Minnesota has already begun to do this with their replacement of outdated culverts along Trunk Highway 61 to accommodate terrestrial wildlife along dozens of stream passages that previously did not allow for their movement. Washington and Oregon are involved in ambitious programs which dedicate millions of dollars each year to replace impassable stream culverts with those that allow salmon and other species access to areas they have been restricted from for decades.

9. **Retrofit existing culverts and bridges**

   In the web-based priorities survey, participants ranked fifth the need to develop and summarize alternative, cost effective wildlife crossing designs. While it may typically be the goal of natural resource professionals to install major wildlife underpasses and overpasses into future transportation project, everyday efforts may present more opportunities to assist in wildlife movement. Low cost retrofits that can be installed by maintenance crews in their everyday operations ranked eighth in the priorities survey. It is these simple efforts that have the greatest potential to be conducted over the large spatial scale. Simple culvert retrofits include the placement of metal shelves for small and medium wildlife species to move through water filled culverts (Foresman 2003) and the placement of weirs in aquatic culverts to assist in fish movement as has been done in Idaho and other northwestern states as a temporary fix.

10. **Always look ahead to new road improvement projects**

    Long range plans and individual transportation projects provide the most probable situations where wildlife mitigation can be placed in a transportation corridor. While wildlife mitigation has been installed solely within its own project, such as was the case with the reptile and amphibian wall and ecopassages along Paynes Prairie in Florida, the majority of wildlife crossings have been established in conjunction with transportation projects. The 50 state long range transportation plans that exist now have taken little to no consideration of wildlife and ecosystem needs. It is within these plans we must begin to work toward such considerations. Those concerned with wildlife and other ecological concerns can begin to promote greater accommodation of wildlife movement by looking to what may become realities in the future and find ways these potential projects must accommodate the natural world. One of the most highly recognized successful wildlife crossing systems in the world is set of 24 wildlife crossings across the Trans Canada Highway in Banff National Park in Alberta. These crossing came about within the context of the twinning project that enlarged the highway. While such projects can be ecologically devastating, early planning for wildlife and ecological needs can be the critical step that makes a tough situation the best it can be for wildlife. Early planning may also help to avoid a transportation project in an ecologically sensitive area, thus preventing the need for mitigation altogether.

The responses from our telephone survey indicate there is a growing awareness of the need to help make the roaded landscape more permeable for wildlife. The results of our web-based priorities survey show that there is a consensus across North America that the top priority for accommodating wildlife within transportation corridors is to incorporate wildlife mitigation needs early in the transportation programming and planning processes. From these research efforts we were able to view the changing paradigm of transportation planning as it develops in response to this greater awareness. Our hope is we help develop a "culture of conservation" in transportation planning across North America that begins to consider and accommodate wildlife and ecosystems across the roaded landscape. From the examples we present, we believe this is not only possible but has been happening across the continent. We look forward to ushering in these changes and the new paradigm.

**Biographical Sketches:** Patricia Cramer. Patricia (Patty) is a Research Associate with the USGS Utah Cooperative Unit at Utah State University. She is finishing up NCHRP project 'Evaluation of the Use and Effectiveness of Wildlife Crossings, and beginning new research on wildlife use of passages in Utah. Her bachelors, masters, and Ph.D. (University of Florida) degrees are all in wildlife conservation. Her work in road ecology includes membership in the Paynes Prairie Wildlife Coalition which was instrumental in placing a herpetile wall and 4 additional ecopassages for wildlife in Paynes Prairie State Preserve along a state highway in Florida. She has also served as a Visiting Assistant Professor at Montana State University and the University of Florida. Her research interests center on wildlife connectivity in the landscape.

John Bissonette. John is Leader of the USGS Utah Cooperative Fish and Wildlife Research Unit and Professor, Department of Wildland Resources in the College of Natural Resources at Utah State University. His degrees were received from University of Vermont (B.A.), Yale University (M.F.S), and the University of Michigan (Ph.D.). His research interests include landscape ecology, wildlife management, and road ecology. He spent 5 months in Germany in 2002 at the Technic University of Munich as a Senior Fulbright Scholar, and 4 months as a Visiting Professor at the Albert-Ludwigs Universitaet Freiburg in Fall 2005. He was co-author of Road Ecology: Science and Solutions. When not working he rides his horse in the mountains of Utah and his Harley on the back roads of the West.

## References


Angermeier, P. L., A. P. Wheeler, and A. E. Rosenberger. 2004. A conceptual framework for assessing impacts of roads on aquatic biota. Fisheries December 2004:19-29.

Bissonette, J.A. 2002. Scaling roads and wildlife: the Cinderella principle. European Journal of Wildlife Research, Proceedings of the XXVth International Congress of the International Union of Game Biologists, Lemesos, Cyprus. Z. Jagdwissenschaft 48,Supplement: 208-214.

Bissonette, J. A. 2006. Evaluation of the Use and Effectiveness of Wildlife Crossings Interim Report. Prepared for the National Cooperative Highway Research Program, Transportation Research Board, National Research Council. url: http://www.trb.org/trbnet/projectdisplay.asp?projectid=762

Cramer, P. C., and J. A. Bissonette. 2005. Wildlife crossings in North America: The state of the science and practice. Pp. 442-447 in, C. L. Irwin, P. Garrett, and K.P. McDermott, editors. Proceedings of the 2005 International Conference on Ecology and Transportation, Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina.

Foresman, K. 2003. Small mammal use of modified culverts on the Lolo south project of western Montana- an update. In 2003 Proceedings of the International Conference on Ecology and Transportation, edited by C. Leroy Irwin, Paul Garrett, and K.P. McDermott. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2003.

Forman, R.T.T. 1999. Estimate of the area affected ecologically by the road system in the United States. Conservation Biology 14: 31-35.

Forman, R.T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. Road Ecology: Science and Solutions. Island Press, Washington, DC.

Gunderson, L. H., A.P. Clevenger, A. T. Cooper, V. H. Dale, L. Evanns, G. L. Evink, L. Fahrig, K. E. Haynes, W. W. Kober, S. B. Lester, K. H. Redford, M. N. Strand, P. Wagner, J. M. Yowell. 2005. Assessing and Managing the Ecological Impacts of Paved Roads. Committee on Ecological Impacts of Road Density. Transportation Research Board. The National Academies Press, Washington, D.C.

Keller, I., C. R. Largiader, and W. Nentwig. 2003. Recent fragmentation due to major roads leads to a reduction of gene flow in ground beetles. Abstract presented at International Conference on Habitat Fragmentation due to Transportation Infrastructure 2003. Brussels, Belgium.

MacDonald, L.A., and S. Smith. 1999. Bridge replacements: An opportunity to improve habitat connectivity. In: G. Evink, P. Garret, and D. Zeigler, eds. Proceedings of the Third International Conference on Wildlife Ecology and Transportation, Missoula, MT. FL-ER-73-99. Florida Department of Transportation, Tallahassee, FL. 330pp.

Trombulak, S. C. and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology (14):18-30.

United States General Accounting Office. 2004. State and Metropolitan Planning Agencies Report Using Varied Methods to Consider Ecosystem Conservation: Report to Congressional Requesters. GAO-04-536, Washington, D.C.

Weigel, L. 2005. Results of a National Opinion Poll Conducted for the International Association of Fish and Wildlife Agencies to Ascertain the American Public's Perceptions and Values of Wildlife. American Conservation Information Conference, Ogden, UT, Proceedings.

# Linking Statewide Connectivity Planning to Highway Mitigation: Taking the Next Step in Linking Colorado's Landscapes

**Julia Kintsch** (303-454-3344, julia@restoretherockies.org), Southern Rockies Ecosystem Project (www.restoretherockies.org), 1536 Wynkoop Suite 200, Denver, CO 80202 USA

**Abstract:** Statewide connectivity planning represents an important first step for informing the transportation planning process at the statewide and regional levels. However, without finer scale assessment, such broad-scale planning does not provide sufficient information for integration into project-level designs. The *Linking Colorado's Landscapes* project – designated as a 2006 Exemplary Ecosystem Initiative by the Federal Highway Administration – was initiated in 2003 to identify, prioritize, and assess wildlife movement linkages throughout Colorado. The project developed as a collaborative effort between the Colorado Department of Transportation (CDOT), the Federal Highway Administration (FHWA) and the Southern Rockies Ecosystem Project (SREP). Under this unique partnership, a FHWA grant enabled CDOT to contract with SREP for the development of a connectivity assessment in Colorado. This arrangement has facilitated CDOT's consideration of landscape-scale permeability for wildlife while addressing the state's transportation needs and environmental stewardship objectives.

*Linking Colorado's Landscapes* consisted of two phases: a statewide assessment of broad-scale wildlife linkages, and an in-depth assessment of twelve of the highest priority linkages. Now complete, the challenge for the project partners lies in integrating both the vision for a connected landscape and the more detailed recommendations into all levels of transportation development – from long range transportation plans to on-the-ground transportation projects. This paper describes the methods and opportunities for implementing the vision as well as the site-specific recommendations provided in *Linking Colorado's Landscapes*.

## Linking Colorado's Landscapes

The primary objective of Linking Colorado's Landscapes was to identify broad linkage zones that facilitate movement for Colorado's diverse array of wildlife species, to prioritize amongst them for further study, and provide in-depth evaluations for a subset of the highest priority linkages. A linkage is defined as the intervening area between larger blocks of suitable habitat that facilitates daily and seasonal movements or dispersal from natal sites by providing animals with the security, food and shelter they need to meet their life history requirements (Dobson et al. 1999; Servheen et al. 2003).

Phase I of this projected consisted of a statewide assessment of wildlife linkages in Colorado (SREP 2005). The resulting connectivity map provides CDOT planners with a comprehensive strategy for maintaining and restoring habitat connectivity for wildlife. As CDOT embarks on its 2035 Statewide Transportation Plan, the data is accessible for direct incorporation, highlighting to planners where concerns about wildlife habitat connectivity intersect transportation routes. Integration at this level acts as an early warning flag to project-level transportation planning, prompting consideration for appropriate mitigation measures and funding for such measures.

The focus of Phase II was a set of wildlife linkage assessments prepared for each of twelve high priority linkages identified in Phase I (SREP 2006). These assessments provide a deeper accounting of both the challenges and the opportunities for improving highway permeability for wildlife along these twelve stretches of highway in Colorado. SREP visited and inventoried each of these linkage areas where they are intersected by highways, compiling information on existing structures, and determining how and where target species (primarily mid- and large-sized mammals) are traversing from one side of the roadway to the other, and identified locations where natural or man-made barriers might prevent such movements. These inventory data were combined with other layers of information, such as land ownership and management adjacent to the highway, traffic volumes, and zoning. Previous research on wildlife road-crossing locations in Colorado suggests that mid- and large-sized mammals focus their crossing activity along specific roadway segments (Barnum 2003). Such stretches of roadway were correlated to features in the surrounding habitat as well as the roadway itself. As the variables influencing crossing activity may vary from one location to the next, the Linkage Assessments capture a broad suite of factors including habitat type, vegetation cover, topographic features, roadway width, roadway barriers (e.g., jersey walls, guardrails), traffic volumes, and existing structures.

To complete the linkage assessments, SREP partnered with transportation engineers and biologists from CDOT, the Colorado Division of Wildlife and the U.S. Forest Service to develop guidelines and recommendations for improving safe passages for wildlife across these critical stretches of highway using the best available techniques. Recommended mitigation measures range from the simple and immediate to the large-scale and visionary. Recommendations are presented for specific mileposts or segments of roadway, focusing on the portions of each linkage with the greatest potential benefit to wildlife movement and the best opportunities for implementing those measures. These recommendations are tailored to the particular site and wildlife populations present. In many instances, several different mitigation measures are combined to create a comprehensive suite of mitigation measures that offer the most effective and feasible means for addressing wildlife movement and highway safety.

The *Linking Colorado's Landscapes* project was designated a 2006 Exemplary Ecosystem Initiative by the Federal Highway Administration as a model for other state initiatives.

## Implementing Linking Colorado's Landscapes at Multiple Scales

*Linking Colorado's Landscapes* was designed to guide CDOT and other local and regional transportation organizations in the creation of more wildlife-friendly landscapes and transportation networks. The key to realizing the vision for a connected landscape as well as the more detailed recommendations lies in implementation - a multi-step process that involves flagging linkage areas early in the transportation planning process; coordinating with the appropriate regional transportation planning units to highlight the purpose and need for mitigation measures; and empowering project-level designers and engineers with both an understanding of the issue as well as the possible remedies. Partnerships through all levels of the transportation agency as well as with sate and federal wildlife and land management agencies, and counties, land trusts and other local organizations are essential for on-the-ground success.

Several challenges that must be addressed to ensure the design of functional crossing structures and other mitigation measures for wildlife include:

- Integrating available ecological data into the planning process so that wildlife considerations arise early in the planning process;
- Reconciling timelines for planning for wildlife mitigation measures (including monitoring) with transportation project timelines;
- Budgeting for wildlife mitigation measures.

A comprehensive strategy that addresses all levels of the planning and design process is needed to adequately address these challenges. The following section describes several implementation activities being pursued in Colorado to meet these needs at the statewide, regional and local scales.

**Statewide Scale**

There are three primary areas where SREP is currently engaging to incorporate considerations for wildlife in the transportation planning and design process: (1) CDOT's 2035 Statewide Transportation Plan, (2) Developing an early warning system to alert transportation planners to potential wildlife conflicts, (3) Public education and awareness to build citizen support for wildlife-oriented mitigation measures.

*Statewide Transportation Planning*

While transportation projects occur at a local-scale, the seeds for each project are planted at the statewide scale in the Statewide Transportation Plan, which is renewed every five years. CDOT is currently undergoing a planning process for the 2035 Statewide Transportation Plan, including a ground-up effort to integrate the transportation concerns and visions from counties, residents and businesses in each region of the state. While the Statewide Plan does not allocate discretionary funds, it does present the dollars amount need to accomplish the vision, and it provides a preliminary prioritization of how funding will be distributed among each of the transportation corridors.

Integrating concerns regarding wildlife movement and animal-vehicle collisions in the statewide vision is the first step in ensuring that these concerns are adequately addressed at the project level. To assist this process, SREP overlaid the statewide linkage assessment data with the transportation corridors to determine where these concerns should be highlighted in the 2035 Statewide Transportation Plan. Based on this overlay, SREP submitted comments and attended meetings of the Transportation Planning Regions to ensure that the vision statements for each transportation corridor acknowledge wildlife concerns, where relevant. While inclusion of these concerns does not guarantee funding for mitigation measures, early consideration of habitat connectivity needs for wildlife can help to streamline wildlife crossings and highway improvement projects, before project designs are complete.

*Developing Mechanisms for Avoiding Impacts and Placing Effective Mitigation*

To further facilitate early considerations for habitat connectivity and wildlife movement in the transportation planning process, SREP and Defenders of Wildlife have teamed up under a grant from the Wildlife Conservation Society to integrate the State Wildlife Action Plans with CDOT's transportation planning processes. Although transportation priorities are set well in advance of construction, many biologists and conservationists only comment at the Environmental Impact Statement stage in the process. At this point, it is often too late to avoid environmental impacts since most decisions are already in place. Furthermore, because highway projects are designed and implemented on a project-by-project, basis often without a landscape-scale perspective, mitigation must occur within the project boundary as opposed to other locations that may be more effective.

A four-step process developed by SREP and Defenders of Wildlife addresses these needs. The first step requires additional analysis of the wildlife linkages identified in Colorado's statewide connectivity assessment to further define the spatial extent of each linkage, producing clear habitat boundaries within the landscape and identifying optimal travel routes for select focal species to move between protected core habitat areas. In the next step these data are overlaid with the Statewide Transportation Improvement Program (STIP) to determine where upcoming highway projects intersect with important wildlife travel routes. The STIP is renewed every 1-3 years and covers the funded projects expected to happen over a 5-year period. By creating a clear spatial and temporal depiction of where planned future highway projects will overlap with priority wildlife habitat movement corridors we will align both the avoidance and mitigation requirements of CDOT with the goals of the State Wildlife Action Plan.

The third step in the process applies Section 6001 of the *Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users* (SAFETEA-LU) that requires each state department of transportation to consult with federal and state land management, natural resource, and wildlife management agencies while developing their transportation plans. Under this act, each consultation will include a comparison of the transportation plan with conservation maps and must also include potential mitigation activities. The GIS overlay of the STIP with spatially-defined wildlife linkages is being used to develop an early-warning flagging system to identify conservation conflicts – areas where high priority wildlife connections intersect with upcoming transportation projects. This warning system will ensure these areas are avoided and impacts are minimized as transportation projects proceed from the planning stage, to design, then construction. An automated GIS spatial query is being developed to flag these conservation conflicts, ensuring that both CDOT and relevant engineering and environmental consulting firms are made aware of these conflicts.

Once the early-warning system is in place, we will apply the framework outlined in the recently released FHWA publication *Eco-logical – An Ecosystem Approach to Developing Infrastructure Projects* (Brown 2006) to ensure sensitive areas are avoided and the right mitigation happens in the right place. Applying this concept of ecosystem-based mitigation, we are developing a 'matchmaking' system that defines the most effective mitigation measure at the ecosystem level. This powerful approach will allow us to look outside of project bounds when assessing a location for mitigation. The following criteria are being applied to ensure that mitigation is placed effectively: (1) species ranking and associated habitat type, (2) degree of conservation threat, (3) land ownership and protection status, (4) roadway engineering assessment to determine mitigation feasibility, (5) conservation opportunity and potential partners to leverage resource, and (6) cost effectiveness. Upon completion of these activities we will have established a clear and replicable framework for adoption by other DOTs and Divisions of Wildlife across the nation.

*Public Education*

The third effort in which SREP is engaging at the statewide level is a public education and awareness campaign. These efforts are an essential component in building public support for mitigation measures that improve habitat connectivity for wildlife. Activities in this category include outreach to counties, land trusts and other local partners working in wildlife linkage areas to ensure due consideration of wildlife concerns in their planning, zoning, and land protection efforts; distributing tens of thousands of driver safety tips sheets across Colorado to educate drivers about animal-vehicle collisions; and semi-annual press releases that reach millions of people via print, TV and digital media.

**Local Scale**

While efforts at the statewide scale are essential for setting the framework for wildlife-oriented transportation development, project development occurs at the site, or local scale. Coordination with project managers, regional environmental personnel, field-based wildlife and land managers, counties and other local partners is essential to facilitate implementation of on-the-ground projects that include protective measure for wildlife. SREP is currently engaged in two site-specific implementation projects. The first is a major effort to construct a large wildlife crossing within a critical wildlife linkage at Vail Pass. The second is a smaller project to make improvements to wildlife fencing along a stretch of Highway 500 in western Colorado. Each project provides an excellent example of project-based partnership, and both are important actions helping to improve habitat connectivity for wildlife across the landscape.

*Vail Pass Wildlife Bridge*

The stretch of Interstate 70 (I-70) over Vail Pass travels between the Gore Range to the northeast, and the Sawatch Range to the southwest. This location was identified in *Linking Colorado's Landscapes* as an ecologically significant site for north-south connectivity (SREP 2005). The main goal for this linkage is to restore landscape-scale connectivity across the interstate, which is the primary east-west route through Colorado and generally recognized as a significant barrier to wildlife movement.

A wildlife bridge has been proposed as an early action, ecosystem–based mitigation measure for the unavoidable infrastructure impacts the I-70 mountain corridor expansion will have on wildlife, including the planned addition of climbing lanes to West Vail Pass. Travel demand has been increasing steadily on the I-70 mountain corridor between Glenwood Springs and Denver. In response to that demand, CDOT released a Programmatic Environmental Impact Statement (PEIS) in November 2004 - a major study that evaluates transportation improvements to I-70, detailing a variety of transportation alternatives and their associated environmental impacts.

According to the draft PEIS, "the primary issue affecting wildlife in the Corridor is the interference of I-70 with wildlife movement and animal-vehicle collisions. Barriers to wildlife movement include structural, operational, and behavioral impediments to wildlife trying to cross I-70" (CDOT 2004). In 2001, CDOT and FHWA convened an interagency group of wildlife specialists called *A Landscape Level Inventory of Valued Ecosystem Components* (ALIVE) to guide the development of wildlife mitigation strategies as a part of the I-70 PEIS. Other agencies engaged in the ALIVE committee included agencies responsible for the protection and management of wildlife habitats and threatened and endangered species - the Colorado Division of Wildlife (CDOW), the Bureau of Land Management (BLM), the US Forest Service (USFS), and the US Fish and Wildlife Service (USFWS).

The ALIVE committee compiled and evaluated a wide range of ecological components. The subsequent GIS analyses highlighted barriers to ecosystem flows and wildlife movement, and impaired landscape components, enabling the committee to assess the direct, indirect and cumulative impacts of transportation improvements proposed in the I-70 PEIS, and target effective landscape-level mitigation strategies. The ALIVE group made comprehensive recommendations on wildlife crossing mitigations in thirteen key wildlife "Linkage Interference Zones", or wildlife movement areas. The committee gave each zone a priority rank and identified specific mitigation measures for locations within each Linkage Interference Zone. Two zones were mapped on Vail Pass, one along the west side of the pass and another along the east side. The identification of Vail Pass as one of these high priority linkage areas crossing I-70 was further substantiated in the statewide assessment of wildlife linkages (Phase I).

While the Final Programmatic Environmental Impact Statement (PEIS) will not be complete until late 2007 and the precise nature of the increased infrastructure uncertain until then, the identification of the Linkage Interference Zones provides guidance for moving forward with appropriate mitigation measures as opportunities arise. Vail Pass presents just this opportunity - Forest Service lands on either side of this stretch of interstate ensure habitat protection in the linkage approaches, a new crossing structure near the summit of the pass will greatly increase north-south permeability across the interstate by complementing the existing span bridges located lower down on the pass by providing an additional crossing option that would be accessible to a greater variety of species. Political factors also play a role in advancing this proposal – due to bi-partisan support from Colorado's congressional delegation, in 2005, the Colorado Department of Transportation received $420,000 from public lands highway discretionary funds for a feasibility assessment and preliminary engineering designs. This initial investment is a crucial step in planning for a crossing structure and additional congressional support will be necessary to raise the full amount of funding needed for construction of the wildlife bridge.

To complement these efforts and begin collecting baseline data on wildlife activity around Vail Pass, SREP, in collaboration with the Denver Zoo and the Gore Range Natural Science School launched the *Citizen Science Wildlife Monitoring* program to engage local citizens in the collection of these data. The program is designed to (1) engage a broad range of community members in an educational wildlife monitoring project, (2) collect critical information about wildlife movement, and (3) develop an informed and active community that engages with scientists, policy-makers and other citizens about the importance of landscape connectivity for wildlife movement.

Thirty-one trained citizen scientists are now maintaining and collecting images from forty-nine motion-sensitive cameras placed along the interstate and in the forested approaches to the roadway. Over the long-term, these data will be compared with post-construction data after the bridge is complete, allowing evaluations of on the effectiveness and impact of this structure.

The Citizen Science Program has been instrumental in catalyzing support among a larger group of agency and university partners to expand the monitoring effort and begin developing protocols for pre- and post-construction monitoring of wildlife crossings. A multi-species monitoring approach that tests several different monitoring techniques could greatly enhance support for monitoring projects at other locations where these data are needed to locate, design and evaluate mitigation projects. The next step for this interagency collaboration is to develop a fundraising plan and submit proposals to accomplish the monitoring goals defined by the group.

*State Highway 550, Wildlife Fencing Improvements*

This stretch of Highway 550 between Montrose and Ridgway was identified in *Linking Colorado's Landscapes* as a high priority wildlife linkage for elk, mule deer and mountain lion. The linkage encompasses important winter and summer habitat for mule deer and elk, and provides dispersal and forage habitat for carnivores such as mountain lion, bobcat, black bear and potentially gray wolf. The main goal for this linkage is to restore the connectivity function of the linkage for these species and to reduce animal-vehicle collisions, which are among the highest in the state along this stretch of roadway.

The Phase II Linkage Assessment identified the existing wildlife fencing that borders eight miles of this highway as problematic for both wildlife movement and driver safety. This long stretch of fencing combined with a lack of adequate structures has created a substantial barrier to successful wildlife crossings over this section of roadway. Yet holes in the fencing and gaps at roadway access points have the undesired effect of allowing animals to enter the highway right-of-way where they can become trapped by the fencing. With the implementation of additional mitigation measures there lies excellent potential to transform the existing infrastructure along this stretch of roadway from a problematic barrier into a comprehensive and effective wildlife crossing system.

To begin addressing these needs and opportunities, SREP, in collaboration with the San Juan Corridors Coalition (a local conservation organization), Ridgway State Park, the City of Ouray, the Town of Ridgway, the Division of Wildlife, and CDOT are submitting a proposal to the Transportation Planning Region for an enhancement grant to reduce animal-vehicle collisions along this stretch of roadway. The proposal calls for removing the existing one-way deer gates, which are too small for elk use and malfunctioning due to disrepair, and replacing them with escape ramps, as well as tying in the fence ends to landscape features to discouraging animals from entering the right-of-way at these locations.

This request is for just $109,000 with a $30,000 local match, which is not sufficient funding for a complete solution for restoring landscape permeability for wildlife across the highway. Regardless, this proposal does represent an important step towards minimizing opportunities for wildlife to get trapped in the right-of-way and providing opportunities for exiting the right-of-way when they do get trapped. By engaging local partners we are setting the groundwork for future collaborations and other improvements including, land protection at key locations, the construction of new wildlife crossing structures, and additional improvements to the wildlife fencing. This proposal has garnered local support, demonstrating the role of even seemingly small improvements in the bigger picture, and can be used to help the partners leverage additional funds for future remediation.

## Conclusion

Both the statewide assessment (Phase I) and the more detailed linkage assessments for twelve high priority linkage areas (Phase II) are proving invaluable resources as SREP moves forward with our partners towards realizing a landscape with restored connections for wildlife. While the statewide connectivity assessment provides a broad view of the landscape, allowing wildlife-highway conflict areas to be identifies early on in the transportation planning process, the recommendations developed in the linkage assessments provide a guide to reducing transportation-related impacts to wildlife along specific stretches of highway.

By integrating considerations for wildlife habitat connectivity and specific recommendations for mitigation measures into transportation projects, Colorado now has the occasion to transform problematic highway segments from danger zones for wildlife and drivers into effective wildlife crossing systems. CDOT, SREP and a number of other partners will play critical roles in public education and citizen engagement, habitat protection, and the planning, design, and construction of appropriate mitigation measures to implement all the components of a vision for a connected landscape.

**Biographical Sketch:** Julia Kintsch is the Program Director at the Southern Rockies Ecosystem Project where she led the *Linking Colorado's Landscapes* project. She received a master's degree in landscape ecology from Duke University where her research focused on conservation design strategies. Her work continues to focus on developing guidelines for designing appropriate mitigation measures for wildlife and assisting project planners and engineers in the implementation of such measures. She oversees a variety of research and implementation projects and advises conservation groups, consultants, and agencies on conservation design and habitat connectivity for wildlife.

The Southern Rockies Ecosystem Project is a nonprofit conservation science organization working to protect, restore and connect ecosystems in the Southern Rockies of Colorado, Wyoming and New Mexico.

## References

Barnum, S.A. 2003. Identifying the best locations along highways to provide safe crossing opportunities for wildlife. Colorado Department of Transportation Research Branch, Report No. CDOT-DTD-UCD-2003-9. Denver, CO.

Brown, J. Eco-logical: An Ecosystem Approach to Developing Infrastructure Projects. Federal Highway Administration Report #FHWA-HEP-06-011. Washington, D.C.

CDOT. 2004. I-70 Mountain Corridor Draft Programmatic Environmental Impact Statement and Section 4(f) Evaluation. U.S. Department of Transportation, Federal Highway Administration, and the Colorado Department of Transportation. Project IM 0703-244. Aurora, CO.

Dobson, A.P., K. Ralls, M. Foster, M.E. Soule, D. Simberloff, D.F. Doak, J.A. Estes, L.S. Mills, D. Mattson, R Dirzo, J Arita, S. Ryan, E.A. Norse, R. Noss, and D. Johns. 1999. Corridors: reconnecting fragmented landscapes. Pages 129-170 in M.E. Soulé and J. Terborgh (eds). Continental Conservation: Scientific Foundations of Regional Reserve Networks. Island Press. Washington, D.C.

Servheen, C.J., S. Waller, and P. Sandstrom. 2003. Identification and management of linkage zones for wildlife between large blocks of public land in the northern Rocky Mountains. U.S. Fish and Wildlife Service and University of Montana: Missoula, MT.

SREP. 2005. Linking Colorado's Landscapes: A Statewide Assessment of Wildlife Linkages, Phase I Report. Southern Rockies Ecosystem Project. Denver, CO.

SREP. 2006. Linking Colorado's Landscapes Phase II Reports. Southern Rockies Ecosystem Project. Denver, CO.

# Linking Transportation and Conservation: How the State Wildlife Action Plans Can Help Protect Wildlife From Road Development

**Patricia White** (202-682-9400 ext. 236, twhite@defenders.org), Director, Habitat and Highways Campaign;
**Julia Michalak** (202-682-9400 ext. 147, jmichalak@defenders.org); and
**Jeff Lerner** (202-682-9400 ext. 291, jlerner@defenders.org), Defenders of Wildlife, 1130 17th Street N.W., Washington, DC 20036, Fax: 202-682-1331 USA

**Abstract:** We reviewed all 51 State Wildlife Action Plans to glean a set of cross-cutting recommendations for future collaboration between wildlife and transportation agencies.

As of October 1, 2005, every state wildlife agency, in conjunction with numerous partners, completed a comprehensive state wildlife action plan. Each plan is unique, but all plans were required to identify 1) declining species, 2) key habitats, 3) threats to those species and habitats and 4) actions to prevent further species decline. We reviewed the plans from all 50 states and the District of Columbia to determine the extent to which the plans identify and address transportation planning and development impacts. To do this we searched every plan for references to roads, transportation, transportation agencies, vehicles, and highways. From these searches we created a compilation of threat and action references and categorized each reference to identify common issues and strategies among the plans.

We found that all 51 plans identified transportation infrastructure as a conservation issue. Specifically, the plans related the following general impacts to transportation planning and construction:

- Habitat loss and fragmentation
- Spread of invasive species
- Road kill mortality
- Altered hydrologic regimes
- Modified population migrations and dynamics

We searched for actions tied directly to transportation issues and found that the states included a wide range of actions relating to transportation. Forty states recognized the need to work with transportation agencies by including one or more of the following actions:

- Improve coordination between wildlife and transportation agencies
- Enter into a Memorandum of Understanding with transportation agencies
- Provide data and technical assistance to transportation planners
- Get more involved in transportation planning and permitting

In addition to promoting coordination, the wildlife plans can provide transportation agencies with information about priority species and habitats and, in many cases, maps of priority conservation areas. The final section of our report presents a set of recommendations, based on information gleaned from the plans, for improving coordination and reducing transportation impacts on wildlife.

The State Wildlife Action Plans are an opportunity for wildlife agencies and transportation planners to begin a dialogue about this issue and foster improved collaboration in the future. Future research should put these plans into action by overlaying GIS layers of transportation plans with maps of conservation opportunity areas, priority habitats, and locations and ranges for species of concern. Further analysis of the plans by transportation planners to identify useful features and information gaps in the plans could help wildlife agencies improve their plans in the future.

The placement and design of transportation infrastructure has significant impacts on wildlife and biodiversity protection. Most obviously, roads, highways and vehicle travel cause immediate mortality through vehicle collisions. However, roads also destroy and fragment habitat, increase air and water pollution loads, spread invasive species, modify animal behavior and increase human access to previously remote areas (Trombulak and Frissell 2000). Scientists can measure these impacts up to 100 meters from the road's edge (Forman et al. 2003). As a result, researchers estimate that each mile of highway has measurable effects on 48 acres of habitat (Council on Environmental Quality 1974) and, collectively, our transportation system negatively affects one fifth of the land area in the United States (Forman et al. 2003).

Habitat loss, degradation and fragmentation are widely viewed as among the most significant causes of species imperilment in the United States (Wilcove et al. 1998). The Endangered Species Act currently lists 1,878 species as either threatened or endangered. However, an additional 15,000 species in the United States are considered globally "at risk" by conservation organizations (NatureServe 2006). It makes both economic and ecological sense to protect these at risk species before they reach the point of endangerment. The transportation planning process offers an important opportunity for proactive conservation work. If transportation planners have information and technical assistance about important conservation resources, they can do a better job of avoiding impacts to important areas and minimizing or mitigating unavoidable impacts.

Enacted in 2005, section 6001 of the *Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users* (SAFETEA-LU) requires that transportation planners consult with available conservation and biodiversity plans during their long-range planning process (Federal Highway Administration 2005). As of October 2005, every state in the U.S. completed a State Wildlife Action Plan aimed at assessing conservation needs for at risk species. The development of these Action Plans means that all states, the District of Columbia and all U.S. territories have biodiversity plans that can inform transportation and help fulfill the section 6001 planning requirements.

We reviewed the Action Plans from all 50 states and the District of Columbia to determine to what extent they identify roads and highways as a threat to wildlife and how they can be used to help alleviate that threat. We searched each of the Action Plans for references to transportation key words including roads, highways and vehicles. We then coded each reference into a series of threat and action themes and identified commonalities across all Plans.[1]

We found that all 51 Action Plans recognized that roads and highways have a negative impact on wildlife. Eleven states indicated that transportation infrastructure constituted a priority statewide threat (AK, AL, AR, DC, FL, MI, NH, OR, SD, VA and VT); eight states prioritized transportation infrastructure as a threat to particular regions, habitats or species taxa; and TX and WY strongly emphasized transportation threats (see Map below).


In most of these passages, states referenced transportation infrastructure as part of larger scale issues like habitat fragmentation and general development. The remaining 30 states did not rank or emphasize transportation infrastructure as a threat to wildlife. In contrast, Defenders' found that 37 states identified development as a significant issue either statewide or to a particular region or habitat type within the state (Michalak and Lerner 2007).

Collectively, the Action Plans included references to all seven categories of ecological effects of roads on wildlife as identified by Trombulak and Frissell (2000): alteration of the physical environment (referenced by 48 Plans), mortality from collisions (35 Plans), behavior modification (31 Plans), alteration of the chemical environment (28 Plans), increased invasive species (21 Plans), increased human use of area (9 Plans) and mortality from construction (6 Plans). The Plans called attention the transportation network's contribution to habitat loss and fragmentation, mortality from vehicle collisions, barriers to migration and dispersal, pollution through runoff, salt and exhaust, spreading invasive plant species and increased recreation use.

We also reviewed the Plans to determine the actions that the states propose to address transportation threats. Using these references, we identified a series of action themes which we grouped into the following categories: improve interagency coordination, integrate planning efforts, design roads to minimize impacts, apply vegetation management, continue research and monitoring efforts, protect land, educate the public and increase capacity. More Plans included actions relating to coordination with transportation planners than any other action category. As part of the 8 Required Elements, Congress required the states to include "plans for coordinating the development, implementation, review, and revision of the State Comprehensive Wildlife Comprehensive Plan [Action Plan] with Federal, State, and local agencies and Indian tribes that manage significant land and water areas..."

Although the majority of Action Plans identified actions to improve coordination and integration of transportation planning and biodiversity conservation, almost none identified specific points in the transportation planning process where this integration could take place. Only 13 Action Plans indicated that transportation planners were either invited or in fact participated in the Action Plan's development.

Transportation planning is an extremely extensive process. It will help resource agencies and conservationists significantly to have a firm understanding of all phases of transportation planning in their state. Traditionally, resource agencies and biologists get involved with a transportation project during the permit review and environmental assessment stages. At this late stage, making significant changes means delays, added costs and usually little environmental benefit. Instead, state wildlife agencies and other conservationists can have a far more productive and effective influence by getting involved during both long and short range planning. The former covers a 20 year time horizon while the latter focuses on the next 2-5 years. Working with planners at these stages can help ensure that especially damag-

[1]Our report focuses on public highways that are built and maintained by county, state and federal agencies and used by the general driving public. We excluded references to the impacts of logging roads, off road trails, illegal roads or roads built to facilitate oil and gas exploration from our analysis.

ing projects are either removed or noted before significant resources are dedicated to a specific project. Transportation planning revolves around maps and spatial analysis. In order to work effectively with transportation planners, natural resources agencies will need to provide them with spatially explicit data.

Twenty-five states included maps of priority conservation areas in their Action Plan. Only eight states included sharing spatial data with transportation planners as an action (AR, FL, GA, MD, NH, NJ, NM, and VT). This stands in sharp contrast to the 39 states that included sharing spatial data with land use planners as an action to help address sprawl and development impacts (Michalak and Lerner 2007).

The recently authorized section 6001 of SAFETEA-LU has significant implications for implementation of the Action Plans. The requirement for comparing conservation and transportation plans offers an opportunity for a proactive, non-regulatory approach to reducing transportation impacts. In addition, SAFETEA-LU authorizes transportation agencies to fund liaison staff positions, invasive species control and further planning. Finally, transportation mitigation funding for unavoidable impacts can provide much needed dollars for land protection and restoration. Based on the findings in this report, we have identified a set of implementation recommendations for natural resource agencies interested in getting more involved in transportation planning. These include:

**Learn the Transportation Planning Process**

Transportation planning is a complicated process that involves scores of planners and occurs over long time frames. Understanding the various phases of this process and being familiar with the time frames and deadlines for transportation planning in your state will be essential in order to engage transportation planners effectively. This report offers a very general overview of transportation planning.

**Provide Meaningful Technical Assistance**

Transportation planners are likely to have little to no background in wildlife conservation. Wildlife agencies and conservationists can play a significant role by providing meaningful technical assistance. In the case of transportation, this means sharing spatial data for priority species, habitat and conservation area locations with planners. Transportation planners absolutely rely on maps and spatial analysis to do their planning and will have significant difficulty using non-spatial data. In addition, resource agencies can create sustained and consistent partnerships between transportation and natural resource planners. Doing so will ensure that transportation agencies have a trusted contact they can access reliably for questions and assistance.

**Target Education Strategically**

Target elected officials, metropolitan planning organizations and long-range transportation planners to inform decision makers about the impacts of roads on wildlife and ecosystems. Wildlife agencies can provide workshops and training sessions about biodiversity and how transportation planners can use their State Wildlife Action Plan as a guide for protecting biodiversity.

**Increase Capacity**

Keeping on top of transportation planning, new projects, public involvement and conservation needs relating to road and highways is a full time job. Luckily, state transportation agencies are authorized to use funding to create joint positions with resource agencies, research transportation impacts and best management practices and further conservation and transportation planning efforts. Furthermore, the strategic use of mitigation dollars for priority land conservation and habitat restoration can provide a much needed boost to existing conservation resources. Given the resources available, every state should have natural resource staff engaged in transportation planning.

## References

Council on Environmental Quality. 1974. The Fifth Annual Report of the Council on Environmental Quality. U.S. Government Printing Office, Washington, DC.

Federal Highway Administration. 2005. SAFETEA-LU. http://www.fhwa.dot.gov/safetealu/ (Accessed on April 25, 2007).

Forman, R. T. T. and D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Farig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. Road Ecology: Science and Solutions. Island Press, Washington, DC.

Michalak, J. L. and J. Lerner. 2007. Linking Conservation and Land Use Planning: using the state wildlife action plans to protect wildlife from urbanization. Defenders of Wildlife, Washington DC.

NatureServe. 2006. NatureServe Explorer: An online encyclopedia of life [web application]. Version 6.1. NatureServe, Arlington, Virginia. Available http://www.natureserve.org/explorer. (Accessed: April 26, 2007 ).

Trombulak, S.C., and C. Frissell. 2000. A review of the ecological effects of roads on terrestrial and aquatic ecosystems. Conservation Biology 14: 18-30.

Wilcove, D.S., D. Rothstein, J. Dubow, A. Phillips, E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience 48: 607-615.

# State Wildlife Action Plans: A Resource for State Wildlife Agencies and State Transportation Agencies to Work Together to Prevent Wildlife From Becoming Endangered

**David Chadwick** (202-624-7890, chadwick@fishwildlife.org), Senior Program Associate, Association of Fish and Wildlife Agencies (www.wildlifeactionplans.org), 444 North Capitol Street N.W., Suite 725, Washington DC 20001 USA

**Abstract:** As a requirement of the federal Wildlife Conservation and Restoration Program and State Wildlife Grants program, each state fish and wildlife agency has developed a wildlife action plan, known technically as a "comprehensive wildlife conservation strategy." The wildlife action plans identify the actions that are needed to prevent wildlife from becoming endangered in each state, including habitat conservation, management, restoration, and research and monitoring. Every state has completed an action plan, presenting an historic opportunity to improve the conservation of at-risk wildlife across the nation.

Since the wildlife action plans draw together the best scientific data, input from a broad array of experts and stakeholders, and recommendations from prior planning efforts, they present the most comprehensive assessment of what needs to be done in each state to conserve declining and imperiled wildlife. The wildlife action plans complement existing fish and wildlife management activities focused on recreationally harvested game and sportfish species. Because the action plans are focused on preventing wildlife from becoming endangered, they can be a powerful platform for a range of collaborative, preventive conservation planning and restoration activities.

## Introduction

The United States has reached another milestone in our nation's long history of conservation success: every state fish and wildlife agency has recently completed a *wildlife action plan*. These comprehensive strategic plans outline the actions that are needed to prevent wildlife from becoming endangered in each state. Taken as a whole, the wildlife action plans present a nationwide platform for protecting at-risk fish and wildlife through aggressive, preventive action in every state. By focusing on preventive conservation for at-risk or imperiled species, the action plans complements existing programs aimed at game species conservation and endangered species conservation, advancing our collective ability to undertake landscape-scale, habitat-based conservation. They also present a powerful resource for transportation planners and managers to work collaboratively with state wildlife agencies.

## Background

Wildlife conservation in the United States is a partnership effort between state fish and wildlife agencies and the federal government. State governments have primary responsibility for managing and conserving fish and wildlife as a public trust resource, a responsibility dating back to the American Revolution and the development of our nation's core political principles. The federal government plays a critical role in funding state-level wildlife conservation activities, managing migratory species, conserving habitat on federally-owned public lands, and protecting endangered and threatened species.

Our nation's approach to funding fish and wildlife conservation has been predominantly a user-pays/user-benefits model in which fees are collected from hunters and anglers and reinvested primarily in the conservation of species that are hunted and fished. At the state level, fish and wildlife agencies have been funded largely by user fees and taxes paid by directly hunters and anglers: relatively little funding comes from general legislative appropriations. Federal funds for wildlife conservation have come through two major programs: the Federal Aid in Wildlife Restoration Program (commonly called "Pittman-Robertson") and the Federal Aid in Sportfish Restoration ("Dingell-Johnson/Wallop-Breaux"). These programs dedicate the receipts from federal excise taxes on hunting and fishing equipment and motorboat fuels back to state fish and wildlife agencies.

The user-pays/user-benefits model has been tremendously successful, resulting in the recovery of many of America's most treasured fish and wildlife species. Landscape-scale habitat conservation has ensured strong waterfowl populations at the continental scale. Reintroduction, habitat management and harvest regulation have helped bring species like wild turkey, striped bass, and elk back from the brink of extinction.

Unfortunately, this very successful model has not provided the resources needed to keep up with the pressures faced by *all* wildlife species. In fact, the vast majority of fish and wildlife – from songbirds to reptiles to invertebrates – have been left largely without reliable funding for conservation. The results have been clear: facing accelerating habitat loss and other threats, a large portion of our nation's native fauna face declines and the threat of eventual extinction.

## Teaming With Wildlife: Broadening the Model

The Teaming with Wildlife initiative was launched in the early 1990s to expand the funding base for wildlife conservation and provide the resources needed to support a more comprehensive approach to wildlife conservation. A core principle of the Teaming with Wildlife effort has been that *all citizens* should contribute to the conservation of fish and wildlife and that *all species* should concurrently benefit from conservation attention. Over time, the initiative has grown to include more than 5000 organizations and agencies, including hunters and anglers, environmentalists, professional biologists, wildlife managers, and nature-related businesses.

During the late 1990s, the efforts of the Teaming with Wildlife coalition helped advance the Conservation and Reinvestment Act, a broad proposal to increase dramatically federal funding for a variety of land, water, and wildlife conservation programs. Despite strong bipartisan support, the Conservation and Reinvestment Act did not pass.

However, Congress did enact two new programs in 2000 to support wildlife conservation: the Wildlife Conservation and Restoration Program (WCRP) and State Wildlife Grants (SWG).

## The Wildlife Conservation and Restoration Program and State Wildlife Grants Program

The Wildlife Conservation and Restoration Program and State Wildlife Grants provide funding to state wildlife agencies for on-the-ground conservation projects and wildlife conservation planning. Both programs are administered by the US Fish and Wildlife Service through the Division of Federal Aid. Under both programs, funds are distributed to states according to a formula based on each state's population and land area. The federal funds distributed by the programs require matching funds from state or other non-federal sources. The Wildlife Conservation and Restoration Program require a 25% non-federal match for all activities. Funds under the State Wildlife Grants program require a 50% match rate (although a 25% rate was applied during the development of the state wildlife action plans).

Although the Wildlife Conservation and Restoration Program was authorized as a permanent program, funding was only provided for the first year. However, federal funding has continued to flow to State Wildlife Grants. Over the last six years, the two programs have meant a total of nearly $500 million in new federal funds for wildlife conservation, matched with several hundred million more in state and private dollars. In a relatively short time, these programs have become the federal government's core programs for preventing wildlife from becoming endangered, with strong on the ground actions implemented in every state. This dramatic growth in a very tough budget climate has been the result of the strong bipartisan support built by the Teaming with Wildlife coalition.

## State Wildlife Action Plans: Proactive, Flexible Conservation

As a condition of both the Wildlife Conservation and Restoration Program and State Wildlife Grants, each state fish and wildlife agency committed to developing a wildlife action plan, know technically as a "comprehensive wildlife conservation strategy." These statewide action plans draw together all available information to evaluate the condition of each state's wildlife species and habitats, identify species in need of conservation attention, outline the conservation issues that need to be addressed, and identify the actions needed to address those issues.

The wildlife action plans represent a balance between structure and flexibility. In the legislation defining the wildlife action plans, Congress outlined eight core planning requirements. Beyond those requirements, Congress and the Fish and Wildlife Service gave states substantial flexibility to develop approaches that fit each state's unique wildlife and habitat resources, management context, and local issues. At the same time, the wildlife agencies worked together to share information and priorities across jurisdictions. This diversity of planning approaches represents the essential strength of this effort. While focused on the same set of core elements, the state wildlife agencies had the flexibility to develop structures that address their own unique needs, translating conservation goals into on-the-ground results for wildlife in each state.

Table 1: Summary of Required Elements for Wildlife Action Plans

**Box 1. Eight Required Elements for Wildlife Action Plans**

*Congress outlined eight core requirements that are contained in every wildlife action plan. Within this framework, state wildlife agencies developed planning approaches that fit their local management issues and needs.*

*(1) Information on the distribution and abundance of* ***wildlife****, including low and declining populations,* that are indicative of the diversity and health of the state's *wildlife*

*(2) Descriptions of locations and relative condition of* ***habitats*** *essential to species in need of conservation*

*(3) Descriptions of* ***problems*** *which may adversely affect species or their habitats, and priority research and survey efforts*

*(4) Descriptions of* ***conservation actions*** *proposed to conserve the identified species and habitats*

*(5) Plans for* ***monitoring*** *species and habitat, and plans for monitoring the effectiveness of the conservation actions and for adapting these conservation actions to respond to new information,*

*(6) Descriptions of procedures to* ***review*** *the plan at intervals not to exceed ten years*

*(7)* ***Coordination*** *with federal, state, and local agencies and Indian tribes in developing and implementing the wildlife action plan.*

*(8) Broad* ***public participation*** *in developing and implementing the wildlife action plan.*

The core goal of the wildlife action plans is to prevent fish and wildlife from becoming endangered. Thus, the first step in the development of the wildlife action plans was the identification of those fish and wildlife species with low or declining populations, or that were otherwise in need of conservation. Most of the wildlife action plans refer to these targets as "species of greatest conservation need." States used various sources and techniques to identify these species, including natural heritage programs and other wildlife occurrence databases, data from other planning efforts and assessments, and input from agency biologists, academics, and other experts. While the selection process included species under formal protection of the federal Endangered Species Act or other state-level programs, the effort placed a major emphasis on identifying a broader set of species of concern that would include at-risk species not yet identified by other protection efforts.

The flexibility of the planning process resulted in substantial variation across the states in the definition of "species of greatest conservation need." For example, Utah's wildlife action plan identifies 196 such species, grouped in three tiers of relative priority. In contrast, Pennsylvania's wildlife action plan identifies 572 species of conservation concern, and Virginia identified more than 925.

The variability from state to state means that the concept of "species of greatest conservation need" is best understood as a broad set of priority species rather than a formal status. In fact, "species of greatest conservation need" should ideally define the broader set of fish and wildlife species that do *not* necessarily fall into a specific legal or regulatory category or status. The focus on species of greatest conservation need also provide an essential complement to existing fish and wildlife management activities aimed at maintaining harvestable populations.

**Habitat-Focused Conservation Strategies**

Many of our great wildlife restoration stories tell the return of one species at a time, from the bald eagle to the striped bass to the wild turkey. However, a species-by-species approach is not practical when dealing with the complete breadth of each state's fish and wildlife species. In even the smallest states, the full array of native fauna can encompass several thousand species, while in Texas, California, and Florida, the number of species reaches into the tens of thousands. In addition, because many of the species targeted in the action plans have received little prior conservation attention, conservation planning faces serious information gaps about even the basic habitat needs and life history.

To comprehensively and efficiently address the needs of each state's full array of wildlife, the wildlife action plans are broadly built around a "coarse-filter/fine-filter" approach to conservation planning. This planning approach combines broad, habitat-focused conservation actions (the "coarse filter") with specific interventions that are needed by individual species or ecological communities whose needs are not completely addressed by habitat-focused actions (the "fine filter").

As a first step in identifying effective habitat conservation and management recommendations, wildlife agencies had to develop a clearer understanding of the habitat needs of their species of concern as well as the basic availability and condition of those habitats in each state. To that end, the wildlife action plans used and refined a variety of existing habitat definition/classification systems, ranging from the ecological systems defined by NatureServe/state heritage programs to the definitions used by Gap Analysis Programs. In some cases, states were developing new systems of classifying habitats where none had even existed before in others, the development of the action plan offered an excellent opportunity to devise ingenious ways to crosswalk and link different systems.

The wildlife action plans took a variety of approaches to identifying habitat conservation priorities and management actions, reflecting decisions about the planning process and existing agency resources as well as biological and social considerations. Several states identified a subset of priority habitat types, ranking them based on criteria such as relative value for species of conservation need or relative threat level. For instance, the Utah wildlife action plan defines a subset of 10 habitats of relative priority for species of greatest conservation need, out of 25 habitats found in the state. Similarly, Mississippi's wildlife action plan identifies a targeted set of 15 habitats from a broader set of 69 habitats.

States also took a variety of approaches to identifying the relative value of different georgraphic locations and/or occurrences of important habitats. Some states identified broad geographic focal areas that encompass a variety of habitat types or landscape features. For instance, the Nebraska Natural Legacy Project identifies 40 "biologically unique landscapes," with priority ecological communities identified in each landscape. Other states focus on the identification of priority occurrences of habitats across different planning units. Minnesota, for instance, identifies the relative value of different occurrences of priority habitat types across the state's ecological subsections. Similarly, the Idaho wildlife action plan identifies priority habitats in each of the state's subsections as well as identifying priority subsections for the conservation of targeted habitat types.

The relationship between the definition of habitat types, the assessment of habitat priorities, and the identification of specific conservation opportunities or priorities plays out in complex ways across the wildlife action plans. Some states identify priority habitats without prioritizing different occurrences or geographic areas, while others might identify priority occurrences without defining relative priority among habitat types. Finally, some states emphasize a landscape/ecosystem approach that identifies priority actions that should be applied in whatever habitat types are present, without imposing relative priority among habitat types or locations.

The diversity of approaches taken by the states to identifying and describing habitat priorities presents challenges to meaningful generalization about how the information can be used. At the most basic level, however, every wildlife action plans contains rich information on what habitats occur in the state, what those habitats mean for imperiled species in need of conservation, and how those habitats need to be managed and conserved.

## Turning the Action Plans Into Action

The strong commitment of the fish and wildlife agencies to the development of the wildlife action plans resulted in the completion of all 56 action plans by October 2005. After an exhaustive review process by a team of federal and state officials, every wildlife action plan ultimately received final approval by January 2007.

The state wildlife agencies are now in the process of translating the wildlife action plans into on-the-ground conservation successes. A core priority for the wildlife agencies is securing reliable and increased funding to implement the wildlife action plans. At the federal level, this effort includes enhanced annual appropriations for the State Wildlife Grants program and reliable funding for the Wildlife Conservation and Restoration Program. At the state level, several initiatives are underway to expand funding for fish and wildlife agencies beyond traditional fee-based systems.

Partnerships remain a core element of implementing the wildlife action plans. While the state fish and wildlife agencies had the formal responsibility for developing the wildlife action plans, the process hinged on strong on input from various partners, including other state, federal, and local government agencies, private landowners and businesses, and conservation groups. From the outset, the wildlife agencies committed to implementing the wildlife action plans as plans for *wildlife* not plans for wildlife *agencies*. States are working together and with partners to share information, identify shared priorities, and translate the action plans to local and regional planning scales. Implementation activities range from collaborative on-the-ground conservation and restoration projects to research and inventory.

## A Resource for Transportation Planning and Management

Transportation infrastructure is widely recognized in the wildlife action plans as a key factor in the decline of many fish and wildlife species through habitat fragmentation, outright habitat destruction, and loss of connectivity among declining populations of wildlife. At the same time, the wildlife action plans are not just about assessing and identifying problems: they are about identifying the positive action steps that need to be taken to protect declining fish and wildlife. To that end, the action plans present an historic opportunity for improving transportation planning and mitigation activities. By identifying habitat needs for species that are at risk of becoming endangered, the action plans can help guide planning decisions to minimize wildlife impacts. In addition, the action plans can provide invaluable guidance for targeting mitigation activities at high value conservation targets.

**Biographical Sketches:** David Chadwick is a Senior Program Associate at the Association of Fish and Wildlife Agencies, where he works to support state fish and wildlife agencies in the development of strong programs for the conservation of declining species and habitats. For the last three years, Dave has served as the association's lead staffperson on the development and implementation of state wildlife action plans, providing assistance and support to wildlife agencies and leading outreach efforts to other agencies and nongovernmental organizations. Dave also works on outreach and policy advocacy associated with the Teaming with Wildlife campaign.

Dave's professional background blends experience in public policy and politics with experience in natural resource planning and management. His policy experience includes several years on the Capitol Hill staff of Senator Dianne Feinstein (D-California) and work for the Citizens League of Minnesota, a nonpartisan civic engagement organization. On the natural resources side, Dave has worked as a field technician for the US Forest Service in northwest Colorado and as a planner and GIS analyst in the Colorado Office of the Natural Conservancy. Dave has a B.A. in Politics from Pomona College and an M.S. in Natural Resources from the University of Michigan's School of Natural Resources and Environment.

## Wildlife Connectivity Across Utah's Highways

**Paul W. West** (801-965-4672, paulwest@utah.gov), Wildlife Program Manager, Utah Department of Transportation, 4501 S. 2700 West, Box 148450, Salt Lake City, UT 84114-8450, Fax: 801-965-4363 USA

**Abstract:** The Utah Department of Transportation sponsored a workshop to identify major sections of Utah's highways that disrupt wildlife connectivity. This workshop was attended by representatives from the Utah Department of Transportation (UDOT), Utah Division of Wildlife Resources (UDWR), U.S. Forest Service, U.S. Fish and Wildlife Service, and several private consulting and conservation groups.

During the workshop, and subsequently in some of the UDWR offices, 64 separate connectivity zones were identified. These were prioritized based on professional opinions and experience of biologists who were familiar with the linkage areas. From this, it was estimated that 222 miles of Utah's roads and freeways cross through critically important connectivity zones, 287 miles of roads cross through highly important zones, and 754 miles cross through moderate priority areas.

Examples of regional connectivity maps and tabulated descriptions are in the Appendix.

### Introduction

The Utah Department of Transportation administers nearly 5,846 miles of highway and freeways, 82% of which run through rural areas. Increasing population and economic growth have contributed to higher traffic volumes in rural areas as well as in urban areas. This, in turn, has led to increasing wildlife-related safety problems. Affected wildlife species may be as small as fish, mice, prairie dogs, rabbits, tortoises, etc., or as large as coyotes, deer, elk, and moose. According to Marshik, et. al. (2001), "In the United States, an estimated one million vertebrates-amphibians, reptiles, birds, and mammals are killed on roads and highways each day."

When wildlife habitat is bisected by highways, animals still have a need to cross the barrier to access their native habitat. Often, due to roadway width, traffic volumes, or other constraints, they are unable, or unsuccessful. This causes what is known as "habitat fragmentation." Habitat fragmentation, and the creation of "fracture zones," can be viewed as a loss of "habitat connectivity." This loss in connectivity is one of the major transportation-related issues DOTs need to address. Wilcox and Murphy (1985) stated, "Habitat fragmentation is the most serious threats to biological diversity…." According to Gore, et al. (2001), "Wildlife habitat connectivity is affected by many human activities, including highway development, private and public land management practices, open space policies, subdivision policies, road access and densities, and many other factors."

Animals crossing roads as they attempt to connect with their natural habitat often pose a safety hazard to motorists. Many species can become trapped on highways by barriers or headlights. Other species either fear to cross these barriers, or are physically incapable of doing so, such as desert tortoises, amphibians, reptiles, rodents and other small mammals, etc. Thus, there is a need for some mechanism to assist these species in crossing.

According to Ruediger (2001), "The primary objective of wildlife and fish crossings is to maintain habitat and population connectivity. For many species, this may require maintaining or simulating the natural functions of their habitat within or on top of traffic crossing structures. Many crossings are designed to facilitate movement of a single or small number of species. Structures would be more functional if connectivity of habitat across highways were given more consideration. More species would be provided for, especially plants, invertebrates, and small animals, if habitat connectivity were at least as important as providing crossings for a few target species. Connectivity of habitat and populations is an ecosystem approach."

### Study Objectives

#### Methods

Following a methodology suggested by Bill Ruediger (then with the U.S. Forest Service in Montana), the Utah Department of Transportation sponsored a workshop to identify major sections of Utah's highways that serve to disrupt wildlife connectivity. This workshop was attended by representatives from the Utah Department of Transportation, Utah Division of Wildlife Resources, U.S. Forest Service, U.S. Fish and Wildlife Service, and several private consulting and conservation groups.

The objectives of this workshop included:

1. Identify where wildlife linkage areas cross Utah's road system.
2. Identify species involved in these linkage areas.
3. Suggest possible solutions to fragmentation.

For this meeting, large (44" x 48") maps of Utah's highway and freeway system were made available for marking of connectivity zones across Utah's highways and freeways. Data sheets were made available for note taking and identification of the problems exhibited in the connectivity zones. Participants were separated into six groups, based roughly on UDOT's six regions and districts.

In this analysis, several key questions were asked on the data sheets:

- Linkage Name
- UDOT Region/District
- Highway or Route Number
- Mileposts
- Conservation Issues Involved
- Species of Concern in each linkage area
- Comments and/or recommendation

Priorities were then assigned to each connectivity zone based on the participants' knowledge of the locales, ecosystems, resident species, habitats, etc. Priorities were designated as critical, high, or moderate. The resulting data and information were then compiled and digitized into a GIS mapping format as shown on figure 1 below.

UTAH'S WILDLIFE CONNECTIVITY ZONES

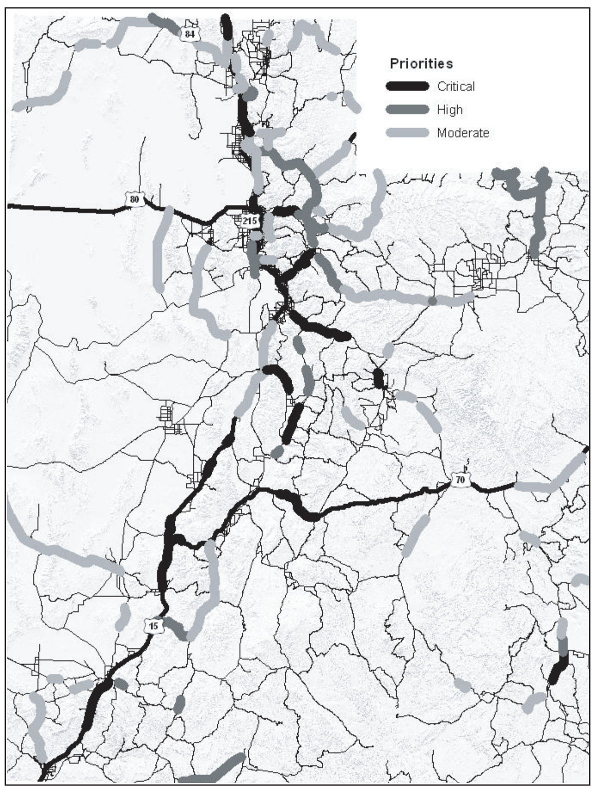



Figure 1. Utah's wildlife connectivity zones

**Discussion of Suggested Practices**

During the workshop, and subsequently in some of the UDWR offices, 64 separate connectivity zones were identified. These were prioritized based on professional opinions and experience of biologists who were familiar with the linkage areas. From this, it was estimated that 222 miles of Utah's roads and freeways cross through critically important connectivity zones, 287 miles of roads cross through highly important zones, and 754 miles cross through moderate priority areas.

Each of these connectivity zones was described in detail in the Appendix of the final report (examples of which are given at the end of this report).

The suggested mitigating practices generally fall into a few categories: fencing, wildlife crossings, and signing (including infrared sensors), being the most common suggestions given. Below is an explanation of the recommendations that were given.

- By far, most of the suggestion practices to protect wildlife involved maintaining and/or installing wildlife exclusionary fencing with earthen escape ramps.
- Closely associated with fencing is the need for overpasses or underpasses to facilitate wildlife crossing of highways. These are especially important in critical and high priority connectivity zones where animals need to migrate across highways and freeways to attain their native habitat. To be effective, such structures require fencing with escape ramps to funnel wildlife into these structures.
- Many of the workshop participants suggested using some kind of signs to warn motorists of wildlife in the right-of-way. A common comment is that the public can become used to seeing signs, so to be effective, they need to be large and eye catching, possibly with flashing lights, and preferably used only seasonally when animals are migrating through the area in the fall and spring. Some new sign innovations include infrared sensors. When animals wander onto the right-of-way, these sensors would detect their movements and trigger flashing lights on warning signs. Another variation is to place video cameras along critical stretches of highway that would take video photographs of the animals and relay these to a screen that motorists can view as they drive past the monitor. This would help motorists realize that these warning signs are serving a real purpose.
- Reduction of speed limits may help in some instances as well. Where sight distance is limited by poor geometry, or heavy vegetation against the right-of-way, reduced speed limits can help if motorists avoid collisions.
- Roadside vegetation management, especially when coupled with water development, can also have a positive effect on wildlife mortality. Keeping the right-of-way mowed and cleared of brush helps motorists to see animals that may be ready to jump in front of them. Often, the reason wildlife cross highways may be to access water. Development of water facilities, such as guzzlers, may help to reduce this need.

## Results and Conclusion

Based on the professional knowledge and experience of the participants at the workshop, it was determined that 222 miles of Utah's highways cross through critically important wildlife connectivity zones. Additionally, 287 miles cross through highly important priority areas, and 754 miles cross through moderately important priority areas. For each of these priority areas, the participants provided important details concerning each connectivity zone, plus suggestions on how to improve connectivity for various wildlife species.

In the Appendix is a map of the one of the UDOT regions (Region 1) to illustrate where some of Utah's connectivity zones occur. Following the map is the table for the connectivity zones in that region. This table contains specific details of the problems for each wildlife connectivity zone, and suggested solutions and recommendations.

During the workshop, it became apparent that biologists alone cannot solve the problems created by highways with regard to the movements of wildlife. Emphasis must be placed on encouraging DOT planners and engineers to incorporate wildlife mitigation measures into new roadway designs, including exclusionary fencing with escape ramps, crossing structures, signage, etc. Highways should not become a barrier to wildlife movement.

**Biographical Sketch:** Paul West earned his Bachelors of Science degree in Range Science from Brigham Young University, with a minor in wildlife biology. He has done graduate studies in Urban Planning at the University of Utah. Mr. West has nearly 31 years of experience as an environmental professional. He has managed, researched, and written NEPA documents and environmental baseline reports, and managed wetland regulatory projects, including delineating nearly 100,000 acres of wetlands in most of the western United States. He has designed and managed mining reclamation efforts, made erosion and sediment control recommendations, conducted order II soils surveys, performed wildlife surveys, including threatened and endangered species surveys, and riparian and vegetation inventories. Currently he is serving as the Wildlife Program Manager for the Utah Department of Transportation where he insures that UDOT's projects conform to the provisions of the Endangered Species Act, and consider wildlife issues in the planning stage.

## References

Gore, James F., J.J. Claar, and B. Ruediger. 2001. Why Did The Bear Cross The Road? It Didn't! In: *Proceedings of the 2001 International Conference on Ecology and Transportation*. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 595-602.

Marshik, Joel, Lyle Renz, Jim Sipes, Dale Becker, and Dale Paulson. 2001. Preserving a Spirit of Place: U. S. Highway 93 on the Flathead Indian Reservation. In: *Proceedings of the 2001 International Conference on Ecology and Transportation*. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 249.

Ruediger, Bill. 2001. High, Wide, and Handsome: Designing More Effective Wildlife and Fish Crossings for Roads and Highways. In: *Proceedings of the 2001 International Conference on Ecology and Transportation*. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 509-516.

Wilcox, B.A. and D.D. Murphy. 1985. Conservation strategy: the effects of fragmentation on extinction. *American Naturalist* 125: pp 879-887.

**Appendix 1 - UDOT Region 1 Wildlife Connectivity**

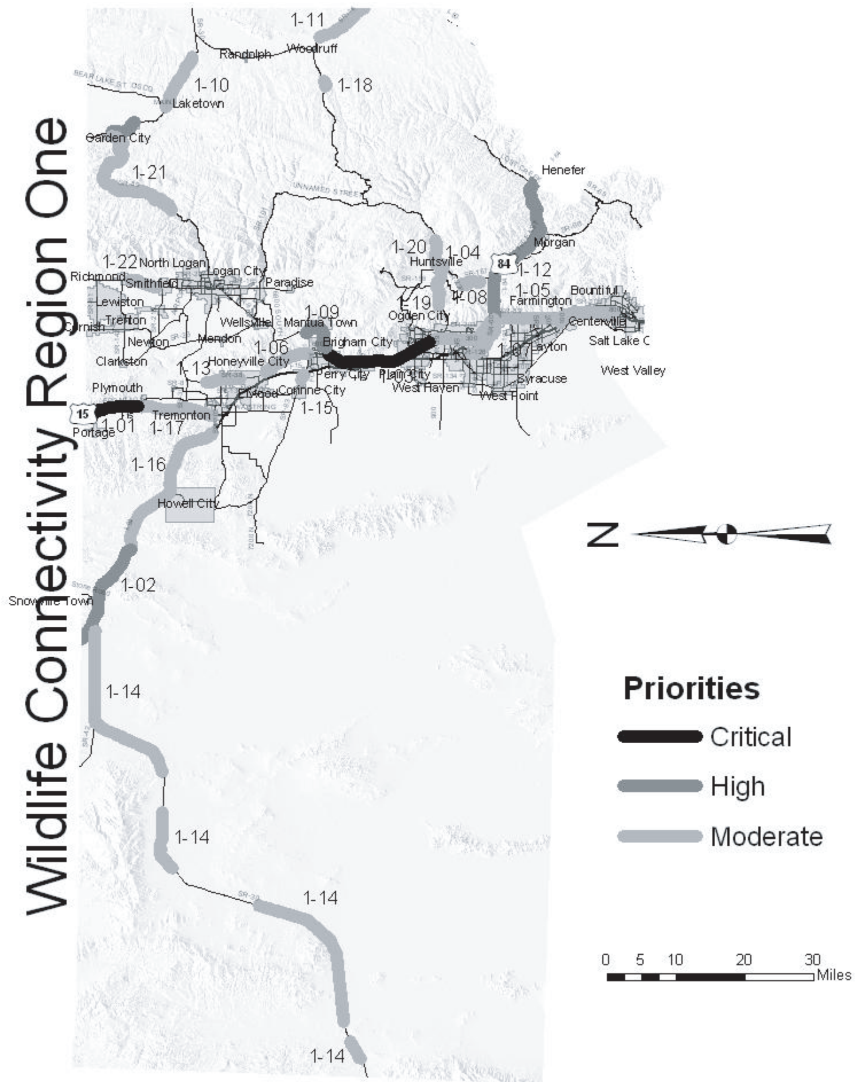


Table 1: UDOT, Region 1 Wildlife Connectivity Zones

| Priority | Linkage Area | Name | Route | Reference Posts | Conservation Issue | Species of Concern | Comments | Recommendations |
|---|---|---|---|---|---|---|---|---|
| Critical | 1-01 | Plymouth Area | I-15 | 392 to 401 | *Big Game<br>*Highway Safety<br>*Connectivity to Public Lands | Deer | Mostly private land along I-15, but high deer kill. Mostly grain fields. | Need deer-proof fencing with escape ramps and some kind of crossing structure every mile or so |
| High | 1-02 | Snowville Area | I-84 | 0 to 16 | *Big Game<br>*Highway Safety<br>*State Sensitive Species<br>*Connectivity to Public Lands<br>Highway safety | Badger<br>Deer<br>Sage Grouse<br>Raptors | Migratory corridor for deer. Badger and sage grouse habitat on both sides of highway. Public lands on both sides of highway | Need to fence both sides of freeway with escape ramps and some kind of crossing structure every mile or so. |
| Critical | 1-03 | Brigham City South | U.S. 89 | 417 to 434 | *Big Game<br>*Highway Safety | Deer | Nuisance deer herd, road safety | Need deer-proof fencing with escape ramps |
| Moderate | 1-04 | Highway 39 | SR-39 | 12 to 19 | *Big Game<br>*Highway Safety | Deer | None offered | Seasonal warning signs might help. |
| Moderate | 1-05 | Highway 89 | U.S. 89<br>I-15 | 388 to 416<br>318 to 326 | *Big Game<br>*Highway Safety | Deer | Deer killed while crossing highway. Some are urban resident deer while some are migrating down from mountains to winter near the river. Problem area with houses, road, RR crossings, etc.<br><br>Jersey barriers also appear to a problem by trapping raccoons crossing. | Modify barriers. |
| Moderate | 1-06 | Honeyville to Dewyville | SR-38 | 0 to 7 | *Big Game<br>*Highway Safety | Deer | None offered | Seasonal warning signs might help |
| Moderate | 1-07 | Riverdale to South Weber – Uintah Area | I-84 | 81 to 88 | *Big Game<br>*Highway Safety | Deer | Deer are killed crossing the highway - resident deer live below Hill Air Force Base bluff, and | Speed Limits?<br><br>Infrared Sensors? |
| | | | | | | | sub-divisions and fields. They seem to cross to the riparian habitats. Concern is more for highway safety issues than connectivity issues – approximately 25 - 40 deer are killed each year. | |
| Moderate | 1-08 | Trappers Loop Road | SR-167 | 4 to 7 | *Big Game<br>*Highway Safety | Moose | Morgan County portion of Trappers Loop Road is worse than the Weber County portion. Approximately 15 moose are killed every year in this area. Yearlong residents so no real migration issues. The whole road has problems, but most are killed in the 3 – 4 mile stretch. Situation may get worse as more sub-divisions are developed and animals are forced to move more often to find better habitat. | Infrared sensors that could let drivers know an animal is in the vicinity might help.<br><br>Suggest seasonal warning signs, and lower speed limits where moose are a problem. |
| High | 1-09 | Sardine Canyon | U.S. 91 | 3 to 9 | *Big Game<br>*Highway Safety | Deer | Deer are still accessing busy corridor. Heavy snow causes problems to fence and deer are moving just when snow melts so no time to maintain fence properly. An important navigation corridor | Better fence maintenance<br><br>Retrofit existing underpasses to encourage deer use<br><br>Add cattle guards to gates which are constantly left open |

| Priority | Linkage Area | Name | Route | Reference Posts | Conservation Issue | Species of Concern | Comments | Recommendations |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Replace/remove/return gates near Mantua that don't close behind deer and that allow other deer to access/re-access highway |
| High | 1-10 | Garden City | SR-30 | 109 to 114 | *Big Game<br>*Highway Safety | Deer | High traffic area. 15 to 20 deer killed/year. A group of resident deer cross highway on evenings to drink from Bear Lake. | Signs would probably work best. |
| Moderate | 1-11 | Outside Evanston | SR-16 | 0 to 8 | *Big Game<br>*Highway Safety | Pronghorn | Antelope are killed due to net wire fencing on both sides of highway. | 4-strand barbed wire, smooth bottom strand about 16" above ground. |
| High | 1-12 | Mountain Green, to Echo Junction. | I-84 | 88 to 119 | *Big Game<br>*Highway Safety | Deer<br>Elk<br>Fish<br>Songbirds<br>Amphibians<br>Small & Medium Sized wildlife | R.P. 112-120 elk hot spot.<br><br>R.P. 149-156 deer hot spot.<br><br>Yearlong mortality, but kill increases during migration.<br><br>About 300 deer are killed per year in this area during a normal, average snow year. More during heavy winters periods.<br><br>Round Valley area historically picks up 100 deer per month.<br><br>The Weber River in | Please give this some serious thoughts – especially with Governor Walker's Waterbody Program!<br><br>We could at least improve aquatic habitat with cross vanes and log (large woody) structures. Another good idea for a collaborative effort.<br><br>Could Jersey barriers either be removed or modified with holes underneath that would allow animals to crawl underneath.<br><br>DWR and UDOT should coordinate efforts to |
| | | | | | | | Weber Canyon between the freeways. This reach is very impacted, with no floodplain and no riparian area. Although this area may be relatively inaccessible to angling, good habitat should grow larger fish, which could potentially move out of the reach into more fishable areas.<br><br>Jersey barriers create movement problems to small to medium sized wildlife that get on the highway?<br><br>Hundreds of animals are killed every year.<br><br>The Weber River in Several sections especially below Echo Reservoir: The construction of I-84 in the 1960s significantly impacted the Weber River. In several locations, especially near Henefer, the river was straightened resulting in stream degradation in the straightened segments and aggradations and | restore stream meanders and floodplain connectivity near Henefer<br><br>Since some of the sportsman's dollars are to mitigate the impacts of I-84, it would seem appropriate that UDOT help fund some stream rehab. Great PR opportunity for UDOT, UDWR & sportsmen's groups to collaborate on making the river great again! |

| Priority | Linkage Area | Name | Route | Reference Posts | Conservation Issue | Species of Concern | Comments | Recommendations |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | lateral erosion in downstream reaches. Currently, most stream rehabilitation efforts are being funded by sportsman's dollars.<br><br>Good floodplain connectivity will also reduce nearby flooding, protect people, home, and highway, and reduce roadbed erosion. | |
| Moderate | 1-13 | Deweyville | SR-38 | 11 to 16 | *Big Game<br>*Highway Safety | Deer | Deer migrate from Wellesville to Bear River floodplain/valley floor. Winter problem; road is at the edge of their winter range. | *Slow speed to 45 mph or less (it is a residential area) |
| Moderate | 1-14 | Grouse Creek | SR-30 | 3 to 6<br>9 to 33<br>47 to 56<br>62 to 88 | *Big Game<br>*Highway Safety<br>*Connectivity of Public Lands | Pronghorn<br>Deer | Annual migration routes.<br><br>Fences are being built now where there have not been any fences. | Require fencing with raised (14-16") smooth bottom wires. No net wire! Height should be 42".<br><br>All new fences must meet above specs. Height is 51" – 54" where they are putting in fences now.<br><br>*Modify existing fence from 54" to 42" |
| Moderate | 1-15 | Corinne | SR-13 | 6 to 7 | *Big Game<br>*Highway Safety | Deer | 20 to 30 deer killed per year from 2600 West to Corinne (3800 West). Resident deer travel corridors of the Bear River drainages and slough. | Lights or sensors |
| Moderate | 1-16 | Snowville | I-84 | 16 to 39 | *Big Game<br>*Highway Safety<br>*Connectivity of Public Lands | Deer<br>Elk<br>Short-eared Owls | Deer migrate from Idaho into Utah for the winter. 10% of deer population is killed from Nov to March. Deer migrate from Idaho to Utah to winter. Significant Elk winter range north of I-84. | Fencing and Overpasses<br><br>Large Flashing Signs |
| Moderate | 1-17 | Plymouth | I-15 | 382 to 392 | *Big Game<br>*Highway Safety | Deer | 10 to 20 deer killed annually between R.P. 384 & 390 – Malad River Corridor. These are mostly resident deer. Some winter migration occurs between R.P. 384 & 390. | Need deer-proof fencing with escape ramps and some kind of crossing structure every mile or so. |
| Moderate | 1-18 | East of Woodruff | SR-39 | 62 to 63 | *Big Game<br>*Highway Safety | Deer | 15 – 20 killed per year.<br><br>Deer cross highway in mornings and evenings to feed in adjacent fields. Deer are present during winter and early spring and then migrate to the top of Monte Cristo. Some deer are resident year round.<br><br>This herd unit is under objective; we don't want to further reduce #'s. | Seasonal, flashing warning signs might help. |

| Priority | Linkage Area | Name | Route | Reference Posts | Conservation Issue | Species of Concern | Comments | Recommendations |
|---|---|---|---|---|---|---|---|---|
| Moderate | 1-19 | Laketown Canyon | SR-30 | 119 to 128 | Big Game Highway Safety | Deer | Migration route for deer, cross in Laketown Canyon. Winter range is on both sides of canyon (steep) so animals are frequently on the road and are killed. 100+ deer are killed/year (mainly fall/winter kills)<br><br>Cache deer herd unit. Herd unit is under objective and sportsmen want us to increase herd numbers | We asked UDOT to sign this canyon 1½ - 2 years ago and we were told that signs in this area were not a priority for UDOT.<br><br>Overpass would make the most sense.<br><br>Could fence draw to force animals to cross in a different area, but this may more widely disperse animals and cause more problems. |
| Moderate | 1-20 | Huntsville | SR-39 | 20 to 23 | *Big Game<br>*Highway Safety | Deer | 50 to 75 deer killed each year<br><br>Deer cross between Monastery & Green Hills Subdivisions.<br><br>Migrating animals mostly (spring & fall) but some yearlong issues. | A few years ago, UDOT put up flashing signs. This has seemed to help reduce mortality. |
| Moderate | 1-21 | Logan Canyon | U.S. 89 | 474 to 499 | *Big Game<br>*Highway Safety | Deer<br>Elk | Tony Grove turnoff area (the large flat)<br><br>Just west of Garden City (where switchbacks & flat areas are)<br><br>Deer are resident; elk are more seasonal. | Slow people down!<br><br>Flashing lights may work. |
| | | | | | | | Tony Grove area is a summer range area so movements are across the highway.<br><br>Garden City area is winter range area. Elk feed in raspberry fields, then cross highway | |
| Moderate | 1-22 | Smithfield to Richmond | U.S. 91 | 35 to 39 | *Big Game<br>*Highway Safety | Deer<br>Elk | Seasonal migrations for deer & elk (spring & fall). Some deer become resident and become a yearlong problem (dairies & haystacks). Animals are coming from USFS lands and cross to the Bear River floodplain.<br><br>Depending upon snow amount, could have hundreds killed during a season.<br><br>These are in the Cache Valley deer herd which is under objective & sportsmen want UDWR to increase herd #'s. | Work on highway is starting now for road widening, so something should be done now. Not sure what the solution is! |

## Case Study: Harbor Boulevard Wildlife Underpass, Los Angeles County, California

**Andrea Gullo** (562-945-9003, agullo@habitatauthority.org), Executive Director, Puente Hills Landfill Native Habitat Preservation Authority (Habitat Authority), 7702 Washington Avenue, Suite C, Whittier, CA 90602, Fax: 562-945-0303 USA

**Abstract:** Wildlife in Metropolitan Los Angeles now have an underpass designed and built exclusively for their safe passage under a busy boulevard. The underpass supports the longevity of the Puente-Chino Hills Wildlife Corridor (Corridor). The Corridor contains some of the last remaining stands of several habitat types that are declining in the Los Angeles Basin. The 31-mile Corridor connects vast open space areas and provides a rare opportunity to preserve functional wildland in southern California. The Harbor Boulevard Wildlife Underpass is the linkage point within this Corridor for approximately 4,600 acres of publicly protected habitat to the west and about 14,000 acres of publicly protected habitat to the east. It strengthens the biodiversity of all lands to the west and adds to the richness in the east. Harbor Boulevard was constructed in 1990 with oversight to wildlife movement in the area. Wildlife populations west of Harbor, especially the bobcat population, would have become completely isolated, and possibly extirpated, if safe passage across Harbor Boulevard was not created. A wildlife movement study, completed in 1999, identified mammalian movement up to and across Harbor Boulevard at the project location. While the purpose of the study was not to count wildlife killed by vehicles, researchers compiled significant roadkill data for Harbor Boulevard. They recommended a specific location for a wildlife underpass to strengthen the connectivity of wildlife habitat and movement. Armed with this scientific data and with support from elected officials, public agencies and local nonprofit organizations, the Habitat Authority, a local government park agency, together with the County of Los Angeles and the California Department of Parks and Recreation took on this project. They pursued and were successful in obtaining grant funding for construction costs. The underpass was designed to accommodate large-to medium-sized mammals. California State University, Fullerton Foundation was hired to monitor wildlife before, during, and after construction. Just nine days after the grand opening celebration of the underpass, deer were photographed using the tunnel. Coyotes and deer appear to regularly use the underpass and bobcat have been detected using the tunnel as well. The underpass project is unique in that it is the first wildlife underpass built by the County of Los Angeles. It is a multi-agency collaborative project that took over nine years to come about. It is a goodwill project that acts as a habitat linkage designed to reduce the amount of vehicle-caused wildlife mortality, and the risk of accidents that could cause harm for motorists.

### Introduction

Wildlife in the Los Angeles Basin now can cross between open space areas on either side of a busy boulevard due to a collaborative win-win effort between Los Angeles County, California Department of Parks and Recreation (California State Parks) and the Puente Hills Landfill Native Habitat Preservation Authority (Habitat Authority). The project is unique in that it is the first wildlife underpass built by the County of Los Angeles, and was not mandated by regulatory agencies from development impacts. The construction of this wildlife underpass was widely supported by numerous municipalities, political representatives and community groups. The result is a safer road for wildlife and motorists, as well as an insurance policy of sorts for biodiversity to support the preexisting public investment of preserved open space in the region.

### Background

The Puente-Chino Hills Wildlife Corridor (Corridor) is approximately 31 miles long and extends from Los Angeles County Whittier Narrows areas in the west to the Cleveland National Forest in Orange County to the east. Despite its long history of use and proximity to urban development, the connectivity still present in the Puente-Chino Hills provides a rare opportunity to preserve a functional wildland in southern California. The Corridor contains some of the last remaining stands of several habitat types that are declining in the Los Angeles Basin including walnut and oak woodlands, chaparral, native grasslands and coastal sage scrub. It sustains important habitat for a number of native animal species including the coastal California gnatcatcher (*Polioptila californica*), cactus wren (*Campylorhynchus brunneicapillus*), mule deer (*Odocoileus hemionus*), mountain lion (*Puma concolor*), coyote (*Canis latrans*), bobcat, American badger, and gray fox. The first two species are target species of regional habitat planning efforts in Southern California. The combined vegetation provides habitat for a unique assemblage of plants and animals. Biologically, this area preserves a microcosm of the California Floristic Province, an identified biodiversity hot spot in North America and a genetic reserve for the continent. As a result, the area is regionally and globally significant as a prime example of this unique habitat web, yet it occurs in an area that is almost completely surrounded by existing urban development. The Corridor provides food, cover, breeding grounds, and refugia in the event of a large disturbance, and contributes to species diversity, dispersal routes for juveniles, home ranges, and the transfer of genetic material, which help maintain healthy populations (Draft Resource Management Plan, 2007).

Located in a metropolitan region of nearly 20 million people and within a thirty-minute drive from downtown Los Angeles, the Corridor provides visitors a unique opportunity to experience natural resources in a setting not commonly found in the highly urbanized Los Angeles region. The Corridor provides a range of recreation opportunities and activities including hiking, jogging, mountain biking, horseback riding, nature appreciation, and wilderness education. The challenge for the Habitat Authority as well as other land managers in the area is to balance natural resource protection and low-impact recreation (Draft Resource Management Plan, 2007).

The Habitat Authority was established in 1994 as a joint powers authority. It has a Board of Directors made up of the City of Whittier, the County of Los Angeles, the Sanitation Districts of Los Angeles County and the Hacienda Heights Improvement Association. The Habitat Authority is dedicated to the acquisition, restoration, and management of open space in the Puente Hills for preservation of the land in perpetuity, with the primary purpose of protecting biological diversity. Additionally, the agency endeavors to provide opportunities for outdoor education and low-impact recreation. To date, the Habitat Authority owns and/or manages 3,860 acres of open space. Extensive efforts of various entities have been made to purchase and preserve more than 19,000 acres of public land within the Corridor.

Overall, the Harbor Boulevard Wildlife Underpass within the Habitat Authority's jurisdiction is the linkage point for approximately 4,600 acres of publicly protected habitat to the west and about 14,000 acres of publicly protected habitat to the east. It will strengthen the biodiversity of all lands to the west that are managed by the Habitat Authority and add to the richness in the east. Harbor Boulevard was constructed in 1990, impacting wildlife movement in the area.

Open space on either side of the boulevard used to be owned by Los Angeles County Department of Public Works (LA Co. Public Works), but is now owned by the Habitat Authority, and the road is currently owned and maintained by LA Co. Public Works. Harbor Boulevard is a major thoroughfare that connects Orange and Los Angeles Counties. It is a 4-lane road with legal speeds allowed up to 50 miles per hour. In 2001, the Average Daily Traffic (ADT) for Harbor Boulevard was 28,585 vehicles, which has most likely only increased since. Motorists use Harbor Boulevard in their commute to job sources in Los Angeles County and Orange County. It directly connects to the 60/Pomona Freeway and the 90/Imperial Highway, which hundreds of thousands of commuters use daily. With continued development in the Los Angeles Basin and subsequent increased traffic over time this Harbor Boulevard crossing point if left unimproved would have become more risky for wildlife and motorists.

## Scientific Momentum

Even though an ample amount of habitat fragmentation has occurred in the Corridor, the largest remaining carnivore in the region, the mountain lion, is still known to use the biological corridor at Coal Canyon that connects the Chino Hills, in the eastern portion of the Corridor, to the Cleveland National Forest (Beier 1995). Mountain lion prints and sightings have also been confirmed by the California Department of Fish and Game in 2003 and by the Habitat Authority as recently as 2005 in the western portion of the Corridor.

A wildlife movement study completed in 1999 and conducted by Chris Haas while at California State Polytechnic University, Pomona, and Kevin Crooks while at University of San Diego, identified mammalian movement up to and across Harbor Boulevard at the project location. While the purpose of the study was not to count wildlife killed by vehicles, researchers found 7 killed coyotes on Harbor Boulevard as a result of vehicle collisions within a period of 3 months in 1997. The study documented that this area was still frequently utilized by wildlife such as deer, bobcat, fox, raccoon, coyote, skunk and opossum. However, they found that bobcats did not traverse either side of the road. The location of the underpass was identified as the most active area for wildlife crossing between the open space habitat areas of the Puente Hills. They strongly recommended the location for a wildlife underpass to strengthen the connectivity of wildlife habitat and movement.

Wildlife movement is important to ensure a healthy functioning ecosystem for the long- term. Movement allows for species to find food, water, shelter, and mates, and to mark and defend territories. Also, movement ensures genetic diversity within species populations that is critical for their survival. If habitats become fragmented, genetic diversity declines. This leads to species populations running the risk of genetic decay, which can lead to extirpation from an area resulting in severe cascading effects throughout the ecosystem. Wildlife populations, especially the bobcat population west of Harbor Boulevard, could have become completely isolated and possibly extirpated if safe passage across Harbor Boulevard was not made certain.

## Funding and Construction Process

Armed with this scientific data and biological knowledge of the importance of installing an underpass, support was gained easily from four elected officials, four local cities, two wildlife agencies and four local nonprofit organizations. The project was viewed as a win-win for wildlife and people. There had already been tremendous community and municipal support for the Corridor with the activities of the local government agency the Wildlife Corridor Conservation Authority, created specifically to preserve the Puente-Chino Hills Corridor.

In the year 2000, once the momentum was gained and spurred by a scientific foundation, the Los Angeles County Sanitation Districts (Sanitation Districts), a partnering agency on the Board of Directors for the Habitat Authority, put together initial cost estimates for an underpass, and helped develop a Request for Proposals for an engineering firm to design the underpass. Project design began in March 2001; it was paid for by the Habitat Authority and supervised with significant help from the Sanitation Districts, and plans were reviewed by the LA Co. Public Works every step of the way. The corrugated metal underpass was designed with assistance from contracted biologist Chris Haas, to accommodate large-to medium-sized mammals, and was sized to be 6.09 m (20') span, 5.18 m (17') rise and 48.76 m (160') in length. The fencing element was eliminated from the design after a compromise could not be achieved between the Habitat Authority and a private land owner, AERA Energy LLC, who owns land abutting the road.

Also in late 2000, the search for construction funding began. The project was embraced by a vital supporter Los Angeles County Supervisor Don Knabe and the LA Co. Public Works. LA Co. Public Works as the lead applicant and the Habitat Authority as a co-sponsor were successful in being awarded grant funds from the Metropolitan Transportation Authority (MTA) share of regional Transportation Enhancement Activities (TEA) in the amount of $901,000. Since this was not enough to complete the project, California State Parks was asked to get involved. As a long-time supporter of the Corridor they, as the lead applicant, with LA Co. Public Works and the Habitat Authority as partners, were successful in being awarded another grant through the California Department of Transportation (Caltrans) for Statewide TEA funds in the amount of $337,000. All funding was transferred to LA Co. Public Works for administration. These grant requests were successful in part because of the following widespread local support: Congresswoman Grace Napolitano, Congresswoman Hilda Solis, Senator Bob Margett, Senator Gloria Romero, United States Fish and Wildlife Services, Wildlife Corridor Conservation Authority, City of Brea, City of La Habra, City of La Habra Heights, City of Whittier, Hills For Everyone, Friends of the Tecate Cypress, Friends of the Whittier Hills and Vantage Pointe Homeowners Association. This grant funding in the total amount of $1.2 million was obtained and administered by LA Co. Public Works, and the Habitat Authority provided the needed local matching funds in the amount of $146,265.

Negotiations for land acquisition on either side of the boulevard began in 2001 between the Habitat Authority and Los Angeles County Department of Public Works who owned open space on either side of the road. In March 2004, 19.9 acres were purchased from the County.

At this point it was a matter of taking several sequential steps to complete this project. Preconstruction mammalian movement and road kill monitoring began in July 2004, by Dr. Paul Stapp and student David Elliot from California State University, Fullerton, contracted by the Habitat Authority. Biological monitoring before, during, and after construction is being conducted in three ways: track surveys, roadkill surveys and camera surveys. In August 2004, the Habitat Authority hired the retired Director of LA Co. Public Works, Harry Stone, who played a key role in overseeing the project. The environmental review process for the construction of the underpass was conducted by LA Co. Public Works and completed in November 2004. Easements for the construction were granted in February 2005, and the contract for construction was approved by both the County and Habitat Authority in July 2005. Construction was managed by LA Co. Public Works and was successfully completed in May 2006 (See figure 1).

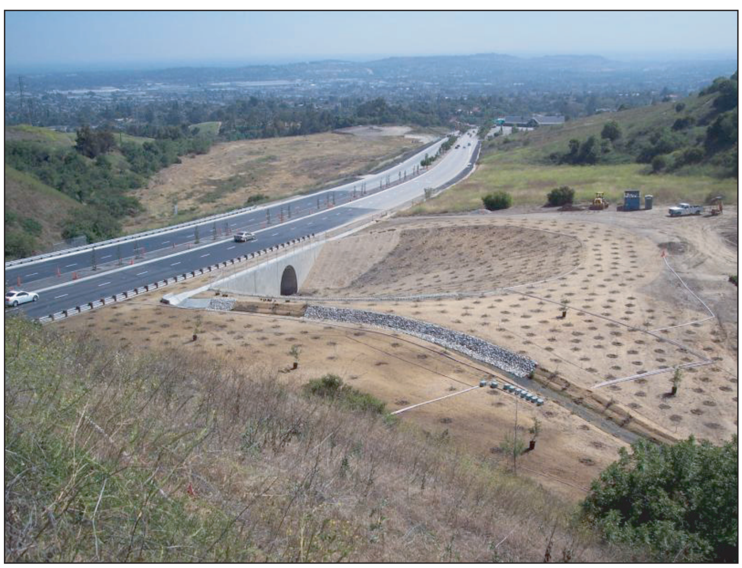


Figure 1. Completed underpass at Harbor Boulevard located in the City of La Habra Heights (Los Angeles County) May 2006.

The Grand Opening for the Harbor Boulevard Wildlife Underpass was held on Thursday, June 1, 2006, and just 9 days after the ceremony, researchers captured a photo of a mule deer using the underpass (see figure 2). Deer and coyotes were detected using the underpass just 3-4 weeks after installation of the cameras (Elliott 2006). Camera surveys will continue until May 2007, and the biological monitoring report will be completed in December 2007. Initial findings show that in addition to coyotes and deer, bobcats are also using the underpass.


Figure 2. First deer captured on film using the Underpass at Harbor Boulevard, 9 days after the Opening Ceremony (Elliott).

## Additional Benefits of the Project

This project benefits not only wildlife and motorists, but also the public by greatly enhancing the nearby existing rural community environment through helping maintain a healthy biologically diverse regional ecosystem. This subsequently can improve the community's quality of life.

Open space is more than an amenity; it is an essential component of community life, producing measurable health, social, and economic benefits. Public investment in parks and open space has shown to invigorate community revitalization, increase property values, reduce health care costs, improve productivity, and stimulate tourism. This project will contribute to these ends by helping maintain a healthy regional ecosystem and enhancing the nearby rural community environment. This in turn will improve the quality of life in the surrounding communities, making them more appealing places to live and work.

## Conclusion

A collaborative effort takes time, but is sometimes the only way a project can be realized. The scientific information gathered in 1999 made it possible to move forward and gain widespread community backing for the project. On the whole, acquisition of open space in the region, state, nation and world is necessary to promote biodiversity and a healthy planet, but is not the only call to action. In essence, this underpass is an attempt by humans to accommodate and peacefully co-exist with their wild neighbors – to give them back what was once available to them. Learning to live with our wild neighbors before, during and after open space acquisitions will in fact be what promotes healthy environments and healthy human as well as non-human populations.

**Acknowledgements:** The Habitat Authority is grateful to all that helped make this project possible including Los Angeles County Supervisor of the Fourth District, Don Knabe, the County of Los Angeles Department of Public Works, California State Parks, Sanitation Districts of Los Angeles County, Caltrans and Metropolitan Transportation Authority.

**Biographical Sketch:** Andrea Gullo is the Executive Director for the Habitat Authority. She has a M.A. from UCLA in Urban Planning.

## References

Beier, P. 1995. Cougar Dispersal in Fragmented Habitat. Journal of Wildlife Management 59:228-237.

Draft Resource Management Plan, Puente Hills Landfill Native Habitat Preservation Authority, prepared by LSA Associates, Inc. in coordination with Amy Henderson and A. Gullo. 2007. (Final expected July 2007).

Elliott, David. 2006. Progress report by Cal State University, Fullerton for study entitled, Effects of a Purpose-Built Underpass On Wildlife Activity and Traffic-Related Mortality in Southern CA: the Harbor Boulevard Wildlife Underpass.

Haas, Chris and Kevin Crooks. 1999. Carnivore Abundance and Distribution Throughout the Puente/Chino Hills. Prepared for Mountains Recreation and Conservation Authority and Southern California Department of Transportation by Haas and Crooks while at CA State Polytechnic University and University of CA San Diego.

Haas, Chris D. 2000. Distribution, Relative Abundance, and Roadway Underpass Responses of Carnivores throughout the Puente-Chino Hills. California State Polytechnic University, Pomona, California. Masters Thesis.

# Green Infrastructure, Environmental Mitigation and Transportation Planning in Kansas City

**Tom Jacobs** (816-474-4240, tjacobs@marc.org), Mid-America Regional Council, 600 Broadway, Suite 300, Kansas City, MO 64105, Fax: 816-421-7758 USA

**Abstract**

This project creates a planning and policy foundation to integrate transportation and environmental planning in the metro Kansas City area.

The Mid-America Regional Council (MARC), the metropolitan planning organization for the Kansas City region, is in the process of advancing a series of initiatives to help promote and incorporate broadened environmental consideration as a part of its regional transportation planning processes. This presentation will describe several interconnected strategies designed to accomplish the agency's long range transportation plan goals related to access, mobility, safety and the natural environment.

In 2004, MARC completed a comprehensive, geographic information system (GIS)-based regional natural resources inventory (NRI). This effort compiled all existing and relevant GIS data pertaining to the Kansas City metropolitan area to facilitate more integrated and proactive environmental planning in a variety of arenas. Data described the distribution, quality and extent of natural habitat types throughout the eight county region. The data serve to facilitate and spatially integrate planning efforts related to transportation, land use, air and water quality and greenways.

Subsequently, NRI data has been used to help prioritize and focus greenway planning, design and acquisition efforts. Beginning with the highly regarded regional greenway plan known as MetroGreen, new natural resource data has been used to prioritize open space conservation needs and opportunities. All analysis has been conducted within an integrated, multiple purpose framework, in pursuit of air and water quality protection, habitat restoration, reduction in flood risk, recreation and alternative transportation.

Planning for prioritized greenways and natural areas will adopt a green infrastructure framework, seeing to maximize connect key areas on a landscape scale to maximize ecological values and ecosystem services. Importantly, the final regional green infrastructure plan will be presented as a draft regional environmental mitigation plan in compliance with new SAFETEA-LU requirements. Mitigation in this venue is broadly construed, though intended to complement other state and federal mitigation requirements as well.

Development and final adoption of the plan will be accomplished through rigorous public participation efforts, including key natural resource management organizations and agencies. Ultimately the objective is to formally articulate via our transportation plan policy how this valuable environmental data can and should be used in helping to prioritize and define the region's investment in the transportation system. All data, planning, design and implementation efforts will be incorporated into MARC's next long-range transportation plan, which is slated for formal kickoff in 2007.

# Impacts of Different Growth Scenarios in the San Joaquin Valley of California

**Karen Beardsley** (530-752-5678, kbeardsley@ucdavis.edu), **Nathaniel E. Roth**, and
**Michael C. McCoy**, Information Center for the Environment, Department of Environmental Science and Policy, One Shields Avenue, Davis, CA 95616 USA

**Abstract:** In the next 40 years, the eight counties of the San Joaquin Valley are projected to double in population from 3.3 million to more than 7 million (Great Valley Center 2006). The region faces many challenges with respect to its capacity to accommodate this dramatic increase in population while maintaining its environmental infrastructure and preserving its diminishing natural resources.

In response to these growing pressures, Governor Schwarzenegger announced in June 2005 the formation of the California Partnership for the San Joaquin Valley (Partnership) to "...improve the economic well-being of the Valley and the quality of life of its residents" (Department of Business Housing and Transportation 2006a). This 26-member Partnership, led by the Secretary of the Business, Transportation and Housing Agency, is composed of eight state government members (primarily cabinet level appointees), eight local government members (primarily members of county boards of supervisor), eight private sector members (representing leadership in various business sectors), and two deputy chairs. The Partnership region includes San Joaquin, Stanislaus, Merced, Madera, Fresno, Tulare, Kings, and Kern Counties.

The Information Center for the Environment (ICE) at UC Davis supported the Partnership by providing geographic information system (GIS) data and growth allocation build-out scenarios. Based on input from the Partnership and the Great Valley Center, ICE developed and produced seven urban growth scenarios for the region that project population to year 2050 using UPlan, a rule-based GIS urban growth model (Johnston et al. 2006). These scenarios were developed based on different goals (such as Compact—within current spheres of influence; Farmland Protection—prime farmland masked; Great Cities—create "mega-cities" in concentrated regions) and produced vastly different outcomes.

This paper discusses the seven growth scenarios and the implications of mapped future urban growth in the San Joaquin under those scenarios on a collection of biologically significant factors. A team of federal, state, and non-government organization biological experts selected 14 key biological layers crucial for protecting high value open space in the San Joaquin Valley. ICE combined the modeled urban growth output for the seven growth scenarios with the 14 biologically significant GIS layers. The growth scenarios reflect seven different policy directions that the region's leaders may choose when planning for growth in the upcoming several decades. Results showed that depending on the scenario chosen (and hence the policy emphasis), the magnitude of biological resources likely to be lost varies significantly. The scenario with the least overall ecological impact is the Compact Growth Scenario (Scenario 3), with Scenarios 6 (New Cities) and 7 (Great Cities) also fairly low in relative impact. Scenario 4 (Prime Farmland Protection) resulted in the largest decline in the acreage of the 14 key biological data layers we examined. Scenarios 5 (I-5 to Highway 99 Exclusion), 2 (East/West Road Improvement) and 1 (Status Quo) also showed relatively high negative impacts.

## Introduction

The growth of human populations inevitably has an effect on the natural environment. As human populations continue to increase, so do the conflicts for land use. As urban areas expand, vital natural resources diminish. Once lost, most of these resources cannot be recovered. Over the long term, the cumulative impact of environmental degradation negatively affects human health and well-being. One way to minimize anthropogenic impacts on the environment is through scientific inquiry and informed planning.

In the United States, the planning process occurs at the local level. Although most laws and regulations, such as environmental protection (CEQA—California Environmental Quality Act) and source water protection laws (Clean Water Act, Safe Drinking Water Act), are made at State and Federal levels, local planning happens on Tuesday nights at City Council and County Board of Supervisor meetings scattered throughout 478 cities and 58 counties across California (Fulton and Shigley 2005). All too often, the results of this system are inconsistent planning across jurisdictional boundaries and lack of regionally coordinated efforts. The cumulative effects of multi-jurisdictional decisions are rarely considered in any one decision. Conceptualizing the effects of individual decisions on regional resources is difficult without the aid of analytical tools seldom available to local decision makers.

One approach to quantifying the magnitude and nature of the impacts of population growth on existing regional resources is to use an urban growth model implemented in a geographic information system (GIS) to assess the ecological impacts of the projected future growth. One example of this approach involved four growth scenarios developed for the San Joaquin Valley using a cellular automata model called SLEUTH (Teitz 2005) to model growth distributions. Another example is the Partnership in Integrated Planning Process implemented in Merced County, California (Smith et al. 2004) where the community interacted with modelers to create scenarios that reflected the community's perceived range of options.

Our approach was to use UPlan, an urban growth allocation model developed by Professor Robert Johnston and others at UC Davis (Johnston, Lehmer et al. 2006). UPlan has been used for several growth modeling projects, including the Partnership in Integrated Planning process in Merced County (Smith, Scherzinger et al. 2004) and, more recently, the San Joaquin Valley Blueprint process (The Great Valley Center 2006). We also chose to use a process of "community" participation in building the model by having Partnership subcommittee members take part in the creation of the scenarios to be modeled.

From a policy perspective, the Partnership for the San Joaquin Valley provides an excellent example of trying to solve a collective action problem through coordinated local planning. The members of the Partnership come from local city councils and boards of supervisors from the eight counties; they are *local* decision makers. Rather than the typical case of individual cities and counties planning land use policy independently, this group coordinated and developed consensus through a series of meetings and produced joint recommendations for the region. Because the Partnership was initiated by an executive order, the State has also played a key role. As a result of the Partnership's efforts, California has allocated 2.5 million dollars in seed money for the first year for projects aimed at fulfilling the Partnership's recommendations (Department of Business Housing and Transportation 2006b).

**Study Area**

The San Joaquin Valley of California (figure 1) includes eight counties and occupies about 17.5 million acres of land (approximately 27,500 square miles). It is a geographically and biologically diverse region with rich natural resources. During pre-European settlement times, the valley floor was well connected to the foothills and mountains through natural community linkages, and thus constituted a healthy, functioning ecosystem (Meade and McCoy 2006). During the late nineteenth and early twentieth centuries, the San Joaquin Valley became one of the most productive agricultural centers in the country. For many decades it was known strictly as an agricultural center, but as housing and population pressures in the coastal regions of California have increased, the population of the San Joaquin Valley region has started to increase and the pressures on its resources have intensified. In the next 35 to 40 years, the population of the San Joaquin Valley is expected to more than double, increasing from 3.3 million in 2000 to more than 7 million by 2040 (Teitz 2005), and by 2050 there are likely to be close to 8 million San Joaquin Valley residents (Department of Finance 2004b).

This region, which is currently growing faster than Mexico (Central Intelligence Agency 2002) and has a poverty rate higher than Appalachia (Rural Migration News 2006), will need to accommodate this predicted growth, while preserving and expanding its economic base. Some interesting statistics about the region in comparison to the rest of the state of California include the following (Department of Business Housing and Transportation 2006b):

- Average per capita incomes are 32.2% lower than the rest of California.
- College attendance is 50% below the state average.
- Violent crime is 24% higher.
- Access to healthcare is 31% lower.
- Air quality is among the worst in the nation.

The need to accommodate growth, stimulate the economy, and protect the environment of the San Joaquin Valley help make this a region of vast importance to the State of California and to the rest of the nation. Individual jurisdictional priorities must give way to effective regional collective action. The use of forecasting tools provides a powerful methodology for stimulating such collective action.

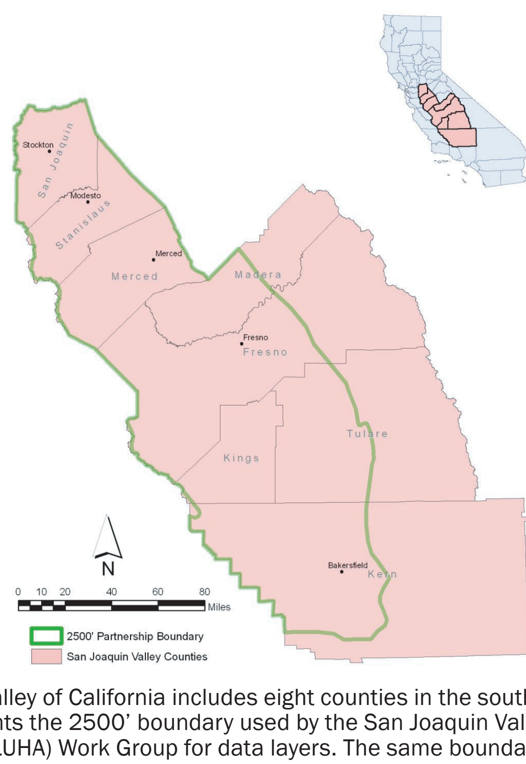



Figure 1. The San Joaquin Valley of California includes eight counties in the southern part of the Central Valley. The thick outline represents the 2500' boundary used by the San Joaquin Valley Partnership's Land Use, Housing and Agriculture (LUHA) Work Group for data layers. The same boundary was used for all analyses described in this paper.

## Methods

### The UPlan Model

In early 2006, the Partnership's Land Use, Housing and Agriculture Work Group (LUHA) requested that ICE implement several potential growth scenarios based on different growth policies defined by LUHA. The parameters associated with each scenario were developed in a collaborative process during several LUHA meetings at the Great Valley Center in Modesto. ICE implemented these scenarios using the GIS-based urban growth model, UPlan, that Robert Johnston created several years earlier (Information Center for the Environment 2006) and that ICE recently enhanced.

UPlan projects spatially explicit urban growth patterns in several land categories. Four residential, one industrial, and two commercial densities are represented. The model does not calibrate based on historical data because its intended use is for long-range scenario testing. It relies on fine-grained raster data (the cell size may be determined by the user) that represent existing urban, local general land use plans, and all other relevant natural and built features that define the model. It is deterministic and rule-based, so as to be transparent to the user. The urban growth allocation rules broadly simulate land markets. The model is free to the public and can be applied to counties, metropolitan regions, watersheds, and bioregions. UPlan allocates growth to different cells using attractors that encourage growth and discouragements that discourage growth.

Some assumptions of UPlan are the following:

- Population growth can be converted into demand for land use by applying conversion factors to employment and households.
- New urban expansion will conform to real or hypothetical city and county general plans.
- Cells have different attraction weights because of accessibility to transportation and infrastructure.
- Some cells, such as lakes and streams, will not be developed. Other cells, such as sensitive habitats and floodplains, can be weighted to discourage new development.

UPlan is easy to use and informative for planners and citizen groups alike (Johnston, Lehmer et al. 2006). UPlan users can change the assumed growth rates or other basic assumptions and can set various environmental and social attractors and discouragements to growth such as the built environment, sensitive habitat, or agricultural lands (Smith, Scherzinger et al. 2004). UPlan has been used for several applications during the past few years, including modeling urban buildout along California's highways (Thorne et al. 2006), transportation planning (Johnston et al. 2003), and modeling future development in California's Sonoma County (Merenlender et al. 2005).

For all seven LUHA growth scenarios, we applied the following set of parameters:

Growth Attractors:

- US Census Blocks with Growth 1990-2000
- Major Arterials
- Minor Arterials
- Highways (not using ramps)
- Freeway Ramps
- Spheres of Influence

Growth Discouragements:

- The Nature Conservancy Priority Conservation Areas
- Vernal Pools (Holland)
- FEMA Q3 Floodplains
- California Natural Diversity Database records

Areas Masked from New Growth:

- Existing Urban (Derived from Department of Conservation's Farmland Mapping and Monitoring Program)
- Streams 100m buffer
- Lakes 100m buffer
- Public Land

Where additional Attractors, Discouragements, or Masks were applied, these are indicated in the specific scenario descriptions in the next section. The growth projection numbers used for all scenarios in the model came from the Department of Finance for the year 2050 (Department of Finance 2004a). Inputs were derived from easily accessible and publicly recognized data sources such as the US Census, California Department of Finance, California Department of Conservation, California Department of Transportation, California Resources Agency and University of California, Davis spatial and demographic data libraries.

**UPlan Scenarios**

We used UPlan to analyze the potential effects of seven different urban growth scenarios on 14 key biological data layers. The following provides a description of the basic goals of each scenario, as described in the ICE metadata for the output GIS layers for each scenario run.

1. **Status Quo Scenario**—Industry, Commercial High, Commercial Low, Residential High and Residential Medium were allowed to go into agriculture if all growth could not be allocated within the current general plans. Residential Low and Residential Very Low were also allowed to go into agriculture if all growth could not be allocated within the current general plans. This model run showed a possible outcome if no significant changes are made to urban growth policies through 2050. This run was used to provide a baseline against which other models can be compared.
2. **East/West Road Improvement Scenario**—Inputs and allocation rules were the same as Scenario 1 except the East/West roads of interest (I-580, 205, Highway 4, 12, 58, 140, 152) were given double weight as hypothetical highway capacity enhancements resulted in increased accessibilities that were attractors to growth. The East/West Road Improvement model run showed a possible outcome if growth is encouraged along seven existing major East/West roads. This run modeled a policy of improving the infrastructure along these already-existing highways.
3. **Compact Growth Scenario**—Inputs were the same as Scenario 1 except Residential Low (RL) and Residential Very Low (RVL) were eliminated and their population was added to Residential Medium (RM). All growth was allocated within current Spheres Of Influence (SOI). If the needed growth was under-allocated then RM housing density was increased to accommodate the growth within existing SOI's. Increased density was necessary in all counties except Kings. In some cases the development could not be sustained entirely in the RM category without dropping RM below 0.1 acre per dwelling unit. When this occurred the development pattern was shifted to 33% RH and 67% RM. These changes were needed in San Joaquin, Merced and Stanislaus counties. This run modeled a policy of very compact growth where increased population is accommodated by increasing densities rather than modifying boundaries and building outside the existing SOIs.
4. **Farmland Protection Scenario**—Prime farmland and farmland of statewide importance were used as a mask. All other variables were the same as Scenario 1. In Fresno County, Commercial Low (CL) and RM were allowed to go into RL, RVL and agricultural land. This run modeled a policy of protecting particularly high-valued farmland as a top priority and required all growth to be allocated outside of these designated areas.
5. **I-5 to Highway 99 Exclusion Scenario**—The area between I-5 and Highway 99 was used as a mask. All other variables were the same as Scenario 1. This run modeled a policy of restricting all new growth to occur to the west of I-5 and to the east of Highway 99. Such a policy would protect a great deal of existing prime farmland and would encourage growth on either side of these major roadways (but not between them).
6. **New Cities Scenario**—Four new cities with populations of approximately 250,000 were created in areas of relatively low agricultural and environmental importance near significant entry points from the California Coast to the SJV. Residential densities were increased by 15% for all classes except RVL (which was eliminated). Population from the RVL class was added to the RL class resulting in a net increase in RL area occupied despite the increased density. This run modeled a policy of creating new cities in areas that do not have high farmland or biological value. Such a policy would focus growth in compact areas by creating four new urban centers.
7. **Great Cities Scenario**—Existing major cities were encouraged to grow to house the predicted population growth. Residential densities were increased by 15% for all classes except RVL (which was eliminated). Population from the RVL class was added to the RL class resulting in a net increase in RL area occupied despite the increased density. This run modeled a policy of creating two or three new "megalopolis" areas of over one million inhabitants. Such a policy would promote growth immediately surrounding existing larger urban centers.

We ran the UPlan model for each of the seven scenarios. The different outcomes of each scenario reflected different potential growth policies. Results from each Uplan model run were in raster format by county. These were merged into one regional layer (all eight counties) for each run and were converted back to a vector layer.

**Biological Conservation Priority Layers**

ICE used a series of GIS data layers to develop the set of conservation opportunity areas for the California Partnership's LUHA Work Group. These areas featured concentrations of priority conservation targets as identified by a group of natural resource professionals during the planning process. The areas were meant to help focus conservation efforts towards those locations that are most critical to the future ecological well-being of the region.

The first step in the process of the ecological data set creation was to hold a series of meetings involving a wide range of natural resource planners representing federal, state, local, and private agencies and organizations. These attendees identified fourteen key biological conservation priority layers in the SJV (Meade and McCoy 2006). The source for each layer is indicated in parenthesis following the layer name.

- Desert scrub (CA GAP Analysis Project)
- Blue oak woodland (CA GAP Analysis Project)
- Sensitive ecological communities (CA Natural Diversity Database)
- Grasslands Ecological Area (Central Valley Habitat Joint Venture)
- Historic lakebeds (Endangered Species Recovery Program)
- Kit fox habitat (intersection of CA Natural Diversity Database kit fox locations with Endangered Species Recovery Program annual grassland and desert scrub polygons)
- Buffers around existing conservation areas (Public/Conservation Trust Lands buffered 2 km)
- 100-year floodplain (FEMA Q3 flood data)
- Riparian corridors (500 m buffers around named rivers from National Hydrography Dataset)
- Perennial grassland (CA GAP Analysis Project)
- Tehachapi corridor (Endangered Species Recovery Program natural land cover polygons between I-5 and Hwy 58)
- High concentrations of sensitive species (CA Natural Diversity Database—A compiled density of threatened and endangered species built around 2000-meter wide hexagonal cells. The dataset was created by generating a blank hexagon grid, intersecting it with the May 2005 CNDDB dataset, and then counting the number if unique species from the CNDDB within each hexagon cell. All hexagons with at least four sensitive species occurrences were used in the analysis)
- Vernal pool complexes in Stanislaus, Merced, Madera, and Fresno Counties (U.S. Fish and Wildlife Service)
- Tulare Basin planning areas (Tulare Basin Wildlife Partners)

These conservation priority factors were obtained in or converted into GIS layers. The map extent used for these layers, shown in figure 1, included all areas in the eight San Joaquin Valley counties up to 2,500 feet in elevation (for a total of 16,736 square miles). This analysis does not include data beyond this boundary.

**Combining UPlan Scenario Outputs with Biological Conservation Priority Layers**

The final step was to combine the output from the seven growth scenarios with the fourteen biological conservation layers. We overlaid each of the seven region-wide scenario outputs with each of the fourteen conservation priority layers developed by ICE (Meade and McCoy 2006) using ESRI's ArcEditor version 9.2 (Environmental Systems Research Institute). We also calculated and summarized the total acreage of each resource that would be converted to human use (including residential, industrial, and commercial uses) given the different growth scenario outcomes. The goal of this analysis was to identify which scenarios, if implemented, would have the least negative impact on these resources in the SJV.

## Results

Depending on the scenario chosen (and hence the policy emphasis), the number of acres of biological resources likely to be lost due to growth varied significantly. The results of this analysis are shown in table 2. The scenario with the overall least amount of impact was the Compact Growth Scenario (Scenario 3), with Scenarios 6 (New Cities) and 7 (Great Cities) also fairly low in relative impact. Scenarios 1 (Status Quo) and 2 (East/West Road Improvement) showed higher overall environmental consequences, while Scenarios 4 (Prime Farmland Protection) and 5 (Between I-5 and Highway 99 Exclusion) resulted in the largest decline in the acreage of the fourteen biological resources data layers we examined.

Another important way to look at the data is to calculate the percent of each biological resource that would be impacted by each modeled scenario (rather than looking at the number of acres of impact). Table 2 presents the results of this calculation. Of particular note are those cases where over 10% of the resource would be lost. This situation occurred for vernal pools in both the Scenario 4 (Farmland Protection - 14.28%) and Scenario 5 (Between Highway Exclusion - 11.53%) model runs. Also, Scenario 2 (East/West Road Improvement) resulted in a 13.72% loss of the region's perennial grasslands, and Scenario 4 (Prime Farmland Protection) was projected to eliminate over 14.5% of the region's blue oak woodlands. Scenario 3 (Compact Growth), on the other hand, would not impact any of the blue oak woodlands, and would result in a less than 2% reduction of each of the other biological factors except for perennial grasslands (4.38%). The results are quite dramatic when one considers the importance of these biological resources to the overall health of the regional ecosystem.

Table 1: Impacts of seven UPlan growth scenarios on selected biological resources (in acres). The number of acres impacted by each Scenario is shown for each of the 14 biological factors. The lowest impact for each resource is shown in Italics, while the highest is shown in Bold

| | Scenarios | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| **Conservation Buffers** | 197,313 | 198,239 | *52,007* | **252,035** | 240,252 | 96,665 | 89,737 |
| **CNDDB High Density** | 52,807 | 52,087 | *21,699* | **74,803** | 57,469 | 24,593 | 22,886 |
| **Desert Habitat** | 10,666 | 11,179 | *1,260* | **15,595** | 10,540 | 2,578 | 2,925 |
| **FloodPlain** | 110,112 | **110,906** | *15,698* | 98,741 | 107,586 | 51,792 | 90,364 |
| **Grasslands** | 6,726 | 7,551 | 332 | 13,585 | *0* | 1,674 | 28 |
| **Kit Fox** | 39,648 | 40,267 | *8,002* | **92,006** | 56,507 | 9,148 | 8,732 |
| **Lakes** | **9,382** | 9,199 | 141 | 6,837 | 1,490 | 1,054 | *88* |
| **Blue Oak Woodland** | 14,162 | 14,037 | *0* | **85,963** | 32,473 | 776 | 47 |
| **Perennial Grasslands** | 692 | 1,188 | 379 | 699 | *4* | 428 | 575 |
| **Riparian** | 19,988 | 20,272 | *2,859* | 21,115 | **22,970** | 10,150 | 13,787 |
| **Sensitive Communities** | 9,385 | 9,754 | *622* | **21,866** | 6,210 | 1,363 | 2,850 |
| **Tulare Basin** | 29,559 | 28,693 | *161* | **41,951** | 7,705 | 1,270 | 413 |
| **Tehachapi** | 1,146 | 1,113 | *0* | **1,551** | 1,469 | *0* | *0* |
| **Vernal Pools** | 16,682 | 15,960 | 2,036 | **43,345** | 34,980 | *668* | 1,899 |

Table 2: Percent of total amount of biological resource impacted by predicted growth allocations in each scenario

| | Scenarios | | | | | | |
|---|---|---|---|---|---|---|---|
| **Biological Factors** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| **Conservation Buffers** | **6.61%** | **6.64%** | **1.74%** | **8.44%** | **8.05%** | **3.24%** | **3.01%** |
| **CNDDB High Density** | **5.68%** | **5.61%** | **2.34%** | **8.05%** | **6.19%** | **2.65%** | **2.46%** |
| **Desert Habitat** | **2.59%** | **2.72%** | **0.31%** | **3.79%** | **2.56%** | **0.63%** | **0.71%** |
| **Flood Plains** | **6.46%** | **6.50%** | **0.92%** | **5.79%** | **6.31%** | **3.04%** | **5.30%** |
| **Grasslands** | **3.64%** | **4.08%** | **0.18%** | **7.34%** | **0.00%** | **0.90%** | **0.02%** |
| **Kit Fox** | **3.27%** | **3.33%** | **0.66%** | **7.60%** | **4.67%** | **0.76%** | **0.72%** |
| **Lakes** | **3.57%** | **3.50%** | **0.05%** | **2.60%** | **0.57%** | **0.40%** | **0.03%** |
| **Blue Oak Woodland** | **2.39%** | **2.37%** | **0.00%** | **14.51%** | **5.48%** | **0.13%** | **0.01%** |
| **Perennial Grasslands** | **7.99%** | **13.72%** | **4.38%** | **8.08%** | **0.04%** | **4.95%** | **6.65%** |
| **Riparian** | **5.05%** | **5.13%** | **0.72%** | **5.34%** | **5.81%** | **2.57%** | **3.49%** |
| **Sensitive Communities** | **4.18%** | **4.35%** | **0.28%** | **9.74%** | **2.77%** | **0.61%** | **1.27%** |
| **Tulare Basin** | **4.97%** | **4.82%** | **0.03%** | **7.05%** | **1.29%** | **0.21%** | **0.07%** |
| **Tehachapi** | **1.75%** | **1.70%** | **0.00%** | **2.36%** | **2.24%** | **0.00%** | **0.00%** |
| **Vernal Pools** | **5.50%** | **5.26%** | **0.67%** | **14.28%** | **11.53%** | **0.22%** | **0.63%** |

## Discussion

The results of this analysis indicate that Scenario 3 (Compact Growth) is the best strategy for minimizing the overall effect on biological resources while accommodating growth during the coming four decades. We are not suggesting that the Compact Scenario be adopted as is without other factors considered. We do recommend accommodation of a large portion of projected growth in high density residential areas that remain, as much as possible, within the footprint of existing towns and cities. We recommend encouraging growth immediately adjacent to and within existing large urban areas and creating "Great Cities" (Scenario 7) and/or considering the development of new cities (Scenario 6) rather than permitting urban and exurban sprawl. These three strategies provide for the projected growth and result in less impact to the region's precious biological resources.

## Conclusion

This paper provides guidance for planners held responsible for the future footprint of human settlement in the region. The San Joaquin Valley of California is one of the fastest growing regions in the country. With staggering projected growth rates for the region, intelligent planning is essential if limited, valuable resources are to be preserved for future generations. The methods presented here may also become a useful template for examining possible outcomes of growth strategies and assessing regional planning in other parts of the state.

**Biographical Sketches:** Karen Beardsley is a GIS Manager and Analyst with the Information Center for the Environment at the University of California, Davis. She is also a PhD candidate with the Geography Graduate Group at UC Davis and studies land use conflicts between human populations and environmental and biological resources.

Nathaniel E. Roth is a GIS Programmer with the Information Center for the Environment, at the University of California, Davis. He is also a graduate student in the Geography Graduate Group at UC Davis. His primary interests are the integration of conservation and recreation open space into urban and near urban environments and the quantitative assessment of impacts caused by differing development patterns.

Michael C. McCoy serves as academic administrator and principal investigator for the Information Center for the Environment. He specializes in the development, aggregation and dissemination of environmental information. In this capacity he works with a variety of agencies, committees and funding sources and works to achieve consensus on the best strategies for integrating data and implementing strategy. Projects include studies of regional environmental planning methodologies, land use and infrastructure planning policy, and the development of rule based and microeconomic land use models.

## References


Central Intelligence Agency (2002). The World Factbook: Field Listing - Population growth rate. Central Intelligence Agency, United States.

Department of Business Housing and Transportation. (2006a). "California Partnership for the San Joaquin Valley." Retrieved December 2006, from http://www.bth.ca.gov/capartnership/sanjoaquinvalley.asp.

Department of Business Housing and Transportation (2006b). California Partnership for the San Joaquin Valley Draft Strategic Action Proposal. The San Joaquin Valley: California's 21st Century Opportunity. Sacramento, CA.

Department of Finance (2004a). Population Projections by Race/Ethnicity for California and Its Counties 2000–2050. Finance. Sacramento, California, State of California.

Department of Finance (2004b). San Joaquin Valley Population in base year (2000) and future year (2050).

Environmental Systems Research Institute. (2007). "ArcEditor--Desktop GIS with Advanced Geographic Data Editing and Management." Retrieved 1/15/2007, from http://www.esri.com/software/arcgis/arceditor/index.html.

Fulton, W. B. and P. Shigley (2005). Guide to California planning. Point Arena, Calif., Solano Press Books.

Information Center for the Environment. (2006). "UPlan User Manual." Retrieved 12/31/06, from http://www.des.ucdavis.edu/staff/roth/uplan/uplan_2_user_manual.doc.

Johnston, R., D. Shabazian and S. Gao (2003). "UPlan: A versatile urban growth model for transportation planning." Transportation Research Record 183: 202-209.

Johnston, R. A., E. Lehmer, S. Gao and N. Roth (2006). UPlan Land Use Allocation Model 2.21 User's Manual.

Meade, R. J. and M. C. McCoy (2006). Identifying High Value Open Space and Conservation Opportunities in the San Joaquin Valley: 18 p.

Merenlender, A. M., C. Brooks, D. Shabazian, S. Gao and R. Johnston (2005). "Modeling Future Development for Sonoma County, California: The Consequences of Agricultural Land Protection Policies for Habitat Conservation." Journal of Conservation Planning 1: 64-68.

Rural Migration News (2006). "San Joaquin Valley: New Appalachia?" Rural Migration News 13(1).

Smith, B., S. Scherzinger, K. Benouar and D. Wheeler (2004). "Partnership for Integrated Planning " Land Development Today March 2004.

Teitz, M. B., Charles Dietzel and William Fulton (2005). Urban Development Futures in the San Joaquin Valley. San Francisco, Public Policy Institute of California: 138p.

The Great Valley Center. (2006). "San Joaquin Valley Blueprint Planning Process." Retrieved November 2006, from http://www.greatvalley.org/blueprint/.

Thorne, J. H., S. Gao, A. D. Hollander, J. A. Kennedy, M. McCoy, R. A. Johnston and J. F. Quinn (2006). "Modeling potential species richness and urban buildout to identify mitigation sites along a California highway " Transportation Research Part D: Transport and Environment 11(4): 277-291.

# Limitations to Wildlife Habitat Connectivity in Urban Areas

**Melinda Trask** (503-986-3504, melinda.trask@odot.state.or.us), Environmental Project Manager, Oregon Department of Transportation, Geo-Environmental Section, 355 Capitol Street N.E., Salem, OR 97301, Fax: 503-986-3407 USA

## Abstract

The Oregon Department of Transportation (ODOT) conducted an evaluation of existing wildlife habitat and movement corridors within southeast Portland, where a new section of highway (the Sunrise Corridor) is proposed. The purpose was to develop a comprehensive strategy to preserve and enhance connections for wildlife passage potentially impacted by the Sunrise Corridor project. The evaluation illustrates limitations to urban wildlife protection that are not typically considered. The proposed alignment and alternatives for Sunrise Corridor project are located in an area that is rapidly growing with urban development but still retains some relatively large natural habitat areas. According to local naturalists, wildlife use of both areas is still fairly high within the context of the urban surroundings. We identified key wildlife movement corridors between the remaining large habitat patches as well as existing and potential barriers to wildlife passage. Larger mammals (e.g., coyote and deer) and migratory song birds were the focal species. We found that approximately 50% of existing wildlife habitat and movement corridors is vulnerable to future planned and potential development as a result of current zoning and land use ordinances. Existing commercial and residential development already constricts the main wildlife corridor, and wildlife access between the remaining habitat patches in the area will be severed if further zoned development occurs.

Comprehensive Plans for many urban areas have provisions for preservation of large tracts of open space, greenways, and parks, with an interest in maintaining habitat for birds and urban wildlife. However, few Plans identify the need for connections between the habitat patches for wildlife movement, an important component of population fitness. Although ODOT's proposed highway project is being designed to avoid blocking wildlife passage, wildlife movement corridors will continue to be threatened by urban development unless organizations or individuals outside of ODOT protect key parcels from future development. As the Sunrise Corridor wildlife evaluation demonstrates, if wildlife on the urban interface are to be protected, early identification and conservation of movement corridors are as essential as conservation of habitat patches.

**Biographical Sketch:** Melinda Trask is an Environmental Project Manager for the Oregon Department of Transportation, with a Master of Science in Plant Ecology from Oregon State University and a Master of Environmental and Regional Planning from Washington State University. Melinda has a broad educational and professional background in ecology of the western United States. She has taught ecology and botany laboratory classes, organized and led field surveys crews for rare plant studies, conducted desert tortoise and peregrine falcon surveys, assisted with fish salvage operations, delineated wetlands, prepared numerous Biological Assessments for Section 7 Endangered Species Act consultations, monitored environmental protection measures during various types of construction projects, and developed site restoration plans. Melinda is currently the co-chair of the Oregon Wildlife Movement Strategy, an interagency working group to address wildlife passage in Oregon.

# Sonoran Desert Conservation Plan and Regional Transportation Planning: A Case Study in Challenges for Protecting and Restoring Wildlife Connectivity in Urbanized Areas

**Carolyn Campbell** (520-388-9925, carolyn@sonorandesert.org), Executive Director, Coalition for Sonoran Desert Protection, 300 E. University, #120, Tucson, AZ 85705, Fax: 520-620-6401 USA

**Abstract**

This project demonstrates full integration of habitat conservation, transportation, and land use planning on a local and multi-jurisdictional level, utilizing best available science and best practices.

The Coalition for Sonoran Desert Protection, an alliance of 38 conservation and community groups, formed in 1998 to protect biodiversity in the Sonoran Desert through Pima County's multi-species habitat conservation planning effort. Pima County, encompassing over 9 million acres of metropolitan Tucson, Arizona and vast rural landscapes, is adjacent to the Mexican border state of Sonora, Mexico. The metropolitan Tucson area is the focus of the planning area, whose population is expected to reach 1 million by the end of 2006. Encompassing Tucson on four sides is federal forest and park lands.

The planning process brought together scientists from state and federal agencies, advocates from NGO's, and local county and municipal officials. A broad group of stakeholders was also convened to produce consensus recommendations to county officials regarding ESA Section 10 compliance. This abstract will outline the steps taken to protect and re-create wildlife linkages utilizing transportation projects through local planning and cooperative creative partnerships.

Methodology in the broad context of protecting biodiversity included a 4-year development, by a science technical team, of a county-wide map identifying and prioritizing biologically-important lands. Categories developed were: Important Riparian Areas, Biological Core Management Areas, Special Species Management Areas, Multiple-Use Management Areas, and Critical Landscape Linkages. As connectivity between reserves was of particular importance to a functional landscape, the linkages category became a focus with its own methodology for implementation.

Critical Landscape Linkages have been defined as, areas that contain potential connectivity corridors for biological resources but also may have now, or in the future, barriers that tend to isolate major conservation areas. The linkage definitions, maps, and land use guidelines have been included in both the draft habitat conservation plan and the county's comprehensive land use plan. The barriers consist of highways, roads, and a federal irrigation (Colorado River) canal.

Methodology to design, implement and construct wildlife connectivity through transportation barriers has been multi-faceted and complex. The Coalition was able to bring attention to the importance of the issue to local officials, adopt the linkages in local public documents, successfully advocate for the adoption of environmentally-sensitive roadway design guidelines, successfully pass voter-approved Open Space Bonds of $174.3 million which includes acquisition of lands within mapped linkages adjacent to roads, and education and cooperation of other road-building agencies. As well, the Coalition Director was involved with state legislation that created a county-wide Regional Transportation Authority to which she was appointed. Through that committee, the Coalition was able to successfully advocate for adoption of a program category for Critical Landscape Linkages that includes $45 million to be expended for wildlife structures. This plan and funding was adopted by county voters in May 2006 as part of a 20-year, $2.1 billion transportation package.

Both the 2004 Open Space Bond acquisitions and the Critical Landscape Linkages funding for wildlife crossing structures are currently being implemented. These programs are being integrated not only with each other, but with multi-jurisdictional land use planning decisions, and on-going research and monitoring.

There is a huge opportunity in future research, which needs to include intensive monitoring of the linkages and their contribution to protection and restoring biodiversity in the Sonoran Desert.

Although this process, begun in 1998, was a direct response to endangered species liability issues county-wide, the scientific and community response has gone far beyond the regulatory compliance. If accepted, the paper will outline in greater detail the technical and biological issues involved in the local process, with particular focus on the challenges faced in successful integration of transportation and conservation planning.

# Wildlife and Terrestrial Ecosystems

*Amphibians and Reptiles*

## Ecological Effects of Roads on Herpetofauna: Understanding Biology and Increasing Communication are Critical for Wildlife Conservation

**Kimberly M. Andrews** (803-725-0422, andrews@srel.edu), Doctoral Candidate, Savannah River Ecology Laboratory, University of Georgia, Drawer E, Aiken, SC 29802, Fax: 803-725-3309 USA

**Abstract**

Roads are the ultimate manifestation of urbanization, providing essential connectivity within and between rural and heavily populated areas. The ecological impacts roads have on herpetofauna across temporal and spatial scales are profound, beginning during the early stages of construction and progressing through to completion and daily use. Herpetofauna have the potential to be negatively influenced from roads as a consequence of urbanization, either directly from on-road mortality or indirectly as a result of a variety of ecological impacts and enabled human accessibility. The quantity and the potential severity of indirect impacts of roads and urban development on amphibians and reptiles far exceed those incurred from direct mortality of wildlife although our understanding of these indirect consequences is premature. As the amount of research on the impacts of roads on reptiles and amphibians increases, scientists find themselves at a stage where determining the appropriate management and conservation direction is critical. While many road impacts have long-term effects, researchers are hampered by the inevitable time constraints imposed by funding agencies and, in the instance of many reptiles, the human life span in relation to their study organism. These complications are subsequently confounded by the necessity to prioritize research. Having science-based conservation decisions answer all questions on all species in all locations over a variety of spatio-temporal scales would be ideal, but is not achievable. The difficulty of long-term complex studies can be mitigated by performing shorter-term or smaller studies that elucidate general trends while specifying areas of research prioritization. Further, an examination of basic biological parameters of organisms can direct areas of susceptibility to road effects that assist in prioritization of research topics and focal species. This synthesis is indicative of the research mileage that can be covered when using multiple studies to assess an ecological issue. Lastly, while some on-road mortality can be minimized in some instances for some species with road crossings, the mitigation of indirect effects such as pollution cannot be accomplished with these measures. In light of the many indirect effects that have been identified and the many more that remain to be documented, proactive transportation planning, public education, and communication among the professional sectors of society are the most effective way to minimize and mitigate road impacts and the *only* effective mechanism for avoidance of road impacts.

For more information on the situation at Savannah River Ecology Lab, a partner in road research, please visit: www.savesrel.org

# Effectiveness of Amphibian Mitigation Measures Along a New Highway

**Jed Merrow** (603-225-2978, jmerrow@mjinc.com), McFarland-Johnson, Inc., 10 Ferry St., Unit 11, Concord, NH 03301, Fax: 603-225-0095 USA

**Abstract:** In 2004-2005, a new highway bypass was constructed through an area of predominantly upland forest with many vernal pools in southern New Hampshire. The highway is complete but is not yet open to traffic. Potential impacts to vernal pool amphibians (spotted salamanders (Ambystoma maculatum) and wood frogs (Rana sylvatica)) and their habitat include habitat loss, barriers to animal movements, potential mortality on roads, and changes in water quantity and quality in breeding pools. Measures to maintain viable vernal pool-breeding amphibian populations along the bypass were implemented and monitored. Effectiveness as used in this paper refers to the ability of the various mitigation measures to contribute to the overall goal of maintaining viable populations, as well as the ability of each measure to provide its specific functions. The mitigation measures and results of their effectiveness to date include:

- Bridges: Two bridges were constructed for general wildlife habitat connectivity.
- Wildlife crossing structure and diversion walls: A 1.2 m by 1.2 m (4' by 4'), 17-m (55') long concrete box culvert and diversion walls were installed. After three years of monitoring spring amphibian migrations, it appears the diversion wall is successfully diverting the few vernal pool-breeding amphibians that encounter it, but there is no evidence the crossing structure has been used.
- Seasonal pool construction: Two new pools were constructed in an effort to maintain viable amphibian habitat and populations on both sides of the new road. Post-construction monitoring shows the new pools are used by a relatively diverse community of amphibians (including spotted salamanders in one pool) and macroinvertebrates, although the pools' long-term value to vernal pool amphibians is not yet certain.
- Drainage: Natural hillside drainage was maintained across the new roadway to maintain existing vernal pool hydrology to the extent feasible. Where possible, roadway drainage was routed to swales and detention basins that discharged outside of vernal pool watersheds. Based on two years of observations, vernal pools immediately adjacent to the roadway have been hydrologically altered, but other pools do not appear to have been affected by the changes.
- Habitat preservation: The land around the greatest concentration of existing vernal pools, all on one side of the new highway, was purchased to preserve habitat integrity. Six years of pre-construction and two years of post-construc tion monitoring show that spotted salamander breeding (as measured by egg mass counts) has not changed substantially compared to pre-construction levels. However, there is a great deal of variation in breeding activity from year to year and pool to pool, and longer-term monitoring may reveal different trends. Opening the highway to traffic may also affect populations.

## Introduction

Southern New Hampshire is part of the metropolitan Boston area and is experiencing rapid development of new residential subdivisions and increasing traffic volumes and traffic congestion. In the early 1990's, the New Hampshire Department of Transportation (NHDOT) proposed improvements for the local highway network in the towns of Windham and Salem, NH that included a new highway bypass to relieve traffic congestion. Figure 1 shows the general project location and identifies the area (labeled "bypass segment") that is the subject of this paper. An Environmental Impact Statement was prepared which identified an important wildlife corridor, an upland habitat area, and two vernal pools along the proposed bypass route. Follow-up studies identified several more vernal pools in the vicinity of the bypass. This paper describes measures implemented to mitigate the bypass's wildlife impacts, focusing on vernal pool-breeding amphibians and their habitat. The paper describes the general wildlife impacts and mitigation measures; the range of possible impacts to vernal pool species and habitats; measures to mitigate those impacts; and the results of pre- and post-construction monitoring.

The portion of the highway bypass which passes through the vernal pool area (figure 2) is approximately 1.2 km (0.75 miles) long, with one lane in each direction and a roadway pavement width of 13.2 m (44 feet). It was constructed in 2004-2005 through an area of predominantly upland forest with many vernal pools. Highway construction has been completed, but the highway is not yet open to traffic.

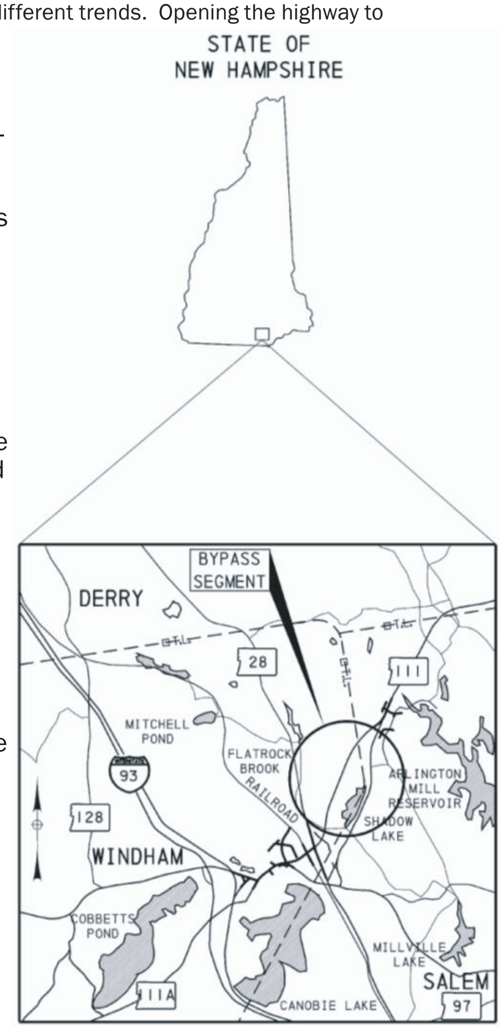



Figure 1. Project location.

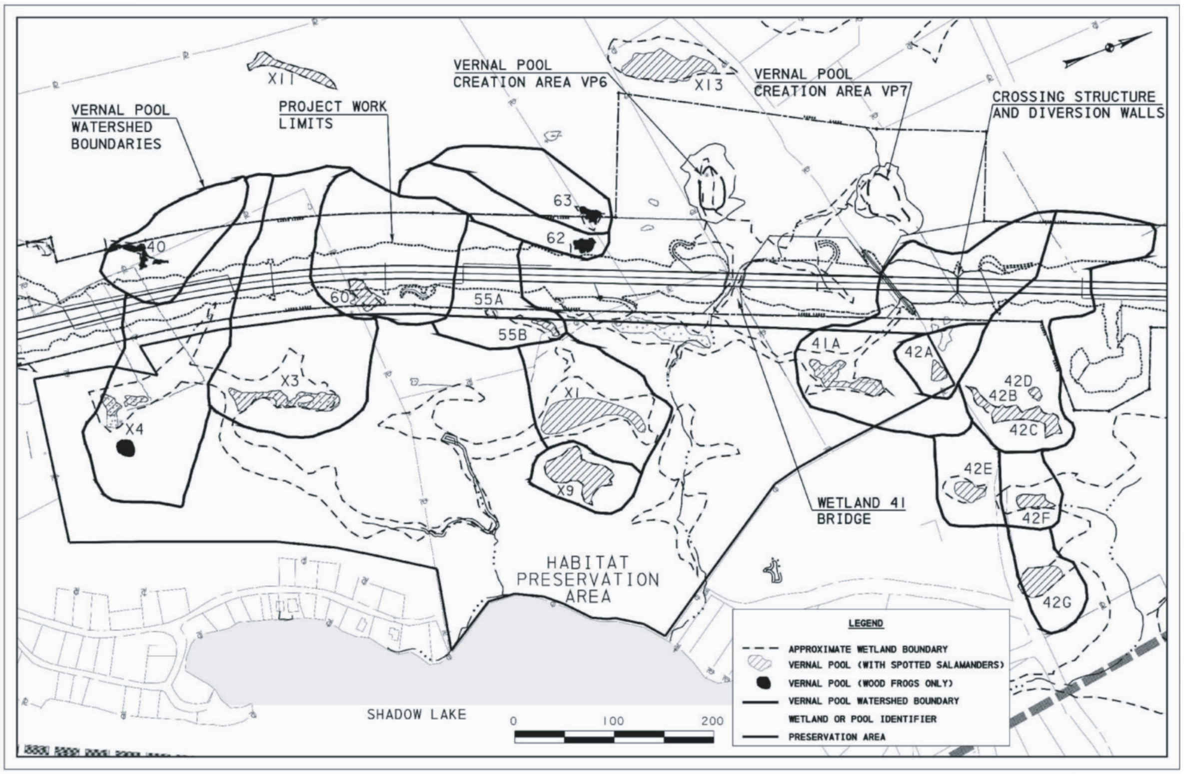



Figure 2. Windham-Salem Bypass Project within vernal pool area. (metric scale)

## General Wildlife Habitat Impacts and Mitigation Measures

In the early stages of the study, the wildlife impact of greatest concern was habitat fragmentation. Measures to counteract this impact included two bridges and permanent protection of important habitat.

The only clear wildlife corridor along the bypass route is a stream corridor located about 200 m (650') south of the vernal pool area along a local road. The corridor includes a 4 to 6 m (13' to 20') wide perennial stream and adjacent floodplain and wetland. A bridge spanning 176 m (577') was constructed over an existing road along with the entire stream, floodplain, and wetland. The construction cost of the bridge was approximately $7 million, a figure which would have been substantially lower if the minimum size structure(s) had been built.

A second bridge with a 15-m (50') span was constructed nearer the middle of the bypass segment over an intermittent stream that connects a network of forested wetlands on each side of the bypass (the "Wetland 41 Bridge", figure 2). The purpose is general habitat connectivity, and the construction cost was approximately $760,000.

The land between the bypass and a nearby lake was purchased and permanently protected ("Habitat Preservation Area", figure 2). The land totals 18 ha (44 acres) and includes the only undeveloped shoreline left on this small lake. It also includes several vernal pools.

## Vernal Pool and Amphibian Impacts

There are several ways in which the new highway may affect vernal pool-breeding amphibians and their habitat. These impacts are described below, followed by a description of mitigation measures and monitoring results.

### Direct Habitat Loss

Within the vernal pool area, the new bypass will convert approximately 5 ha (12.5 acres) of forested habitat to pavement, embankments, detention basins, and other structures. Most of the affected land is former upland forested habitat that was presumably used by spotted salamanders and wood frogs that breed in the pools. If upland habitat, rather than vernal pool breeding habitat, is a limiting factor in these species' population sizes, then the habitat loss could result in smaller populations of these species.

One vernal pool has been directly impacted by the project. About a third of a particularly productive pool (pool 60) was filled in. It is smaller and possibly shallower than before and receives more sunlight, but continues to be used by both wood frogs and spotted salamanders. It remains to be seen whether, following the opening of the highway to traffic, this pool will continue to be viable habitat for these species.

### Barriers to Animal Movements and Direct Mortality on Roads (Road Kill)

Spotted salamanders and wood frogs are known to travel several hundred feet or more to their breeding pools (Colburn 2004). Since several productive vernal pools (such as X1, X3, and 42C on figure 2) are 100 m or so (300' to 400') from the new highway, the road presumably crosses amphibian migration routes. The road may serve as a barrier in several ways: some amphibians may be reluctant to cross open spaces such as roads; some may be disoriented by the new landscape configuration; and, when the road opens to traffic, some may be run over by vehicles and killed on the road.

### Water Quality and Hydrology

Hydrology is perhaps the single most important characteristic of vernal pools. The most productive vernal pools for pool-breeding amphibians are those that contain water long enough for amphibians to metamorphose, but that dry out periodically so they do not support predatory species such as fish or green frog tadpoles. The bypass passes through the surface watersheds of many vernal pools (pool watersheds are shown on figure 2), and may affect runoff/recharge ratios, water temperature, and other factors affecting water quantity and quality.

To determine the hydrologic impact of the project on vernal pools, efforts were made to understand the hydrology of existing vernal pools. The hydrology of a typical existing pool (pool 60 on figure 2) was studied by placing three water table wells around the pool: one just upslope, one on a lateral slope, and one just downslope. Water depth was also measured within the pool. It was found that in springtime, there are both surface water and groundwater inputs to the pool. Snowmelt, precipitation, and a groundwater table that is higher than the pool's water level combine to fill the pool. Over the course of the growing season, the groundwater elevation gradually drops to a level below the bottom of the pool. The surface water elevation of the pool drops more slowly than groundwater drops, so that in summer and early fall the pool's water may be perched above the groundwater table.

The bypass is constructed in a cut section upslope of the pools. This has the potential to intercept both surface water and groundwater that would normally flow into the pools.

## Vernal Pool and Amphibian Mitigation Measures

### Wildlife Crossing Structures

One way to address the travel barrier and road kill effects of the new highway is to make the highway permeable to amphibian movements. One approach to making a road permeable to amphibians is to install wildlife crossing structures (culverts or bridges). Amphibians have been found to be sensitive to moisture, light, temperature, and other physical characteristics of wildlife crossing structures (Jackson and Griffin 2000). There have been mixed results in getting vernal pool-breeding amphibians (particularly spotted salamanders and wood frogs) to pass through crossing structures. An amphibian crossing structure installed in Amherst, MA reportedly allowed 76% of amphibians to cross the road safely (Jackson 1996). However, that design involved a smaller road crossing and was able to incorporate slotted tops that allowed rain water to enter the crossing structures.

For this project, efforts were made to develop a structure design that would provide the requisite conditions, particularly moist substrates, for amphibian crossing. Slotted top and open grate designs were considered, but highway maintenance personnel believed the safety risks and maintenance concerns of such a design (particularly during snowplow operations) would be unacceptable. There were also concerns about the effects on amphibians of road runoff entering the structure. Other design concepts, such as grates in road shoulders or swales or pipes carrying road runoff into a crossing structure, were found to have potential maintenance problems or water quality concerns.

The selected wildlife crossing structure location is shown in figure 2, and the design is shown in figure 3. The structure cost approximately $100,000 to construct. The design has the following features:

*Location:* There were no clear amphibian travel corridors within the project area, and the target species do not converge along common travel routes. The wildlife crossing structure was therefore constructed where the road approaches the most productive vernal pool (in terms of spotted salamander egg mass counts), pool 42C, as this area was likely to have the greatest number of amphibian movements.

*Length:* 17 m (55'). The length was shortened as much as possible by constructing headwalls and wingwalls just outside the road shoulders.

*Opening:* 1.2 by 1.2 m (4' by 4'). The opening is larger than those generally recommended for amphibians (e.g., Jackson and Griffin 2000).

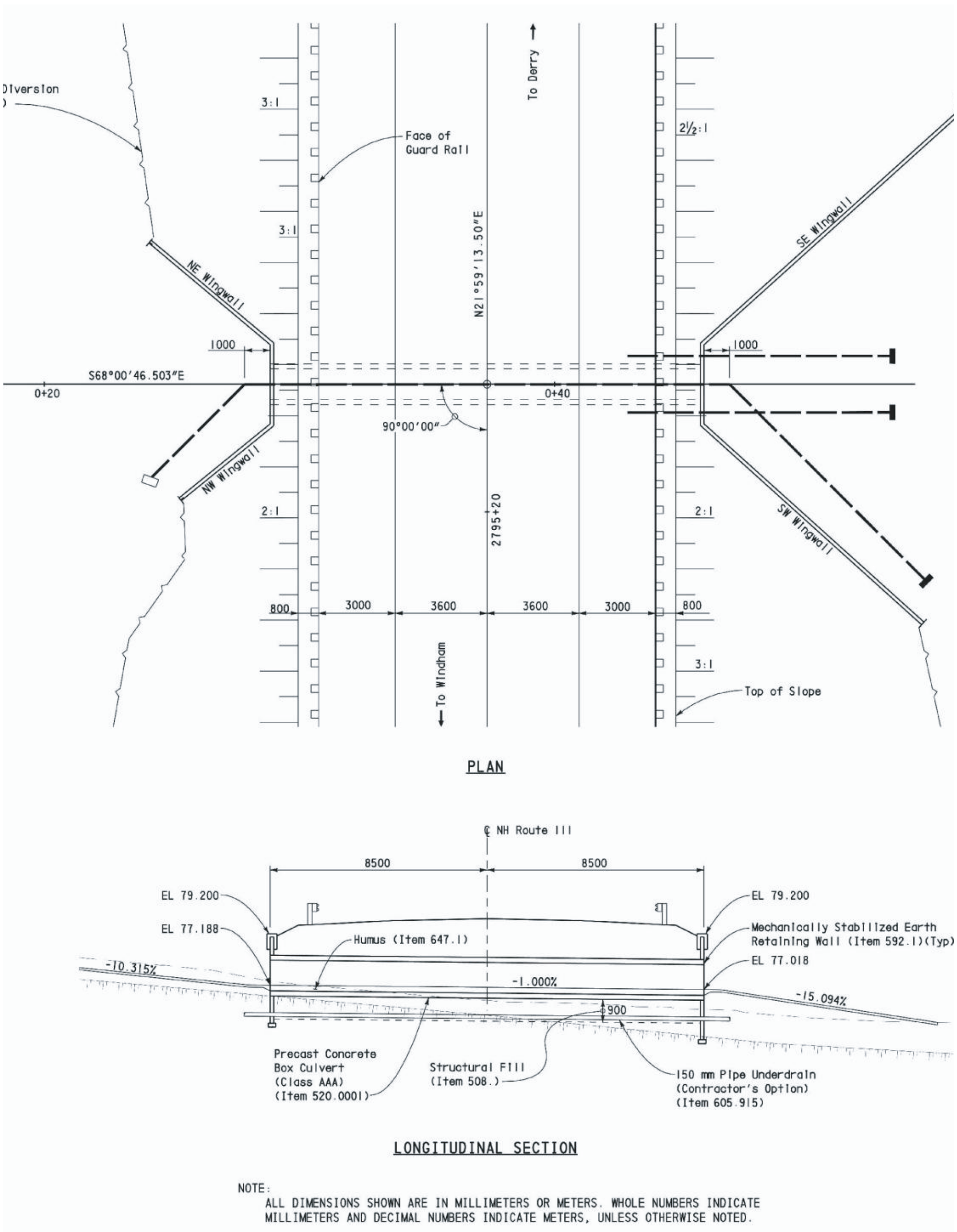



Figure 3. Crossing structure plan and section (in metric units).

*Substrate:* The substrate was a loamy soil material which would allow absorption of moisture and some resistance to erosion. The soil material was sloped across the width of the structure so that any stream flow would be confined to one side, potentially resulting in a gradient of moisture conditions and allowing passage of animals along the higher ground.

*Moisture:* The wildlife crossing structure was placed in a landscape position in which it can receive a small amount of overland flow from the surrounding land, but not enough to create stream conditions, which spotted salamanders may avoid. In early spring, especially while snow is still melting and the ground thawing, a small amount of water flows into the structure and creates moist conditions along one side of it. Following snowmelt, the substrate gradually dries out.

*Wildlife diversion wall:* Also designed and implemented was a “wildlife diversion wall”, a low wall intended to prevent amphibians from crossing over the road surface and to funnel them to the crossing structure. Wildlife diversion walls were 0.3 m (12 inches) or higher and extended from the wildlife crossing structure opening to a stone-lined stream channel on one side and a larger pedestrian culvert with a crushed stone substrate on the other side. The diversion wall was specified as a smooth wall, but the final specifications were ambiguous and a rough concrete block ("Versa-Lok") was used by the contractor.

### Vernal Pool Habitat Creation

Despite the above design features, there remained uncertainty about the wildlife crossing structure's ability to succeed in accommodating vernal pool amphibians, particularly considering the mixed success that other amphibian crossing structures have reportedly had in New England (B. Butler and B. Windmiller, pers. com.). The crossing structure was therefore considered experimental, and more attention was paid to ensuring sufficient vernal pool habitat on both sides of the highway to support viable amphibian populations.

As shown in figure 2, there is more vernal pool habitat on the east side of the new highway, and three of the four most productive pools in the area are located there. In an effort to ensure there is sufficient vernal pool habitat on both sides of the highway to support viable populations, two new pools (VP6 and VP 7 on figure 2) were constructed. The size and hydrology of these two constructed pools were designed to mimic that of existing pools in the area. A 60-m (200') upland buffer was preserved around both pools. Conditions found in these pools are discussed in the *Monitoring Results* section below.

### Mitigation for Hydrologic and Water Quality Impacts

To minimize the potential hydrologic effects of the bypass intercepting surface water and groundwater flowing into the pools, as well as possible water quality effects of road runoff, the following mitigation measures were implemented:

- The integrity of each pool's watershed was maintained to the extent possible by allowing natural hillside drainage to cross under the new roadway, separate from road runoff.
- Road runoff, where feasible, is collected and discharged to detention basins and swales that discharge away from vernal pool watersheds.
- Underdrains were installed at many places along the bypass to ensure a stable road bed. This is clean groundwater and is discharged directly to the adjacent land, so most of the affected groundwater stays within the pools' watersheds.

There are no baseline data of preconstruction vernal pool hydrology or water quality to determine the effectiveness of these measures. Visual observations suggest that the hydrology of most existing vernal pools has been little affected. However, three existing pools located immediately adjacent to the roadway appear to have altered hydrology. These include pool 60, which was partially filled by the project, but still has wood frog and spotted salamander egg deposition; pool 40, which continues to have wood frog egg deposition but appears smaller and drier than previously; and pool 62, which supported wood frogs and now has spotted salamander breeding activity, and appears deeper and wetter than previous conditions.

### Additional Habitat Preservation

The 44-acre parcel that was preserved for general habitat mitigation includes many of the most productive vernal pools (in terms of amphibian breeding activity) in the vicinity of this bypass segment. When the extent of vernal pool and amphibian habitats and impacts in this area became known, NHDOT agreed to extend the preservation land to the north to include approximately 20 additional acres, which contain several vernal pools (42C, 42F, 42G) along with upland and wetland forest habitat. NHDOT also agreed to preserve a 60-m (200') right-of-way buffer around two constructed vernal pools (discussed below).

## Monitoring Results

### Existing Vernal Pool Breeding Activity

Six years of pre-construction and two years of post-construction monitoring (with no traffic on the new road) show that spotted salamander breeding in existing pools (as measured by egg mass counts) has not changed substantially compared to pre-construction levels (figure 4). However, there is a great deal of variation in breeding activity from year to year and pool to pool, and longer-term monitoring may reveal different trends. Opening the highway to traffic may also affect populations.

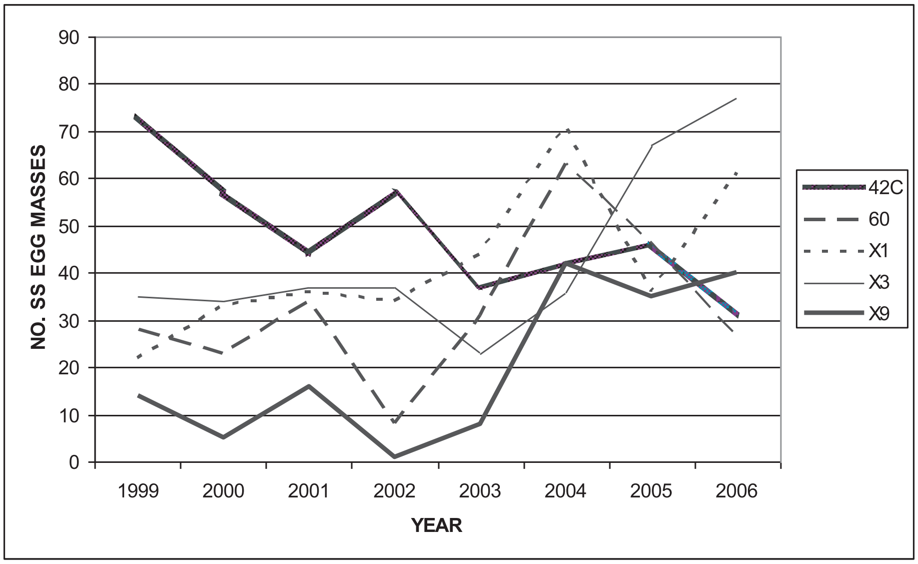



Figure 4. Spotted salamander (SS) egg mass counts in existing vernal pools by year. Vernal pool identifiers are at right; see figure 2 for pool locations. The highway bypass was constructed in 2004 and 2005.

**Constructed Vernal Pools**

Post-construction monitoring shows the new pools are used by a relatively diverse community of amphibians (including spotted salamanders in one pool) and macroinvertebrates. In the two years since construction, the pools have not dried out, although both years have been wetter than normal. It appears the pools are valuable amphibian habitat and are likely to provide habitat for at least one vernal pool breeding amphibian, although the long-term value to vernal pool amphibians is not yet certain. Other issues that have arisen include the relative lack of shading around new pools (necessitated by grading to construct the pools) and the resulting growth of dense emergent vegetation in portions of the pools.

**Wildlife Crossing Structures**

After three years of monitoring spring amphibian migrations, there is no evidence the wildlife crossing structure has been used by amphibians. Small numbers of spotted salamanders and wood frogs have been found moving along the wildlife diversion walls, but have not been found within the structure. Reasons most likely include a combination of substrate, opening size, and length of the structure. The diversion wall is diverting vernal pool-breeding amphibians, although spring peepers have been observed scaling the rough wall. There is also dense growth of grass in some places along the wall, which could make amphibian travel along the wall difficult, and could give amphibians the means to cross over the diversion wall.

Small numbers of spotted salamanders and wood frogs have also been found crossing the road in areas where there are no wildlife diversion walls or crossing structures, suggesting there will be mortality once the road is open to traffic.

## Conclusions and Recommendations

Roads may affect vernal pool breeding amphibians and their habitats in a variety of ways, including by habitat loss, barriers to animal movements, mortality on roads, and changes in water quantity and quality in breeding pools; all of these potential impacts need to be considered for these species.

It is clear that more information is needed on ways to successfully design crossing structures for amphibians, especially across larger highways. For this project, it does not appear the highway will accommodate safe crossing by amphibians. However, through habitat preservation and the creation of new habitat, there is likely sufficient habitat to allow for viable amphibian populations on both sides of the new roadway. Occasional crossing by amphibians is likely to be sufficient to allow for gene exchange and recolonization needed for healthy metapopulations. Monitoring will continue at least through 2009, and should reveal the effects of roadway traffic, results of mitigation efforts, and population trends.

**Biographical Sketch:** Jed Merrow is with the consulting firm McFarland-Johnson, Inc. Jed has an MS in Natural Resources Science from the University of Rhode Island and specializes in wetland and wildlife ecology. He has particular expertise in reptiles and amphibians, and has worked on a variety of vernal pool studies, herptile inventories, rattlesnake habitat studies, as well as many bird surveys. He has also served on New Hampshire committees related to a vernal pool manual, vernal pool wetland regulations, and reptile and amphibian listings, and is active with the NH transportation/wildlife working group. He has over 15 years of experience on transportation projects.

## References

Colburn, E. 2004. Vernal Pools, Natural History and Conservation. The McDonald & Woodward Publishing Co. Blacksburg, VA.

Jackson, S.D. 1996. Underpass systems for amphibians. 4 pp. In G.L. Evink, P. Garrett, D. Zeigler and J. Berry (eds.) Trends in Addressing Transportation Related Wildlife Mortality, Proceedings of the Transportation Related Wildlife Mortality Seminar. Florida Dept. of Transp. Tallahassee FL. FL-ER-58-96.

Jackson, S.D. and C.R. Griffin. 2000. A strategy for mitigating highway impacts on wildlife. Pp. 143-159 in Messmer, T.A. and B. West (eds.) Wildlife and Highways: Seeking Solutions to an Ecological and Socio-economic Dilemma. The Wildlife Society.

# Road-Crossing Structures for Amphibians and Reptiles: Informing Design through Behavioral Analysis

**Hara Woltz** (212-729-6887, hara@harawoltz.com), Nelson Byrd Woltz Landscape Architects, 276 Riverside Drive, No. 11B, New York, NY 10025 USA

**James P. Gibbs** (315-470-6764, jpgibbs@esf.edu), Associate Professor, Conservation Biology/Wildlife Management, State University of New York, College of Environmental Science and Forestry, 247 Illick Hall, 1 Forestry Drive, Syracuse, NY 13210, Fax: 315-470-6934 USA

**Abstract**

Seasonal movements are fundamental to the life cycles of many species of amphibians and reptiles. These patterns of migration can be compromised by the presence of roads. Roads negatively impact many amphibian and reptile populations in various ways, such as obstructing movement, fragmenting and degrading habitats and causing increased mortality through vehicular contact. Road crossing structures provide one possible way to mitigate the negative effects of roads and facilitate safe passage for these organisms. However, if crossing structures are to be effective, animals must be willing to use them. Through a series of behavioral choice experiments, we examined whether certain aspects of structural design might influence animal preferences for particular crossing structures. We tested four qualities of possible under-road crossing structures: aperture size, substrate material, length, and light availability. For these qualities, we evaluated the responses of individuals from four species: northern green frogs (*Rana clamitans*), leopard frogs (*Rana pipiens*), painted turtles (*Chrysemys picta*), and snapping turtles (*Chelydra serpentina*), Results indicate that for particular organisms, specific variables did seem to influence patterns of choice. In the aperture treatment, the choices of painted turtles, snapping turtles, and leopard frogs indicate that pipe diameter exerts a significant influence on choice. The substrate treatment indicated that green frogs have a significant preference for soil and gravel over other materials. Overall, these results elucidate important considerations for the design of behaviorally palatable crossing structures.

# Road Effects on a Population of Copperhead Snakes in the Land Between the Lakes National Recreation Area, K.Y.

**Valorie R. Titus** (607-232-0343, vtitus7@mac.com), Department of Biological Sciences, Binghamton University, P.O. Box 6000, Binghamton, NY 13902 USA
**Ed Zimmerer, Ph.D.** (ed.zimmerer@murraystate.edu), Department of Biological Sciences, Murray State University, 334 Blackburn Science Building, Murray, KY 42071-3346 USA

Abstract: With increasing human development encroaching on wild areas, an understanding of the interactions of wildlife in their natural surroundings is becoming imperative. Over the past few decades, a concern for the conservation of herpetofauna throughout the world has become prevalent. Lack of information on reptiles and amphibians have raised many questions on the effects of roads on their populations. In this study, snake movements on roads in a mostly natural area were examined. Individuals of the copperhead snake (*Agkistrodon contortrix*) were studied in the Land Between the Lakes National Recreation Area (LBL) in Kentucky. LBL is a 170,000-acre federally protected area between Kentucky Lake and Lake Barkley in Western Kentucky and Tennessee. On a typical night of road cruising, over 60 percent of the snakes captured are copperheads in this area. Over two hundred individual copperheads, both alive and dead, were observed during this study from April 2002 through October 2003. Males and females exhibited different frequencies of movements, while juveniles exhibited different frequencies of movements when compared to adults. Road-crossing sites were not random, showing a preference toward less maintained roads with a denser canopy cover. Slightly more snakes were found dead on the road (DOR) than alive on the road (AOR). Significantly higher percentages of DOR were also observed on the highly traveled road as compared to the less maintained roads. Thus, a concern arose with the high numbers of road mortality observed because even though the snakes preferred to cross in areas of low traffic and more cover, significantly higher mortality was seen on the high speed and high traffic road. With LBL being a fairly undisturbed area, this poses a concern for the survivability of the copperhead, along with other wildlife, in more densely populated areas.

## Introduction

Movement in relation to habitat preferences is vital to the understanding of the ecology of many organisms. Studies of this type on how an organism relates to its environment can provide great insights into the biology of the species as a whole. Conservation efforts rely on these studies in order to create management plans for species or populations of special concern. Whether the reason for concern is natural or man-made, this holds true for snakes, as well as any other organism (Langley et. al. 1989; Bernardino and Dalrymple 1992; Bonnet et. al. 1999). Natural disasters, such as hurricanes, along with man-made issues, such as rapid development and overpopulation, are inevitable when working with any organism. When these issues arise, there is a need for knowledge of the natural history of the organisms affected to ensure their survival.

Snake movement has long been of interest and knowledge of which has increasingly become essential in the conservation of both common and threatened species. Due to their cryptic nature and the difficulty of locating them in their natural habitat, pertinent studies have lagged behind those of other vertebrate groups (Cross and Petersen 2001). Most movement is assumed to be associated with the attainment of resources such as prey, shelter, and hibernacula, as well as for purposes of reproduction (Pough et. al. 2001). Problems associated with the study of snake movement are attributed most often to two general factors: difficulties in the methodologies used to study movement in snakes (Cross and Petersen 2001), and the lack of relatively undisturbed natural areas in many regions. The latter problem, in particular, applies to many large snake species (Whitaker and Shine 2000).

Much of what we know now about snake movement has been derived from just a few sampling methods. Since the 1930's, one of the most widely used techniques for herpetological studies is known as "road-running" or "road cruising," (Klauber 1939; Dodd et. al. 1989; Bernardino and Dalrymple 1992; Pendley 2001). This involves driving along roads in search of animals that are crossing or thermoregulating along the roads. There are some limitations to road cruising, however. There are species or individuals who are more or less likely to cross roads (Shine et al. 2004), which can lead to potentially false population estimates. Also, direction of movement might be skewed due to human presence when coming upon an animal. Animals found dead on the road may also not have been moving in the direction they were found. Despite its limitations, road cruising is still a powerful tool. Since roads are open spaces, it is easier to see the animals than sampling in grassy or wooded areas, particularly in studying nocturnal animals (Dodd et. al. 1989; Bernardino and Dalrymple 1992). Road cruising can also provide estimates of road mortality rates within the study area (Dodd et. al. 1989; Bernardino and Dalrymple 1992, Shine et. al. 2004).

In many parts of the world, the lack of fairly undisturbed, natural areas can further complicate the study of snake movement. Many areas are highly developed, which has resulted in persecution and road mortality (Langley et. al. 1989; Bernardino and Dalrymple 1992; Bonnet et. al. 1999; Whitaker and Shine 2000). It is ironic that one technique used to study and collect snakes (road cruising) is the result of intrusion into their natural environment and is largely responsible for habitat loss and mortality. With such rapid development across the world, it is often difficult, therefore, to study any animal in its truly "natural" surroundings. Protected areas can provide insights as to how animals may behave in undisturbed areas, while studies in developed areas can provide information on the adaptability of an organism to human activities.

With a broad distribution across the easterly United States, the copperhead, *Agkistrodon contortrix*, may prove to be of particular interest in the study of snake movement. Its relative abundance across this range is highly variable, with many areas in which it is considered rare, and others where it may be one of the most abundant snake species (Fitch, 1960; Gloyd and Conant, 1990; Conant and Collins 1998). Copperheads are found in a range of habitats throughout their geographic range including coastal marshes, mixed deciduous forest, and pine forests, and some have also readily adapted to human habitats (Fitch and Shirer, 1971; Conant and Collins 1998).

One area in which the copperhead is particularly abundant is the Land Between the Lakes National Recreation Area in Kentucky and Tennessee (figure 1). LBL is a 170,000-acre federally protected area between Kentucky Lake and Lake Barkley (Lynn 1994). This area can provide an exceptional source of baseline population data for many species because of its relatively undisturbed nature. Since there are several roads that are found throughout LBL, this area can also provide some insight into snake behaviors in relation to roads. This study focuses on the location and road types at the crossing sites of copperhead snakes, as well as looking at mortality of these snakes in association with these roads.

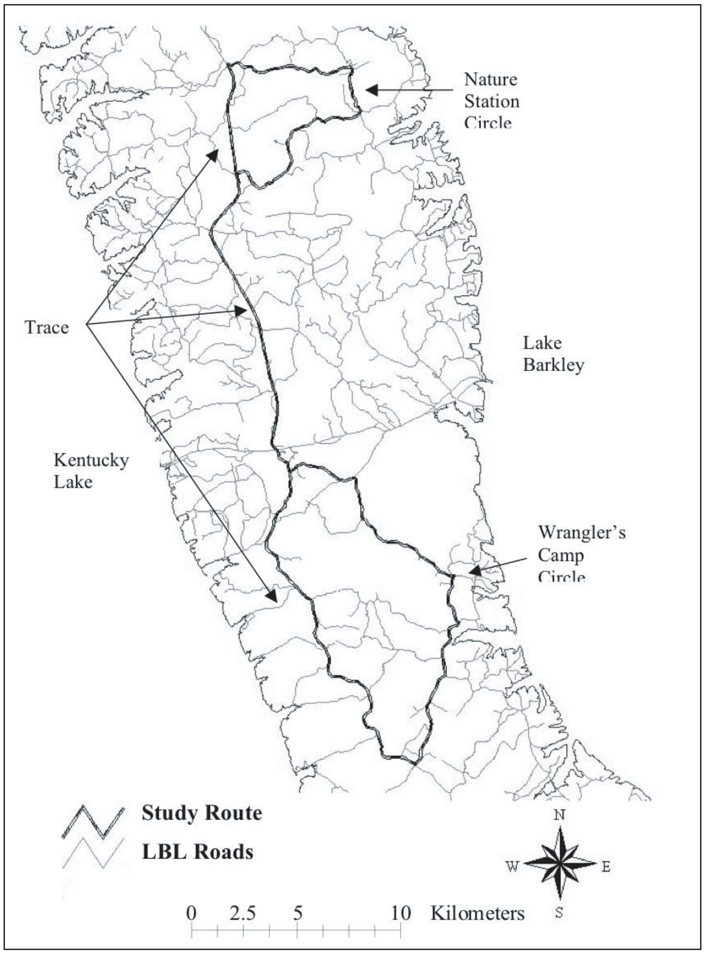



Figure 1. Map of study area in the Land Between the Lakes National Recreation Area, Kentucky.

## Methods

Copperhead seasonal movement patterns along roads were evaluated along LBL roads from April 2002 through October 2003. These routes were the Nature Station Circle (Mulberry Flat Road and Silver Trail), Wrangler's Camp Circle, and the Trace connecting the two (figure 1). Data were collected by road cruising between dusk and dawn (Bernardino and Dalrymple, 1992; Pendley, 2001). Vehicle speeds did not exceed 40 km/h during collection. Select road routes within LBL were sampled between the months of April and October.

For each date of data collection, start time, ending time, temperature, rainfall, wind, sun and moon rise, sun and moon set, moon illumination, distance traveled, and average speed were recorded. Live snakes were bagged and taken in for measurements, marking (scale clipping (Brown and Parker, 1976b)), and sexing. Data from road-killed snakes were recorded on site. For each data point, time of observation, location, status (alive on road (AOR) or dead on road (DOR)), sex, recapture, UTM points, direction traveled, scale clip number (AOR or recapture only), snout-vent length (SVL), total length, and release date and time (AOR only) were recorded. A juvenile was defined as any copperhead that is under 35 cm where sex could not be determined without probing. Also, for individuals that size or smaller, there is little likelihood of that individual being older than one year, thus not sexually mature (Fitch, 1960). An unidentifiable individual was either an AOR who avoided capture or a DOR and crushed to the point that sex was indeterminable.

Global Positioning System (GPS) Universal Transverse Mercator (UTM) coordinates were taken at five-kilometer distances beginning at the north end of where the Wrangler's Camp Circle and Trace meet and ending at the southern point of where the Nature Station Circle and the Trace meet using a Garmin™ E-Trex Venture GPS unit (Garmin Ltd. Taiwan) (figure 2). This was done in order to provide reference areas along the route for later statistical analyses of snake observation location data. At each point of observation, GPS coordinates were also recorded. Coordinates were recorded monthly from April through October. They were then uploaded and plotted on maps using ArcInfo™ and ArcView™ software

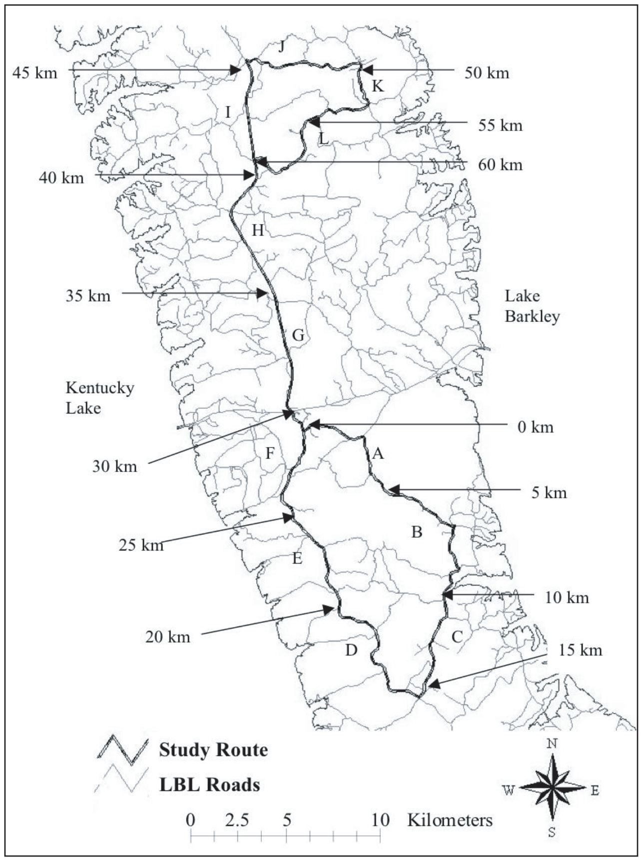



Figure 2. Distance at 5 kilometer intervals along the study route beginning at Wrangler's Camp Circle and ending at the end of the Nature Station Circle. Each letter signifies a section used in analysis.

## Results

Three hundred seven copperheads were observed within the study areas. Only one animal was recaptured throughout the entire study. One hundred six males, 102 females, 46 juveniles, and 53 unidentifiable individuals were observed. The numbers of snakes observed per month, dividing observations between males, females, juveniles, and unidentifiable individuals is illustrated in figure 3. The average percentage of observations per month for each was 34.2% for males, 36.1% for females, 14.5% for juveniles, and 15.2% for the unidentifiable specimens. The number of males and females observed were fairly uniform. A chi-square analysis of the total observations of males and females showed no significant difference between the numbers of each observed (α=.05; p=.782; Chi-Square value=.077). However, when comparing males and females within months, chi-square analyses indicated that significantly higher numbers of males than females were observed in August (α=.05; p=.046; Chi-Square value=5.70).

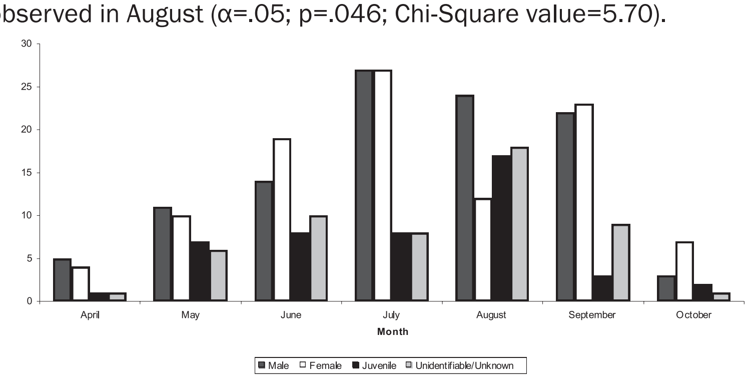



Figure 3. Number of male, female, juvenile, and unidentifiable copperheads observed per month.

Road crossing of the snakes was not uniform across sites. In a comparison between crossing sites, a chi-square analysis (α=.05) indicated that the snakes had different frequencies of crossing sites between the five-kilometer reference areas, suggesting non-uniform movement (p<.001; Chi-Square value=103.32). Snakes were found most often within reference areas A through D (located on the Wrangler's Camp Circle) and within area K (located on the Nature Station Circle) (See figure 2 for reference areas), with area A and B with significantly higher observations than the other reference areas and E, H, I, and L with significantly lower observations (Scheffé-type post-hoc test; Dunn critical value=2.94; α=.05; Chi-Square values=54.7 (A), 16.3 (B), 5.24 (E), 9.49 (H), 6.19 (I), and 7.21 (L)).

Seasonal variation in crossing sites was also seen (figure 4). Significantly more animals were found on the Wrangler's Camp Circle than the Trace in June, July, and August (Scheffé-type post-hoc test; Dunn critical value=2.77; α=.05; Chi-Square values=48.1, 24.4, 50.8). Significantly more observations of animals on the Nature Station Circle than on the Trace were also seen in June, July, and August (Scheffé-type post-hoc test; Dunn critical value=2.77; α=.05; Chi-Square values=14.3, 11.6, 21.8), however, more animals were observed on the Trace than on the Nature Station Circle in September (Scheffé-type post-hoc test; Dunn critical value=2.77; α=.05; Chi-Square value=12.3). When compared, there were significantly more snakes observed on the Nature Station Circle in June (Scheffé-type post-hoc test; Dunn critical value=3.15; α=.05; Chi-Square value=14.85), while more were observed on the Wrangler's Camp Circle than the Nature Station Circle in August (Scheffé-type post-hoc test; Dunn critical value=3.15; α=.05; Chi-Square values=15.9).

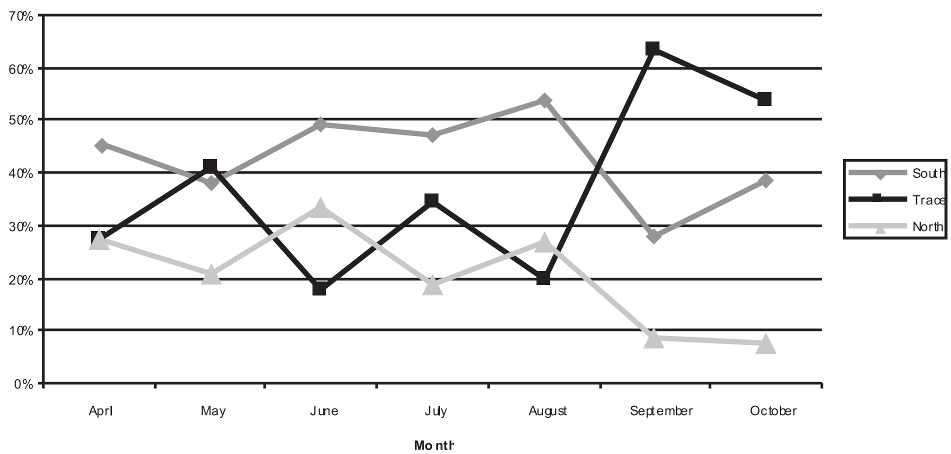



Figure 4. Percent snakes observed along the Nature Station Circle, Wrangler's Camp Circle, and the Trace per month.

The overall percentage of snakes found AOR compared to DOR was close to equal (48.3% AOR and 51.7% DOR) (figure 5). The frequency of those found AOR compared to DOR, however, varied significantly within August and September (Chi-Square test α=.05; p=.0436, p=.0243). Due to small sample size, April and October were subjected to an exact binomial test and were not significant (α=.05; p=.558, p=.267,). Snakes observed in August showed 24% lower DOR observations (p=.044). The percentage of DOR snakes found in July and September were 20% and 21% higher (p=.094, p=.024, respectively).

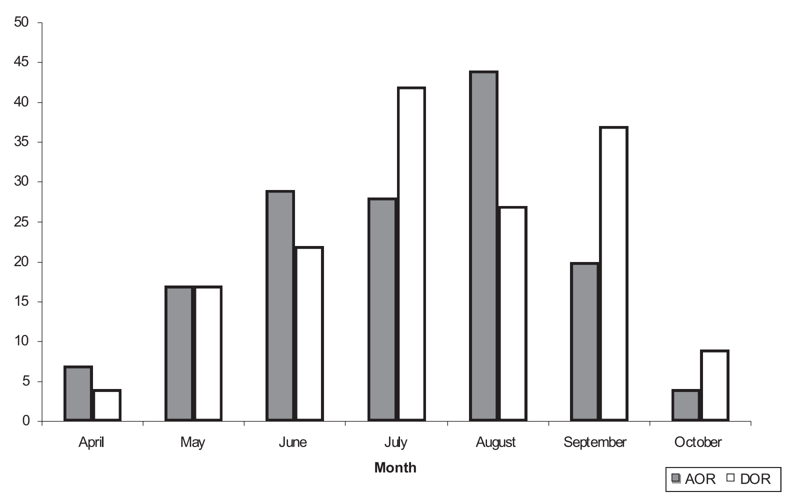



Figure 5. Monthly AOR and DOR observations for Agkistrodon contortrix.

A difference in frequency of DOR snakes compared with AOR snakes was noted within the reference areas (figure 6). There were significantly higher differences in percentages of DOR snakes were observed within reference areas D, E, F, H, and I, all along the Trace (Chi-Square test α=.05; p=.002, p=.0001, p=.0001, p=.0063, p=.0008). In contrast, significantly more AOR snakes were observed in reference areas K and L within the Nature Station Circle (Chi-Square test α=.05; p=.0008, p=.0210). There were no significant differences between AOR and DOR snakes observed within reference areas A, B, C, G, and J (Chi-Square test α=.05).

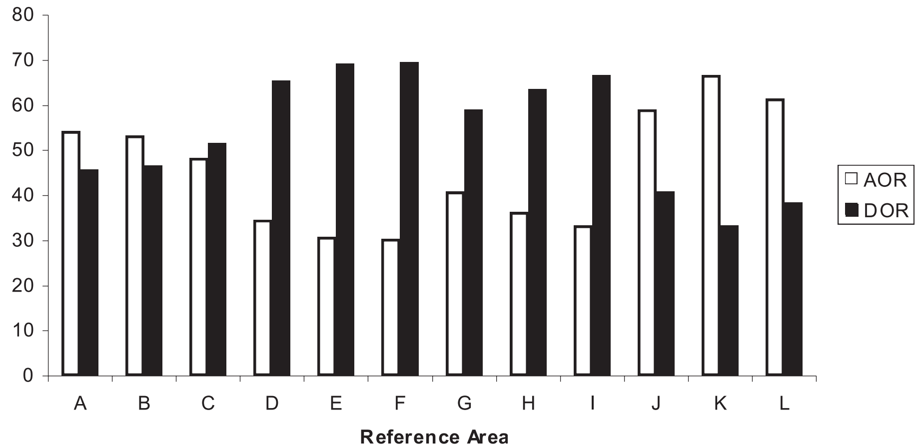



Figure 6. Percentage AOR and DOR per reference area.

Gender and age with reference to the AOR/DOR status were also observed (figure 7). Males and females did not show a significant difference in status when all months were pooled (Chi-Square test α=.05, p=.133), but were significantly different in May and July, where males were more likely to be found DOR (Chi-Square test ?=.05, p=.0156, p=.0038). There was a significant difference between adults and juveniles when all months were pooled, where juveniles were more likely to be found AOR (Chi-Square test α=.05, p=.0239). In July, in particular, adults were more likely to be found DOR than juveniles (Chi-Square test α=.05, p=.0024).

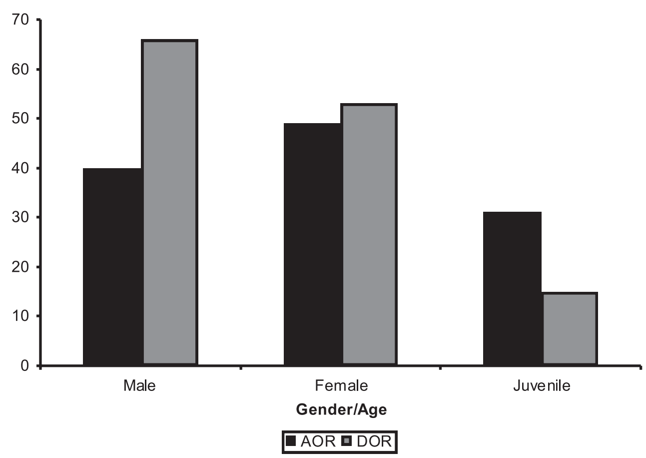



Figure 7. Gender and Age Differences in AOR and DOR snakes observed.

The average copperhead snout-vent lengths (SVL) within each month are illustrated in figure 8. An ANOVA (α=.05) and Tukey comparison were used to determine differences between the monthly average SVL of the copperheads. The average SVL of the snakes observed in April and in September were significantly greater than the average SVL of the snakes observed in the remaining months (p<.001). A Spearman's Rho Correlation was also computed between average SVL and the air temperature on observation nights, showing a significant negative correlation between the two variables (α=.01, correlation value=.40, p<.001). It showed that the warmer the air temperature was, the better the chances of finding a smaller sized snake.

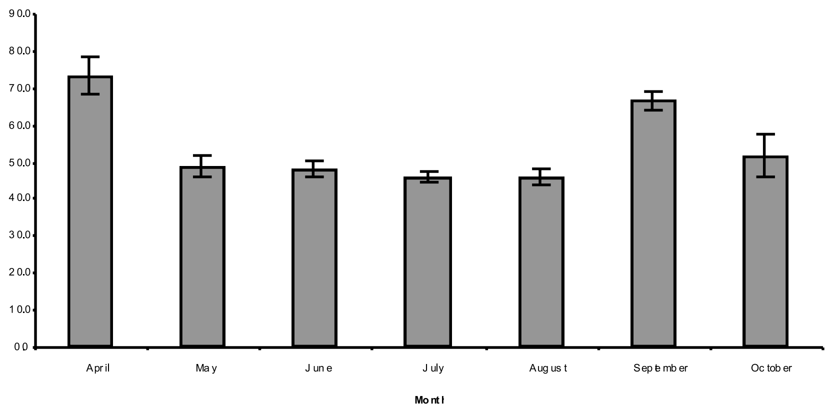



Figure 8. Mean snout-vent lengths of *Agkistrodon contortrix* observations per month.

## Discussion

### Movement

The majority of copperheads were observed from late spring to early fall. Observations began in April and continued through October. Since there was only one recapture, however, population size cannot be accurately estimated. Nevertheless, with the large number of individuals observed, it can be postulated that LBL contains a large and healthy population. Accounting for around fifteen percent of the total captures, the numbers of juveniles observed can also be seen as an indication of high recruitment into the population. Fitch (1960) noted that in a sample of 637 copperheads collected in eleven seasons, 213 (33%) were juveniles under 40 cm. However, this sample was taken in the fall when the females had finished birthing and when most snakes in this population had returned to the hibernacula, providing a concentration of the population.

The non-random locations of the road-crossing sites are due mostly to the road type at those sites. The roads with significantly more crossing sites are less maintained than those with fewer sites. Most individuals were found on secondary roads associated with the Nature Station and Wrangler's Camp Roads with a corresponding dearth of sightings along the main north/south road, the Trace. Significantly more snakes were observed in areas A and B along the Wrangler's Camp Circle, while significantly fewer were observed along the Trace in areas E, H, and I, as well as one section of the Nature Station Circle (area L). Area L on the Nature Station Circle connects directly to the Trace and is highly traveled, as it is the most direct route to the Nature Station where multiple programs are offered during the year. The Trace, which connects the two areas, is a more heavily traveled road with wider shoulders and verge (Mandt, 2004). The edges of the Trace are mowed, with much wider verge than the other roads, and much less, if any, canopy cover (Mandt, 2004). This may contribute to the lower number of sightings due to lack of cover and potential dangers. However, data for other snake species (including smaller snakes such as the earth snake, *Virginia valeriae*) do not show this pattern (Mandt, 2004).

The Wrangler's Camp Circle and Nature Station Circle have at least some canopy cover and smaller verge than the Trace (Mandt, 2004). The slight increase in observations along the Trace during late season months may be a reflection of less shading in the other areas. Due to the colder weather late in the season, the more open canopy areas could also provide more sites for basking, thus providing a thermoregulatory advantage. This increase could also be due to late season searching for hibernation sites.

### Road Mortality

The numbers of snakes found AOR versus DOR were fairly even throughout the season. A trend was seen toward an increase in DOR in July and September, but was not significant. This does, however, correspond with high traffic time between July and September in the LBL region, where an average of about 1.5 million people annually visit the park (Schmittou pers. com. based upon 2003 records). The significantly higher percentages of DOR snakes along the Trace, while significantly more AOR snakes were found within the Nature Station Circle, raises concern for the more traveled roads, as well. Such high mortality in a population is of special concern in a National Recreation Area where the balance between recreational use and wildlife welfare must be considered.

There were no significant differences in the number of males and females observed each month except in August. Gravid females tend not to move as much and may have spent most of August in a very small area, not traveling near the roads (Fitch, 1960; Sanders and Jacob, 1981). It is not known if females breed every year, thus the non-gravid females could have continued moving throughout the season while the gravid females remained in smaller home ranges for the other months (Sanders and Jacob, 1981). Since copperheads in this area do not use communal hibernacula in this area, the use of hibernacula for birthing is most likely not prevalent in this population (Zimmerer, pers. obs.). The significantly higher amount of DOR male snakes could be because male copperheads tend to move more frequently and have larger home range sizes than females (Fitch 1960, Fitch and Shirer 1971). Juveniles also tend to stay close to the area where they were born and have much smaller home range sizes than adults, which could explain the higher percentage of AOR as compared to adults (Fitch 1960).

## Summary

Copperheads in the LBL region seem to follow similar behaviors as other populations of copperheads throughout their range. The population begins movement in early spring and continues through late fall. The patterns of activity observed appear to be unimodal, with activity beginning slow in early spring with a single crest of activity between late spring and late summer and tapering off in the fall (Moore, 1978). These activity patterns fit into the three general types of movements described by Fitch (1960), which include travel within a home range, travel to a new home range, and seasonal travel to and from a hibernaculum. Travel within home range, since it is the primary reason for movement, can explain the majority of the observations. Travel to a new home range, while it could explain some of the movement, cannot be determined without long-term telemetry data, or at least recapture data. Seasonal travel to and from hibernaculum, or in the case of this study, hibernation sites, may explain the early and late movements, particularly in the areas that differ significantly between the early and late months and the mid-summer months.

The road-crossing site data showed that these snakes probably have a preference for less developed areas, even though they have shown adaptability to human development (Fitch and Shirer, 1971; Conant and Collins, 1998). The Wrangler's Camp Circle and the Nature Station Circle, while less traveled than the Trace, are still frequented by visitors and the prevalence of the copperhead in these areas shows that these animals still thrive even with human activities.

The road side along the Trace has little to no cover protection. Copperheads have a preference for deciduous or mixed pine-deciduous forests in both rocky areas and areas of high ground cover (Gloyd and Conant, 1990). This is much more common around the Wrangler's Camp Circle and the Nature Station Circle. The areas along the northeastern edge of the Wrangler's Camp Circle and the easternmost edge of the Nature Station Circle showed the highest numbers of observations throughout the year, indicating that the amount of cover over the roads is important to whether or not snakes will cross a road at a particular point.

Probably the most disturbing results of this study were the high number of DOR snakes collected. This is a huge percentage of DOR snakes compared to AOR ones, even considering that dead snakes cannot escape capture. One must add, however, the potential of scavengers picking up dead snakes, thus removing individuals from the roads, and decreasing the DOR potential bias. All the reference areas along the Trace showed more DOR snakes than AOR snakes, indicating that this road in particular is an area of concern for mortality of all different species. Other studies have shown similar road mortalities and worse. In the Pa-hay-okee Wetlands in the Everglades National Park, it was discovered that seventy-three percent of all snakes observed in the main road of the park were either injured or dead (Bernardino and Dalrymple, 1992). Road mortality is becoming an increasing concern for protecting all species. If mortality such as this occurs in a protected area, it implies that unprotected areas are of an even greater threat to wildlife. Further road mortality studies are essential to this and other species conservation.

This study provides a template for management and for future studies of the copperhead in the LBL area. The lack of development within LBL provides fairly undisturbed habitat, with the exception to roads. With rapid human development infringing on wild areas, an understanding of the interactions of wildlife in their natural surroundings is becoming crucial to the conservation of both flora and fauna. The concern for the conservation of reptiles throughout the world has become prevalent in the recent past and the lack of information has raised many questions on their natural history (Gloyd and Conant, 1990; Cross and Petersen, 2001). Without the emphasis on the interactions of organisms and their environment, proper management of species cannot be executed. Studies such as this can be utilized to understand portions of natural history and can be applied to the conservation and management of species.

**Biographical Sketches:** Valorie Titus obtained her B.S. from Cazenovia College in 2001 and her M.S. in biology from Murray State University in 2006, where she studied road usage patterns of the copperhead snake in western Kentucky. She is currently a Ph.D. candidate at Binghamton University in the Department of Biology.

Dr. Ed Zimmerer earned his Ph.D. from Rutgers University in 1980. He is currently a professor of biological sciences and graduate coordinator at Murray State University in Murray, KY.

## References

Bernardino Jr., F.S. and G.H. Dalrymple. 1992. Seasonal activity and road mortality of the snakes of the Pa-hay-okee wetlands of Everglades National Park, USA. *Biological Conservation*. 62:71-75.

Bonnet, X., G. Naulleau, and R. Shine. 1999. The dangers of leaving home: dispersal and mortality in snakes. *Biological Conservation*. 89:39-50.

Brown, W.S. and W.S. Parker. 1976. Movement ecology of the *Coluber constrictor* near communal hibernacula. Copeia 1976:225-242

Conant, R., and J.T. Collins. 1998. Peterson field guides reptiles and amphibians Eastern/Central North America, 3rd ed. New York, New York. Houghton Mifflin Company. 616p.

Cross, C.L. and C.E. Petersen. 2001. Modeling snake microhabitat from radiotelemetry studies using polytomous logistic regression. *Journal of Herpetology*. 35:590-597.

Dodd, Jr. C.K., K.M. Enge, and J.N. Stuart. 1989. Reptiles on highways in North-Central Alabama, U.S.A. *Journal of Herpetology*. 23:197-200.

Fitch, H.S. 1960. Autecology of the copperhead. University of Kansas Pubic Museum of Natural History. 13:85-288.

Fitch, H.S. and H.W. Shirer. 1971. A radiotelemetric study of spatial relationships in some common snakes. *Copeia* 1971:118-128.

Gloyd, H.K. and R. Conant. 1990. Snakes of the *Agkistrodon* complex. Oxford, Ohio. Society for the Study of Reptiles and Amphibians. 614p.

Klauber, L.M. 1939. Studies of reptile life in the arid southwest. Part 1. Night collecting on the desert with ecological statistics. Bulletin of the Zoological Society San Diego. 14:7-64.

Langley, W.M., H.W. Lipps, and J.F. Theis. 1989. Responses of Kansas motorists to snake models on a rural highway. Transactions of the Kansas Academy of Science. 92:43-48.

Lynn, C.H., 1994. Kentucky wildlife viewing guide. Helena, Montana, Falcon Press Publishing Co., Inc.: 1-80.

Mandt, M. 2004. Master's Thesis. Murray State University.

Moore, R.G. 1978. Seasonal and daily activity patterns and thermoregulation in the southwestern speckled rattlesnake *Crotalus mitchelli pyrrhus* and the Colorado Desert sidewinder *Crotalus cerastes laterorepens*. Copeia 1978:439-442.

Pendley, B.E. 2001. Road mortality of snakes in the Davis Mountains region of Texas. Master's Thesis. Sul Ross State University.

Pough, F.H, R.M. Andrews, J.E. Cadle, M.L. Crump, A.H. Savitzky, and K.D. Wells. 2001. Herpetology, 2nd ed. Upper Saddle River, New Jersey. Prentice-Hall, Inc. 612p.

Sanders, J. and J.S. Jacob 1981.Thermal ecology of the copperhead (*Agkistrodon contortrix*). *Herpetologica*, 37:264-270.

Shine, R., M. Lemaster, M. Wall, T. Langkilde, and R. Mason. 2004. Why did the snake cross the road? Effects of roads on movement and location of mates by garter snakes (Thamnophis sirtalis parietalis). Ecology and Society. 9:9. URL: http://ecologyandsociety.org/vol9/iss1/art9.

Whitaker, P.B. and R. Shine. 2000. Sources of mortality of large elapid snakes in an agricultural landscape. *Journal of Herpetology*. 34:121-128.

Chapter 7

# Data Surveys and Decision Support Guidelines

## Animal-Vehicle Collision Data Collection Throughout the United States and Canada

**Marcel P. Huijser** (406-543-2377, mhuijser@coe.montana.edu), **Meredith E. Wagner**, **Amanda Hardy**, and **Anthony P. Clevenger**, Western Transportation Institute, Montana State University (WTI-MSU), P.O. Box 174250, Bozeman, MT 59717-4250, Fax: 406-994-1697 USA
**Julie A. Fuller**, Montana Fish, Wildlife and Parks, 1400 S. 19th Ave., Bozeman, MT 59717 USA

**Abstract:** Animal-vehicle collisions affect human safety, property and wildlife, and the number of animal-vehicle collisions has substantially increased across much of North America over the last decades. Systematically collected animal-vehicle collision data help estimate the magnitude of the problem and help record potential changes in animal-vehicle collisions over time. Such data also allow for the identification and prioritization of locations that may require mitigation. Furthermore, systematically collected animal-vehicle collision data allow for the evaluation of the effectiveness of mitigation measures in reducing the number of animal-vehicle collisions. In the United States and Canada, animal-vehicle collision data are typically collected and managed by transportation agencies, law enforcement agencies and/or natural resource management agencies. These activities result in two types of data: data from accident reports (AR data) and data based on animal carcass counts (AC data). Here we report on a survey that examined the extent to which AR and AC data are collected across the United States and Canada. While a substantial percentage of the DOTs and DNRs collect and manage AR and/or AC data, many of them do not. Furthermore, DOTs and DNRs that do collect or manage AR or AC data typically do this for different or only partly overlapping reasons. In addition, DOTs and DNRs use different reporting thresholds, have varying search and reporting effort, and only have partial overlap in the parameters recorded. These differences also occur between DOTs and between DNRs, and oftentimes one and the same organization collects inconsistent data as certain parameters may only be recorded 'sometimes'. These differences and inconsistencies affect the comparability and ultimately the usefulness of the data. Before an AR or AC program is initiated or improved, it is important to illustrate the needs and benefits of such data collection. We list the most important needs and benefits and provide considerations for the initiation or improvement of AR and AC data collection programs.

### Introduction

Animal-vehicle collisions affect human safety, property and wildlife, and the number of animal-vehicle collisions has substantially increased across much of North America over the last decades (Hughes et al., 1996; Romin & Bissonette, 1996; Khattak, 2003; Tardif & Associates Inc., 2003; Knapp et al., 2004; Williams and Wells, 2005; Huijser et al., in prep. a). Systematically collected animal-vehicle collision data help estimate the magnitude of the problem and help record potential changes in animal-vehicle collisions over time. Such data also allow for the identification and prioritization of locations that may require mitigation. Furthermore, systematically collected animal-vehicle collision data allow for the evaluation of the effectiveness of mitigation measures in reducing the number of animal-vehicle collisions.

In the United States and Canada, animal-vehicle collision data are typically collected and managed by transportation agencies, law enforcement agencies and/or natural resource management agencies. These activities result in two types of data: data from accident reports (AR data) and data based on animal carcass counts (AC data). However, not all transportation agencies, law enforcement agencies and/or natural resource management agencies record animal-vehicle collisions. Furthermore, the agencies that do record such data often use different methods, causing difficulties with data integration and interpretation, and ultimately with the usefulness of the data.

Here we report on a survey that examined the extent to which AR and AC data are collected across the United States and Canada. This paper is a subset and a summary of a full report (see Huijser et al., in prep. b).

### Methods

We sent a survey to the transportation agency (DOT) and natural resource management agency (DNR) in each state (n=50) or province (n=13) of the United States and Canada. The survey questions covered a wide range of topics related to AR and AC data, starting with if and why the DOTs or DNRs collect these data. Other key sections of the survey focused on the parameters recorded and potential reporting thresholds.

We approached at least two key persons for each state or province: a representative of the DOT (with a focus on public safety) and a representative of the DNR (with a focus on natural resource conservation). The survey was posted on a website and the interviewees were encouraged to fill out the survey on this website. The survey was also available in MS Word and PDF format which could be sent in by e-mail, fax or mail. The survey was sent to the interviewees on 6 March 2006 and the survey ended on 5 April 2006.

If there was more than one respondent for an individual DOT or DNR the answers for these respondents were combined into one response. This resulted in a maximum of two responses for each state or province; one for a DOT and one for a DNR. The responses were summarized through calculating the percentage of respondents that selected the different options or categories for their responses. The percentages were calculated as the number of responses in each category divided by the total number of respondents to that question. Furthermore, several questions permitted multiple responses, in which case the sum of the percentages in the categories could add up to more than 100%.

In addition to the survey, the crash forms posted on the website for the National Center for Statistics and Analysis of the National Highway Traffic Safety Administration (NHTSA, 2006) for all 50 states were reviewed with regard to the type of information recorded for animal-vehicle collisions (AR data). The data for the 50 states (NHTSA, 2006) were supplemented with accident report forms from two provinces (British Columbia and Northwest Territories), and the four responses from other Canadian provinces (Alberta, Manitoba, Newfoundland and Nova Scotia) to the survey.

## Results

### Response Rate

For DOTs and DNRs combined the response rate to the survey was 88.9% (56 out of 63 states and provinces). DOTs (63%) had a slightly higher response rate than DNRs (57%). However, not all respondents answered all questions.

### AR Data

According to the survey, most of the responding DOTs (65%) and some DNRs (36%) collect AR data. However, a review of the crash forms showed that 49 out of 50 states (98%) and all of the provinces (100%) that sent in their crash forms allow for the recording of animal-vehicle collisions on their crash forms in one way or the other. Multiple organizations collect AR data, but according to the combined responses of DOTs and DNRs this type of data is typically collected by Highway Patrol or other law enforcement agencies (44%). Others who were reported to collect AR data include DOTs (23%), DNRs (19%), and local contractors and the public (11%).

Based on the survey, DOTs indicated public safety was the number one reason they collect or manage AR data (80%) with wildlife management or conservation as the number two reason (61%) and accounting as the third (53%). DNR respondents were divided between wildlife management/conservation (50%) and public safety (42%) as the number one reason they collected or managed AR data. Similarly DNR respondents were divided between wildlife management/conservation (50%) and public safety (40%) as the number two reason. Accounting reasons formed the third most important reason for DNRs (53%).

Many crash forms only have a checkbox for 'animal' (36% of all reviewed crash forms) and do not have a space dedicated to the entry of the species name of the animal involved. Based on the survey, most DOTs (65%) identify large wild mammals (deer and larger) only to the genus level whereas DNRs typically identify them to the species level (69%). According to the review of the crash forms, most states and provinces have reporting thresholds (typically a minimum of $1000 in damages (46% of all reviewed crash forms)). The search and reporting effort for ARs typically depends on the reporting of an animal-vehicle collision by the public and on whether law enforcement personnel happens to pass by an accident location shortly after the collision (DOTs 32%; DNRs 45%).

The location of the crash is usually described based on the distance to certain road or landscape features such as mi or km markers or road sections (56% of all reviewed crash forms). Based on the survey results the accuracy is always or usually 0.1 mi/km for DOTs (68%) and always or usually 1.0 mi/km for DNRs (63%). Relatively few states and provinces (36% of all reviewed crash forms) use coordinates (obtained through either a Global Positioning System (GPS) or a map).

### AC Data

According to the survey, half of the responding DNRs (50%) and some DOTs (37%) collect AC data. Multiple organizations collect AC data but according to the combined responses of DOTs and DNRs this type of data is typically collected by DOTs (30%). Others who collect AC data include DNRs (28%), and local contractors and the public (21%).

Based on the survey, DOTs indicated public safety was the number one reason they collect or manage AC data (42%) with wildlife management or conservation as the number two reason (50%) and accounting as the third (33%). DNR respondents indicated wildlife management or conservation was the number one reason they collect or manage AC data (75%) with public safety as the number two reason (50%).

Most DOTs and DNRs never record amphibians or reptiles for AC data. However, most DOTs (100%) and DNRs (92%) do record large wild mammals (deer and larger), and the agencies that record AC data for this species group mostly identify them to the species level (DOTs 70%; DNRs 92%). Some DOTs and some DNRs record birds (DOTs 56%; DNRs 55%), small wild mammals (smaller than deer) (DOTs 60%; DNRs 60%), and domesticated animals (DOTs 90%; DNRs 89%). Most DOTs (70%) and DNRs (57%) have reporting thresholds for AC data. Most DOTs reported that in order to be reported a carcass had to be in the road or in the right-of-way, regardless of the visibility to drivers (77%). DNRs usually record only certain species (54%). The species of interest were deer, moose, 'bear', 'medium- and large-sized mammals' (including livestock, 'furbearers' and carnivores), other ungulates and birds. Most DOTs (55%) search and report for ACs on a daily basis as part of their routine while the search and reporting effort for DNRs is based on 'when they occur' or when they are reported (46%).

Most of the responding DOTs and DNRs always or usually record the date of the observation (DOTs 100%; DNRs 91%), the district or unit (DOTs 80%; DNRs 91%), the name of the observer (DOTs 60%; DNRs 64%), the road or route number or name (DOTs 100%; DNRs 73%), the carcass location (DOTs 80%; DNRs 64%), the species name of the animal involved (DOTs 89%; DNRs 100%), and whether the carcass was removed (DOTs 50%; DNRs 55%). Most DNRs also record the sex (64%) and the age (55%) of the individual involved.

Animal carcass location recording varied between DOTs and DNRs. Most DOTs never use GPS technology (89%) or maps to derive coordinates (67%). Most DOTs always or usually use mile or kilometer reference posts (90%) or road sections (80%). Of the responding DNRs, most rarely or never make use of GPS technology (60%) or maps to derive coordinates (55%). DNRs sometimes use mile or kilometer reference posts (50%) and usually or sometimes record the road sections (78%). DOTs always or usually record AC data with 0.1 mile or kilometer (67%) or 1 mile or kilometer accuracy (57%). DNRs always or usually record AC data with 0.1 mile or kilometer (33%) or 1 mile or kilometer accuracy (50%).

### Implementation or Improvement of AR and AC Programs

DOTs and DNRs identified the lack of a demonstrated need, underreporting, poor data quality (consistency, accuracy - especially spatial accuracy - and/or completeness), and delays in data entry as the main obstacles to implementing or improving AR or AC data collection and analyses programs. Using more rigid and standardized procedures, including centralized databases, GPS technology, and the use of GIS were specifically mentioned to address some of these problems and improve the data collection and data analyses procedures.

## Discussion and Conclusion

While a substantial percentage of the DOTs and DNRs collect and manage AR and/or AC data, many of them do not. Furthermore, DOTs and DNRs that do collect or manage AR or AC data typically do this for different or only partly overlapping reasons. In addition, DOTs and DNRs use different reporting thresholds, have varying search and reporting effort, and only have partial overlap in the parameters recorded. These differences also occur between DOTs and between DNRs, and oftentimes one and the same organization collects inconsistent data as certain parameters may only be recorded 'sometimes'. These differences and inconsistencies affect the comparability and ultimately the usefulness of the data.

### Needs and Benefits of AR/AC Data Collection Programs

Before an AR or AC program is initiated or improved, it is important to illustrate the needs and benefits of such data collection. The most important needs and benefits are:

- With a standardized AR/AC data collection program the occurrence of incidents that affect human safety, natural resource conservation, and monetary losses are documented.
- With a standardized AR/AC data collection program changes in animal-vehicle collisions in time or space can be documented.
- With a standardized AR/AC data collection program locations that may require mitigation can be identified and prioritized, allowing for an effective use of resources.
- With a standardized AR/AC data collection program the effectiveness of mitigation measures in reducing collisions can be evaluated. This allows for modifications (if needed) and the application of the lessons learned at other locations, again allowing for an effective use of resources.

### Considerations for AR and AC Programs

Based on the results of the survey, one may consider the following points when initiating new, or improving existing, AR or AC data collection programs (also partially based on Knapp and Witte, 2006):

- Include animal-vehicle collisions as a check box on all crash forms (AR data) and allow for checkboxes and/or free space to write down the name of the species.
- Coordinate with the other data collection program (AR or AC) (if applicable) in the state or province and coordinate within and between agencies (especially DOTs and DNRs in the same state or province). This may expand into coordination with insurance companies and municipalities that manage smaller roads.
- Standardize the parameters and procedures, not just at the state or provincial level, but preferably at a national, or even international level (United States and Canada). Such standardization could include "priority" and "non-priority" variables. The latter group would allow for the collection of specific variables in certain states or provinces or by certain organizations, and not in or by others.

- Increase the spatial accuracy for the crash location (e.g. through the use of GPS).
- For AC data, focus on large species that are a concern to human safety and species that are a conservation concern and that can be readily identified by the personnel collecting the data. Do not focus on species that are neither a safety or conservation concern, especially if these species are very frequently hit by vehicles or if the species cannot be readily identified by personnel collecting the data.
- Establish a central database, starting at the state or provincial level, and eventually at a national level.
- Consider direct data entry in a digital database through the use of handheld field computers, eliminating manual data entry in the offices.
- Have a follow-up procedure in place to identify errors, retrieve missing data, and verify unusual data.
- Train personnel in data collection, especially with regard to species identification and an accurate description of the location of the crash. Such efforts will also help reduce underreporting for AC data. Training for DOT personnel may have to place more emphasis on animal related parameters, especially species identification, whereas training for DNR personnel may have to be initiated altogether.
- Provide resources for data management and analyses, including GIS facilities.
- Share the (raw) data and reports, especially within and between agencies (e.g. DOTs and DNRs).

At a minimum, use the data to:

- Illustrate the magnitude of the problem and analyze trends.
- Identify and prioritize road sections that may require mitigation measures and to evaluate their effectiveness in reducing collisions.
- Evaluate the status and performance of the program on a regular base and make adjustments where necessary.

**Acknowledgements:** This paper is based on a report to the Transportation Research Board of the National Academies in Washington, DC, USA (NCHRP Project 20-05/Topic 37-12; contract no.: HR 20-05 (37-12)). The authors would like to thank all the respondents to the survey. In addition, the authors thank the committee members and TRB staff for their guidance and help: Debbie Bauman, William Branch, Duane Brunell, Dennis Durbin, James Hedlund, Keith Knapp, Richard Pain, Michael Pawlovich, Greg Placy, Leonard Sielecki, Keith Sinclair, Carol Tan and Donna Vlasak.

**Biographical Sketches:** Marcel Huijser received his M.S. in population ecology (1992) and his Ph.D. in road ecology (2000) at Wageningen University in Wageningen, The Netherlands. He studied plant-herbivore interactions in wetlands for the Dutch Ministry of Transport, Public Works and Water Management (1992-1995), hedgehog traffic victims and mitigation strategies in an anthropogenic landscape for the Dutch Society for the Study and Conservation of Mammals (1995-1999), and multifunctional land use issues on agricultural lands for the Research Institute for Animal Husbandry at Wageningen University and Research Centre (1999-2002). Currently Marcel works on wildlife-transportation issues for the Western Transportation Institute at Montana State University (2002-present). He was a member of the Transportation Research Board (TRB) Task Force on Ecology and Transportation (through December 2006) and currently co-chairs the TRB Subcommittee on Animal-Vehicle Collisions.

Julie Fuller received her B.S. in wildlife biology at the University of Montana, Missoula, MT, in 2001. She received a M.S. in Fish and Wildlife Management at Montana State University, Bozeman, MT in 2006. Her M.S. focused on bison population demography in Yellowstone National Park, and her coursework emphasized statistics and population dynamics. At WTI-MSU, Julie worked with connectivity questions regarding wildlife fencing and wildlife-vehicle collisions along the I-90 corridor outside of Bozeman, MT, the pre-construction data analysis for black bear and deer crossings along the US 93 corridor near Polson, MT, and a national synthesis of animal-vehicle collisions. Currently employed by Montana Fish, Wildlife and Parks, her research focuses on elk and wolf interactions in southwest Montana.

Meredith Wagner received her B.S. in biology from California State University, Chico in 1994 and an M.S. from the School of Natural Resources and Environment at the University of Florida in 2004. Her master's thesis evaluated potential causes of a cheetah population decline in a human dominated landscape in Nakuru District, Kenya. Her work demonstrated the negative effect humans can have on wild populations even when necessary resources are available and abundant and the will to conserve wildlife exists. In 2006, Meredith participated in several road ecology projects at WTI-MSU. She is currently working on a Ph.D. at the University of Florida. Her work explores how striped hyenas alter their behavior patterns and landscape use in response to variation in human pressures. She is currently living in Kenya while conducting the research for her doctoral degree.

Amanda Hardy obtained her B.S. in biology - fish and wildlife management in 1997 and an M.S. in ecology - fish and wildlife management in 2001 at Montana State University, Bozeman, MT. She began studying transportation and wildlife interactions in 1998 with the initiation of her research thesis assessing bison and elk behavioral and stress hormone responses to winter recreation in Yellowstone National Park. Amanda joined WTI-MSU in 2001 and helped to develop the wildlife and transportation program into one of WTI-MSU's focus research areas. Her current work relates to the evaluation of wildlife crossing structures and driver responses to wildlife warning signs, as well as methods to analyze animal-vehicle collision data. She is also serving as a facilitator of an interagency effort to develop an ecosystem approach to mitigation of the highway program impacts on ecosystem processes. Amanda has served on the planning committee of the 2003, 2005 and 2007 International Conferences on Ecology and Transportation and was a co-organizer of the Wildlife Crossing Structure Field Course in Banff National Park, Alberta, Canada, in September 2002. Ms. Hardy is an appointed member of the Transportation Research Board's (TRB) Task Force on Ecology and Transportation, co-chairs the TRB Animal-Vehicle Collisions Subcommittee, and acts as a liaison between these groups and other TRB affiliates including the TRB Environmental Analysis in Transportation Committee.

Tony Clevenger is a senior wildlife biologist at the Western Transportation Institute at Montana State University. In 1996, he was contracted by Parks Canada to carry out longterm research assessing the performance of mitigation measures designed to reduce habitat fragmentation on the Trans-Canada Highway in Banff National Park, Alberta, Canada. Tony is currently a member of the U.S. National Academy of Sciences Committee on Effects of Highways on Natural Communities and Ecosystems. Since 1986, he has published over 40 articles in peer-reviewed scientific journals and has co-authored three books including, Road Ecology: Science and Solutions (Island Press, 2003). Tony has worked as a research wildlife biologist for the World Wide Fund for Nature–International (Gland, Switzerland), Ministry of Environment–France (Toulouse), U.S. Forest Service, and U.S. National Park Service. Tony is a graduate of the University of California, Berkeley, has a master's degree in wildlife ecology from the University of Tennessee, Knoxville and a doctoral degree in Zoology from the University of León, Spain. He is currently an adjunct assistant professor at the Department of Ecology, Montana State University. He lives year-round outside Banff National Park.

## References


Hughes, W.E., A.R. Saremi & J.F. Paniati. 1996. Vehicle-animal crashes: an increasing safety problem. *Institute of Transportation Engineers Journal* 66: 24-28.

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith & R. Ament. In prep. a. Wildlife-vehicle collision study: literature review. Report for Federal Highway Administration. Western Transportation Institute, Montana State University, Bozeman, MT, USA.

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith & R. Ament. In prep. B. Wildlife-vehicle collision study: literature review. Report for Federal Highway Administration. Western Transportation Institute, Montana State University, Bozeman, MT, USA.

Khattak, A.J. 2003. Human fatalities in animal-related highway crashes. *Transportation Research Record* 1840 (03-2187): 158-166.

Knapp, K.K., X. Yi, T. Oakasa, W. Thimm, E. Hudson & C. Rathmann. 2004. Deer-vehicle crash countermeasure toolbox: a decision and choice resource. Wisconsin Department of Transportation. Report No. DVCIC-02, Madison, WI, USA.

Knapp, K.K. & A. Witte. 2006. Strategic agenda for reducing deer-vehicle crashes. Results from the conference 'Deer-Vehicle Crash Reductions: Setting a Strategic Agenda'. Midwest Regional University Transportation Center, Deer-Vehicle Crash Information Clearinghouse, University of Wisconsin-Madison, Madison, WI, USA.

NHTSA. 2006. Crash forms, National Center for Statistics and Analysis of the National Highway Traffic Safety Administration (NHTSA). Available from the internet: URL: http://www.nhtsa-tsis.net/crashforms/

Romin, L.A. & J.A. Bissonette. 1996. Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. *Wildlife Society Bulletin* 24 (2): 276-283.

Tardif, L-P & Associates. 2003. Collisions involving motor vehicles and large animals in Canada: Final report, Transport Canada Road Safety Directorate, Canada.

Williams, A.F. & J.K. Wells. 2005. Characteristics of vehicle-animal crashes in which vehicle occupants are killed. *Traffic Injury Prevention* 6 (1): 56-59.

# Can Wildlife Vehicle Collision be Decreased by Increasing the Number of Wildlife Passages in Korea?

**Tae-Young Choi** (82-17-615-1277, gumiran3@snu.ac.kr), Researcher, Environmental Planning Institute, and
**Chong-Hwa Park**, Graduate School of Environmental Studies, Seoul National University, San 56-1, Sillimdong, Gwanakgu, Seoul 151-742 Korea

**Abstract:** The mitigation of fragmentation due to high density road network has been a hot topic among environmentalists and road construction engineers of South Korea. Over the last ten years 92 wildlife passages, 55 ecoducts and 37 wildlife underpasses, have been constructed on existing roads, and many more will be constructed in the future (Ministry of Environment of the Republic of Korea, 2006). We are at an early stage of data collection on wildlife vehicle collision and the role of traditionally non-wildlife-engineered passages, such as underpasses including bridges, culverts, and human underpasses, for wildlife passages.

The objective of this study was to analyze the effectiveness of the number, size, and density of non-wildlife-engineered passages. This study employed three monitoring methods: wildlife vehicle collisions, the passages use ratio (Servheen, 2003) and radio telemetry. The effectiveness of such unintended wildlife passage was evaluated by using the relationship between monthly wildlife vehicle collision data, number of usable passages, use rate of passages, and passage density.

The number of usable passages represents all crossing structures after excluding those inundated circular culverts during summer season, since they are impassable for most wildlife species. The use rates of wildlife passages were collected from 14 underpasses. They were seven circular culverts, two box culverts, and four human underpasses, and were selected from 31 structures constructed on a 6.6km segment of a four-lane highway. The landscape of study area mainly consists of rice fields on an alluvial plane and scattered forest, and the road runs along the stream. Every passage has similar surroundings. Wildlife monitoring was carried out for 12 months, from Sept. 2005 to Aug. 2006; using camera traps (an average of 239 camera operating days). The number of recorded mammals was 2,593, consisting of 13 species. We also documented 93 mammal vehicle collisions comprising 12 species by monitoring the same road daily over a period of two years (Sept. 2004-Aug. 2006).

The results of our analysis are as follows. First, the use rate of passages and the number of mammal vehicle collisions showed a positive correlation ($r=0.890$). Second, the fluctuation of the number of usable passages and collisions had no correlation ($r=0.402$). Third, the density of passages and collisions had a very weak positive correlation ($r=0.559$, $p<0.093$). Fourth, the use rate of box-type passages did not increase when pipe-type culverts were blocked by water inundation ($p=0.561>\alpha=0.05$). These results differed from following common expectations: higher numbers and use ratings of passages could cause less frequent collisions, high density areas of passage would cause fewer collisions, and the decreased number of passages would increase the use ratings of remaining passages. Fifth, most monitored mammal species with small-to-medium body sizes used all types of passage structures frequently, but water deer (Hydropotes inermis) rarely used these passage structures of under 0.7 on the openness index. Last, we found by radio telemetry that only one out of 13 radio-collared raccoon dogs was killed by vehicle `collision over a two-year period. However, a total of 12 raccoon dogs that had been killed by cars were found on the same road during the same period.

The results of our research can be summarized as follows. First, there were already enough usable passages for wildlife, in spite of seasonal blockage of some passages or the uneven spacing between passages. Second, there were many occurrences of wildlife vehicle collisions, but settlers showed relatively low collision ratio. Third, most collision victims might be wanderers or newcomers unfamiliar to existing passages or occupying settlers. Finally, water deer should be the target species for the construction of wildlife passages, and the size should be O.I of over 0.7. Vehicle collision of other mammal species can be reduced significantly by installing wildlife fences without worsening habitat fragmentation in the case of roads that have many non-wildlife-engineered passages.

## Introduction

Installing wildlife passages and fences around roads in order to reduce wildlife roadkills and habitat fragmentation is the most pro-active and effective as well as most costly method in and outside of Korea. However, studies on the true extent to which roadkills and habitat fragmentation can be mitigated by installing costly wildlife passages in addition to fences, are in reality insufficient.

Meanwhile in the construction process of roads, countless culverts and passageways are created underneath roads to enable thoroughfare of water and humans, and not wildlife. In recent years, some countries have been active in their efforts to increase the potential and efficiency of the use of such structures as wildlife passages (Clevenger et al, 2001; Brudin, 2003; Lapoint et al, 2003; Donaldson, 2005; Mata et al, 2005). Especially in Korea, as a country with many mountainous areas and the world's 3rd highest population density, the structural characteristics of roads mean that crossing structures such as tunnels, viaducts, culverts, underpasses and overpasses are much more common compared to other countries. Given this context, an analysis of the potential for these structures to serve as wildlife passages will provide important foundational data for Korea's plans for building wildlife passages.

The goals of this study are therefore as follows. The first goal is to understand the potential of the crossing structures of roads, to serve as wildlife passage systems. Secondly, this study aims to analyze the changes each month, within a given area, in the number of passages that can be used, according to changes in the volume of water flow through culverts, and to analyze the resulting changes in the rate of use of passages by wildlife as well as in the number of roadkills that occur. Thirdly, this study analyzes the relationship between the concentration of passages and the frequency of roadkills. Finally, based on all of the above results, this study aims to present the factors that should be considered when establishing measures to prevent roadkills and habitat fragmentation that are suited to the realities in Korea.

## Methods

### Survey of Roadkills and Crossing Structures

Roadkills were examined once each day using vehicles, and after recording positional data using the GPS, and removing the carcass from the road, spray paint was used to mark the spot on the road where the body was found, to make sure that the carcass would not be accidentally recounted later on. Furthermore, roadkills were surveyed in the same areas where studies were being conducted on wildlife use of road crossing structures, in order to increase the consistency between these two sets of collected data.

For the survey of underpass structures that could potentially be used as wildlife passage systems, circular culverts about 1m in diameter were monitored by installing infra-red-operated 35mm camera in the ceilings, 1~2m into the entrances. In the case of box culverts and passageway boxes, the cameras were installed in the walls or ceilings of their central sections, and where the ranges of the sensor and of the lens did not cover the entire passageway, two cameras were installed on each opposite wall. Cameras were installed in a total of 14 structures, and the types and characteristics of the structures in which cameras were installed are as shown in [table 1].

The camera sensors were programmed so that after taking a picture, the cameras would not photograph again for the next minute at the minimum, in order to eliminate the possibility of an animal being photographed repeatedly at once. The cameras thus installed were inspected once a week on average, during which time their films were replaced.

Table 1: Types of underpass in study area

| Type | Purpose | Dimension | Count of passage | Usable passage | monitored passage | Material of bottom |
|---|---|---|---|---|---|---|
| Box | human | 2~4.3 m span by 2~4.3 m rise (6.6'~14.1×6.6'~14.1') | 11 | 11 | 5 | concrete |
| Box | culvert | 2.5 m span by 2.5m rise (8.2' x 8.2') | 5 | 2 | 2 | concrete |
| Circular | culvert | 0.8~1.2 m in diameter (2.6'~3.9') | 19 | 13 | 7 | Concrete or steel |
| Bridge | stream | 7~260 m span (23.0'~853.0') | 5 | 5 | 0 | Soil and stream |
| Total | - | - | 40 | 31 | 14 | - |

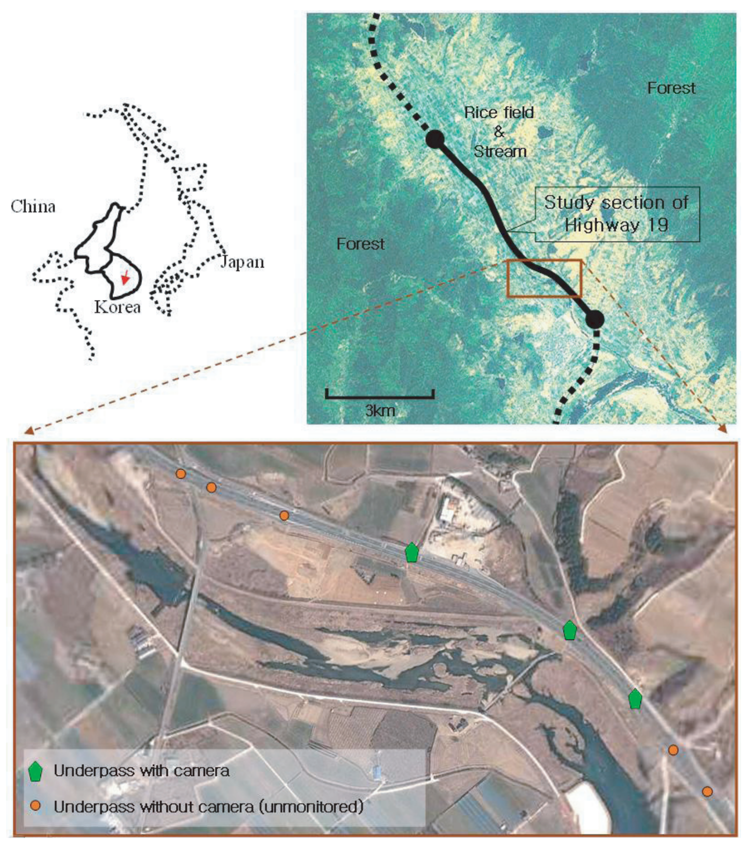



Figure 1. Location of study area and Highway 19 in Gurye county, Korea.

Figure 2. Box passageway

Figure 3. Box culvert

Figure 4. Circular culvert (waved steel pipe)

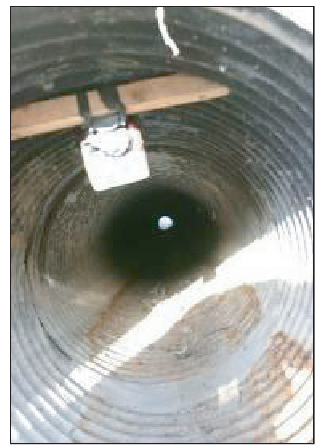


Figure 5. Installed camera in circular culvert

### Study Area and Survey Period

The area surveyed was the 4-lane highway 19, in Gurye county in the Jeollanamdo province, a 6.6 km section along the Seosi stream in Gurye-eup that was completed in 1995. As part of a preliminary study, a roadkill survey was conducted on a 30 km section of the said highway for 1 year, beginning in September 2004. At the end of this period, a section was selected where roadkills occurred frequently, and where the types of habitat in the vicinity of the highway were similar. The selected 6.6 km section is adjacent to the Jirisan National Park. Most of the lands to the east of the highway are rice fields, with a few towns and forests; to the west the Seosi river flows along the highway, and in the areas between the highway and the watercourse, riparian vegetation such as reed grass predominate. Results from the on-site survey of the 6.6 km section showed that a total of 40 crossing structures existed, and that in 9 of these structures, entrances were either blocked, or deep pools of water were always present, making animal movement physically difficult. Therefore out of the 31 structures that animals could use, monitoring was carried out on 14 structures, after taking into consideration, factors such as the interval distances between structures, availability for use by wildlife, and potential for camera theft. The survey of passages using camera trap took place from September 2005 until August 2006, and the survey of roadkills was carried out from September 2004 until August 2006.

### Radio-telemetry

In order to understand the effects of the roadkills that occurred within the reference survey section on wildlife populations, and to identify the characteristics of the wildlife being killed, 13 raccoon dogs were captured within 100m of the highway, between October 2004 until May 2005, and VHF radio-collars were worn on their neck. Appearances of these collared animals were recorded during surveys of camera traps and roadkills.

### Methods of Analysis

The structures that served as circular culverts functioned as agricultural water channels between April and September, thus making animal movement physically impossible during those times. Therefore the counts between the usable number of crossing structures per month, and the number of roadkills occurring per month were compared to analyze the relationship between the seasonal fluctuations in the number of crossing structures and roadkill incidence.

In addition, changes in the frequency of roadkills according to fluctuations in the rate of use of crossing structures per month were examined, and analysis was also carried out on whether or not during periods when usage of some of the passages became impossible, use rates of other passages increased. Use rate here refers to the figure obtained after dividing the total number of confirmed movements, with the total number of days surveyed, and it represents how many movements take place in a given passageway per day (Servheen, 2003).

In order to analyze spatial pattern of roadkills as the density of passages increase, the point density (Silverman, 1986) module of the ArcGIS (ESRI Inc.) software was used to classify the density of passages for the given highway. Here, the buffer range for each passage was selected as 500m, and this was because the home range of the raccoon, for which the most data was collected in this study, was an average of 0.8 $km^2$ (Choi and Park, 2006) which in linear terms means a movement distance of about 1km.

Correlation analysis between passages-specific factors such as counts, use rate, and density, and roadkill-specific factors such as frequency and density was conducted to obtain Pearson correlation coefficients. Wilcoxon tests were performed for the investigation on whether during periods when some of the passages could not be used, use rates for other passages increased. SPSS 10.0(SPSS Inc., 2000) was used for statistical analyses.

Figure 6. Raccoon dog at dry season. Figure 7. Inundated circular culvert.

## Results

### Survey Results for Crossing Structures and Wildlife Roadkills

For 1 year, surveys using infra-red-operated cameras were carried out on a total of 14 underpasses, for an average of 239 days each; in the case of mammals 2,593 movement cases were photographed for 13 species. Additionally, within the same section, over a period of 2 years, 93 mammalian roadkill incidents were discovered for 12 species (fig. 10).

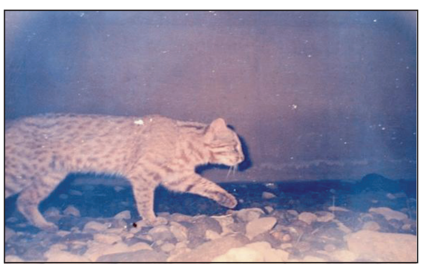


Figure 8. Leopard cat in box culvert. Figure 9. Eurasian otter in circular culvert.

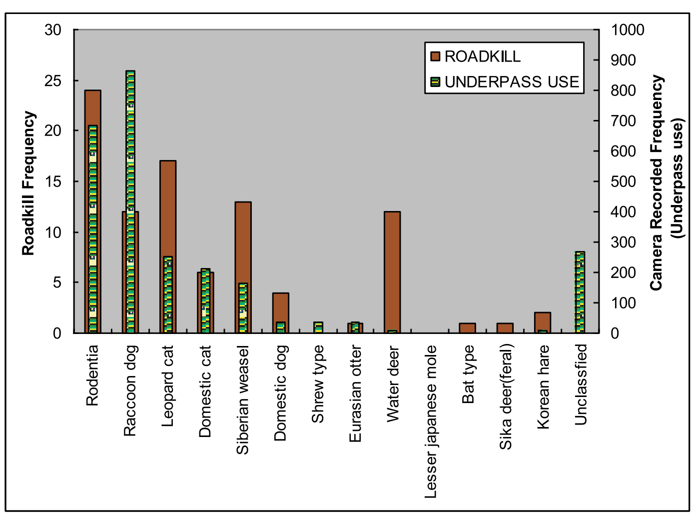



Figure 10. The frequencies of roadkill and underpass use by mammal species.

Out of total underpass movements, raccoon dogs (*Nyctereutes procyonoides*) were most frequently photographed 865 times (33.4% of total photography) and the next most frequent was the brown rat (*Rattus norvegicus*), which was photographed 455 times, accounting for 17.6% of total photography. Instances when the camera sensor detected animal movement but the flash failed to go off, or when the animal was outside of the camera's recording range and so the species could not be identified, accounted for 10.3% of total photography, or 268 photographs. Meanwhile movements of water deer (*Hydropotes inermis*) were confirmed on only 32 occasions (1.23%) and so it seemed reasonable to infer that the deer had an aversion to the crossing structures currently in place.

The species identified during roadkill surveys were: brown rats, which at 20 bodies comprised 21.5% of the total number of roadkills; wildcats, occupying 18.3% with 17 bodies; and water deer which made up 12.9% with 12 bodies (fig. 10). Therefore, compared to their highway mortalities, the water deer showed extremely low rates of use of passages, which suggests that they may be highly vulnerable to roadkills and habitat fragmentation. Leopard cats (*Prionailurus benalensis*) also showed tendencies similar to yet weaker than, those of the water deer, and therefore they were expected to be relatively vulnerable to roadkills (fig. 10).

Table 2: The results of infra-red-operated camera monitoring on 14 underpasses in study area

| Structure ID | Type | Material | Measurement | Openness Index [c] | Duration Days (Functional Camera Days) | Unusable Days (Inundated Days) | Usable Days | Mammal species [a] | | | | | | | | | Use rate [d] of Duration days | Use rate of Usable days |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Rodents [b] (*Rodentia*) | Water deer (*Hydropotes inermis*) | Domestic cat (*Felis silvestris*) | Raccoon dog (*Nyctereutes procyonoides*) | Korean hare (*Lepus coreanus*) | Leopard cat (*Prionailurus benalensis*) | Eurasian otter (*Lutra lutra*) | Siberian weasel (*Mustela sibirica*) | Total | | |
| 3 | Circular culvert | Ferroconcrete | D: 1.2m (3.9') | 0.033 | 311 | 135 | 176 | 24 | 0 | 16 | 0 | 0 | 14 | 2 | 8 | 64 | 0.21 | 0.36 |
| 4 | Box passageway | Ferroconcrete | 3.5m span by 3.5m rise (11.5'?11.5') | 0.438 | 69 | 0 | 69 | 2 | 0 | 38 | 30 | 0 | 2 | 0 | 0 | 72 | 1.04 | 1.04 |
| 11 | Circular culvert | Ferroconcrete | D: 1.2m (3.9') | 0.035 | 301 | 105 | 196 | 26 | 0 | 53 | 13 | 0 | 57 | 2 | 11 | 158 | 0.52 | 0.81 |
| 12 | Circular culvert | Waved steel pipe | D: 0.8m (2.6') | 0.018 | 262 | 165 | 97 | 16 | 0 | 36 | 65 | 0 | 20 | 7 | 9 | 153 | 0.58 | 1.58 |
| 15 | Box passageway | Waved steel pipe | 3.0m span by 3.0m rise (9.8'?9.8') | 0.310 | 259 | 0 | 259 | 0 | 0 | 32 | 53 | 0 | 2 | 0 | 0 | 86 | 0.33 | 0.33 |
| 20 | Box culvert | Ferroconcrete | 2.5m span by 2.5m rise (8.2'?8.2') | 0.100 | 184 | 30 | 154 | 0 | 0 | 0 | 52 | 0 | 24 | 11 | 2 | 89 | 0.48 | 0.58 |
| 21 | Box culvert | Ferroconcrete | 2.5m span by 2.5m rise (8.2'?8.2') | 0.100 | 230 | 180 | 50 | 1 | 0 | 0 | 25 | 0 | 6 | 6 | 2 | 41 | 0.18 | 0.82 |
| 22 | Circular culvert | Waved steel pipe | D: 0.8m (2.6') | 0.017 | 253 | 0 | 253 | 217 | 0 | 0 | 52 | 0 | 13 | 4 | 49 | 232 | 0.92 | 0.92 |
| 23 | Circular culvert | Waved steel pipe | D: 0.8m (2.6') | 0.017 | 282 | 0 | 282 | 95 | 0 | 0 | 175 | 0 | 9 | 1 | 20 | 246 | 0.87 | 0.87 |
| 28 | Box passageway | Ferroconcrete | 3.5m span by 3.5m rise (11.5'?11.5') | 0.383 | 189 | 0 | 189 | 0 | 7 | 12 | 34 | 0 | 5 | 0 | 0 | 58 | 0.30 | 0.30 |
| 31 | Box passageway | Ferroconcrete | 2.0m span by 2.0m rise (6.6'?6.6') | 0.138 | 310 | 90 | 220 | 0 | 0 | 3 | 80 | 0 | 8 | 0 | 10 | 101 | 0.33 | 0.46 |
| 32 | Circular culvert | Waved steel pipe | D: 0.8m (2.6') | 0.014 | 288 | 135 | 153 | 133 | 0 | 5 | 87 | 0 | 66 | 0 | 41 | 309 | 1.07 | 2.02 |
| 34 | Circular culvert | Waved steel pipe | D: 0.8m (2.6') | 0.011 | 302 | 165 | 137 | 170 | 0 | 14 | 65 | 0 | 20 | 2 | 8 | 234 | 0.77 | 1.71 |
| 35 | Box passageway | Ferroconcrete | 4.3m span by 4.3m rise (14.1'?14.1') | 0.700 | 111 | 0 | 111 | 0 | 25 | 4 | 134 | 10 | 8 | 0 | 6 | 187 | 1.68 | 1.68 |
| SUM | - | - | - | - | 3351 | 1005 | 2346 | 684 | 32 | 213 | 865 | 10 | 253 | 35 | 166 | 2029 | 9.30 | 13.48 |

[a] Rodents include 455 brown rats(*Rattus norvegicus*) and 229 striped field mice(*Apodemus agrarius*).
[b] Domestic dog(38), Shrews(38, occurred only in circular culverts), Lesser Japanese mole(1), and Bat(1) were omitted.
[c] Openness Index = (Span x Rise)/Length, (Reed & Ward, 1985), Example (6ft. x 8ft.) / 150ft. = 0.32 OI
[d] Use Rate = (? #of photographs)/(? #of functional camera days), (Servheen, 2003)

**Relationship between Crossing Structures and Wildlife Roadkills**

Fluctuations in the number of accessible passageways also appeared to have no correlation with roadkill incidence (r=0.243) (fig. 13), and this was contrary to the general belief that the greater the number of passageways, the fewer would be the number of roadkills.

Meanwhile, use rates of passages and roadkill frequencies showed a strong positive(r=0.890) correlation (fig. 14), which was meaning that increasing movements of wildlife result in increasing roadkills.

During the April~September period, when some (max. 64%) of the passages became unusable caused by inundation, use rates for other passages showed no corresponding increase ($p=0.516>\alpha=0.05$).

Furthermore, there appeared to be a very weak but positive correlation (r=0.559, p<0.093) such that the more passages there were in an area, the higher the roadkill frequency, which again differed from the general expectation that roadkill accidents would decrease in areas where crossing structures were concentrated (fig. 15, 16).

The reason for these results may be as follows. Since 31 usable passages exist in the given 6.6km highway section, even if the number of usable passages falls to 14 during the month of July, when a lot of water accumulates in the culverts, the number of usable passages remaining is 2.2 extra structures per 1 km. Taking into consideration the fact that the home range for the raccoon dog, which is the most common wildlife in Korea, is 0.8 $km^2$ (Choi and Park, 2006), then as can be told from the fact that an animal would be able to use about 2 passages within its given home range, it is deemed that a sufficient number of passages exist already in the given section.

Of the 13 raccoons that were radio-collared after capture, 3 animals were caught on camera, continuously using all types of underpasses to cross roads and these animals were not observed to move to other areas to use other available passages between the months of April~September when the culverts were filled with water. This may have been due to the fact that each animal has its own home range and therefore was careful not to encroach upon the territory of other animals, or because food was available plentifully during that particular season, and thus the raccoons felt no urgent need to change their home ranges by using unfamiliar passages located in other raccoon dog's home range.

Meanwhile, it appeared that there was no correlation between number of roadkills per month and average daily fluctuation in night time traffic per month (r=0.075). This is deemed to be because, compared to the monthly changes in traffic volume in the given highway, the monthly changes in wildlife movement are much greater, and therefore, the roadkill frequencies following from changes in traffic volume are not being expressed.

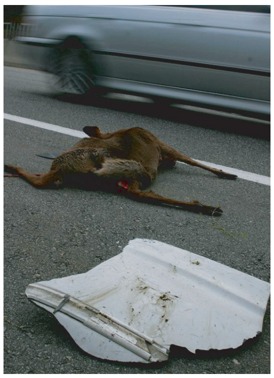


Figure 11. Water deer roadkill.


Figure 12. Water deer in box passageway (Openness index 0.7).

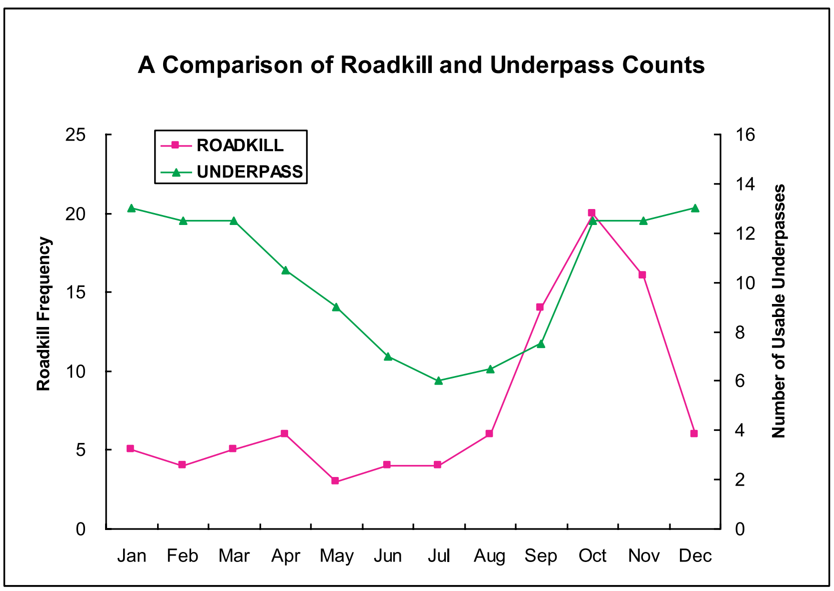



Figure 13. Fluctuations in the number of accessible passageways also appeared to have no correlation with roadkill incidence (r=0.243), and this was contrary to the general belief that the greater the number of passageways, the fewer would be the number of roadkills.

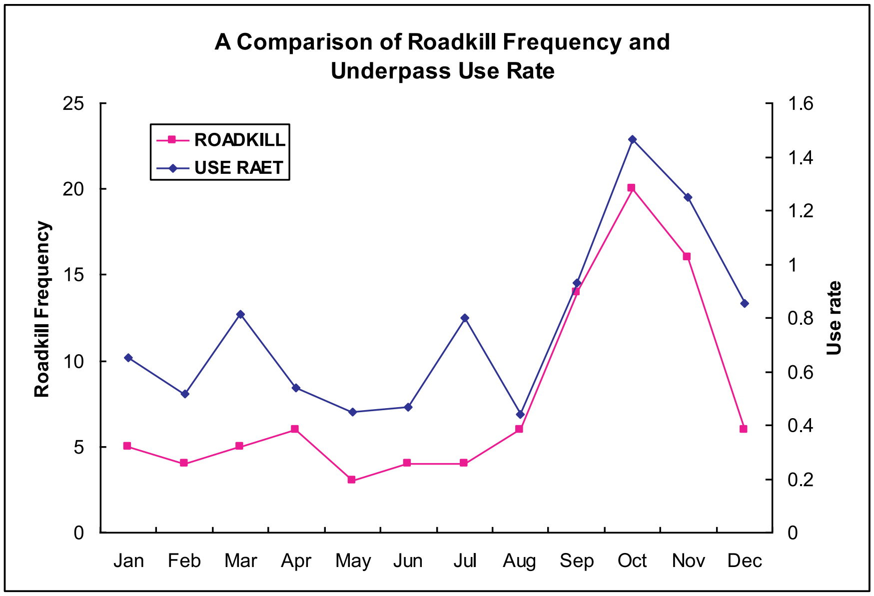



Figure 14. Use rates of passages and roadkill frequencies showed a strong positive(r=0.890) correlation, which was meaning that increasing movements of wildlife result in increasing roadkills.

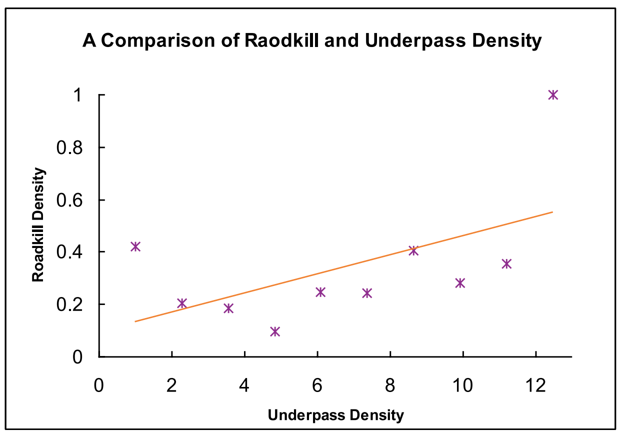



Figure 15. The more passages there were in an area, the higher the roadkill frequency, which differed from the general expectation that roadkill accidents would decrease in areas where crossing structures were concentrated (r=0.559, p<0.093). Refer to Fig. 16.

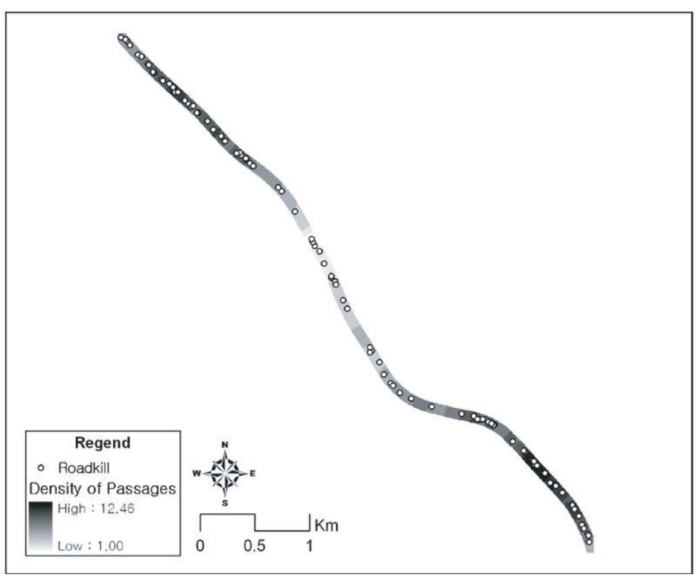



Figure 16. Spatial distribution of mammal roadkills and passage densities; 12 of density value means 12 passages are located within 1km.

**Roadkills of Radio-collared Wildlife**

After capturing and 13 raccoon dogs within 100m of the given highway, from October 2004 to April 2005, and releasing them after wearing radio-collars on their neck, of the total of 12 raccoon dogs that were found during the roadkill survey conducted from September 2004 until August 2006 in the reference highway, only 1 was found to be collared.

Through radio-tracking, Choi and Park (2006) discovered that the average home range of raccoon dogs that inhabited the reference area was 0.8 $km^2$, and considering this fact, capture of 13 raccoon dogs in a 6.6km section represents the collaring of a substantial number of the animals inhabiting that reference location, and the 12 roadkill bodies discovered similarly seem to represent a very high figure.

The fact that despite all this, only 1 out of the 12 roadkill bodies examined was collared, seems to indicate that a significant number of highway mortalities are of animals that do not inhabit the reference location, and that these animals were killed while they were on the migrations, most likely to secure new territories, either because they were not familiar with the existing passages, or because they were not allowed access to the passages by occupying settlers.

Figure 17. Radio-collared Raccoon dog.

Figure 18. Raccoon dog killed by vehicle.

## Discussion

Upon examining 14 of these usable structures (non-wildlife-engineered passages), a total of 2,593 mammalian movements were confirmed during a 1 year period, which meant that these structures were functioning as crossing structures, to the extent that for each passage, an average of 0.53 mammalian movements were taking place in 1 day. These figures indicate that in the 6.6 km-long reference highway, mammalian movement using passages under the highway is taking place actively, through 31 different passage locations, at an average of 16.6 times each day.

The significance of this result is therefore that there is no reason for concern about mammalian habitat fragmentation due to highways. Given the fact that Korea has many mountainous regions and high population density, and that these conditions by definition necessitate the construction of structures such as bridges, tunnels, passageway boxes and culverts, there is a high probability that highways in other agricultural regions may have conditions quite similar to that described above. According to Choi et al.'s study (2006), after surveying 86 crossing structures in 8 highways across the nation, over a section totaling 21.5km, 1~3 days after heavy snows, 67 instances of traces of wildlife movement were found in 44 structures.

However, in the case of the water deer, only 32 instances (1.23% of total photography) of movement were confirmed over a 1-year period, so concerns are great that they may be vulnerable to habitat fragmentation and roadkills, compared to other species. 25 of 32 recorded water deer crossing occurred in the box passageway with 0.7 openness index (4.3m span by 4.3m rise (14.1'?14.1')) the largest measurement in study area. Meanwhile, out of roadkill survey, water deer made up 12.9% of total mammal roadkills. Our results showed in Choi et al.'s study (2006), it has been reported that movement of water deer does not take place through passageway boxes but that the deer only make use of bridge underpasses. Although excluded from this analysis on crossing structures, underneath some of the bridges within study area, movement tracks of water deer could be found frequently. Inter-bridge distances are however necessarily greater compared to intervals between other structures, and this increases the likelihood of habitat fragmentation for water deer, or of being forced to access roads and highways for movement.

Therefore, additional studies on the water deer's territorial ranges and movement characteristics need to be carried out in the future, to present the structure sizes that are most appropriate for water deer movement, as well as the optimal inter-structural distances.

Another obtained result was that over a 2-year period, in a 6.6 km section, 12 raccoon dog roadkills were discovered, but that out of the 13 animals that had been radio-collared, only 1 was discovered as a roadkill. This result means that most roadkill victims might be wanderers or newcomers unfamiliar to existing passages or occupying settlers. Furthermore, October when many young mammals' dispersals occurred was the seasonal peak of roadkills.

The results of this study suggest that merely increasing the number of crossing structures, or reducing the intervals between them will not lead to an increase in wildlife movement, or to a decrease in roadkills. In the case of agricultural region of Korea, where facilities that function as wildlife crossing structures are already abundant in highways, even if some of the structures become unavailable for wildlife use in certain seasons, or even if some differences do exist in the intervals between passages, sufficient numbers of passages exist such that all wildlife except water deer can make use of them as necessary.

Therefore given the unique conditions in Korea, if wildlife passages are created in agricultural region, water deer should be selected as a target species, and the optimal size for structures such that the deer will not be averse to using the passages must be considered. Additionally the home ranges and movement characteristics of water deer must be factored in when deciding upon optimal inter-structural distances. For species other than the water deer, wildlife fences that restrict access to roads and highways will be sufficient to guide wildlife to the existing passages, and that they will thereby have a huge positive impact in terms of reducing wildlife roadkills, without aggravating habitat fragmentation.

So in the end, the construction of wildlife passages, which take place under current road and highway conditions without sufficient basic research, may actually not be having any meaningful impact in terms of reducing roadkills and habitat fragmentation.

**Biographical Sketches:** Choi, Tae Young is a wildlife research biologist who is currently working on his Ph.D. in Graduate School of Environmental Studies, Seoul National University, Korea. His research is investigating the causes of wildlife vehicle collisions and suggests mitigation measurements. He has a master's degree in wildlife habitat modeling using geographic information system (GIS) from Seoul National University, Korea. He will work for Nature and Ecology Research Department of National Institute of Environmental Research, Korea from July 2007.

Park, Chong Hwa is an ecology research biologist and professor at the Graduate School of Environmental Studies, Seoul National University, Korea. He has been studying habitat analysis using geographic information system (GIS) and Remote Sensing (RS). Dr. Park is a graduate of the State University of New York, and has a master's degree in landscape architecture from the Seoul National University. He is currently a leader of the Korea Institute of Landscape Architecture.

## References

Brudin, C.O. 2003. Wildlife use of existing culverts and bridges in north central Pennsylvania. *Proceedings of The 2003 International Conference On Ecology & Transportation*. Lake placid, New York: 344-352.

Choi, T.Y. and Park, C.H. 2006. Home-range of raccoon dog *Nyctereutes procyonoides* living in the rural area of Korea. *Journal of Ecology and Field Biology*. 29(3): 259~263. In Korean.

Choi, T.Y., Lee, Y.W., Hwang, K.Y., Kim, S.M., Park, M.S., Park, G., Cho, B.J., Park, C.H., and Lee, M.W. 2006. Monitoring the Wildlife Use of Culverts and Underpasses Using Snow Tracking in Korea. *Korean Journal of Environment and Ecology*. 20(3): 340-344. In Korean.

Clevenger, A.P., Chruszcz, B. and Gunson, K. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. *The Journal Of Applied Ecology*. 38(6): 1340-1349.

Donaldson, B.M. 2005. Use of highway underpasses by large mammals and other wildlife in Virginia and factors influencing their effectiveness. *Proceedings Of The 2005 International Conference On Ecology & Transportation*. San Diego, California: 433-441.

Lapoint, S., Kays, R.W., and Ray, J.C. 2003. Animals crossing the northway: Are existing culverts useful? *Adirondack Journal of Environmental Studies*. Spring/Summer 2003: 11-17.

Mata, C., Hervás, I., Herranz, J., Suárez, F., and Malo, J.E. 2005. Complementary use by vertebrates of crossing structures along a fenced spanish motorway. *Biological Conservation*, 124(3): 397-405.

Servheen 2003. A sampling of wildlife use in relation to structure variables for bridges and culverts under I-90 between Alberton and St. Regis, Montana. *Proceedings Of The 2003 International Conference On Ecology & Transportation*. Lake Placid, New York: 331-341.

Silverman, B.W. 1986. Density Estimation for Statistics and Data Analysis. New York: Chapman and Hall.

# Inventory and Typology of Fauna Passages on French Transport Infrastructures

**Sabine Bielsa** (+33 1-46-11-31-31, sabine.bielsa@equipement.gouv.fr) and
**Christophe Pineau** (+33 1-46-11-31-31, christophe.pineau@equipement.gouv.fr), Environmental Engineers, Technical Department for Transport, Road and Bridges Engineering and Road Safety (SETRA), Ministry for Transport, Infrastructure, Tourism, and the Sea, 46 Avenue Aristide Briand, BP 100, 92225 Bagneux cedex, Fax: 01 46 11 31 69 France
http://www.setra.equipement.gouv.fr

**Abstract:** French transport infrastructures network increased significantly since 1980th. The french roads network is one of the densest in the world, nearly 1 million kilometres long. Habitat fragmentation by transport infrastructure is recognised as one of the prime cause of eroding biodiversity in the industrialized countries. Providing links between habitats can directly reduce fragmentation. Thus, fauna passages need to be built to mitigate the increasing negative barrier effect of infrastructures on wildlife and maintain connectivity.

In 2000, 400 crossing structures (fauna passages and others structures of permeability) were inventoried on French transport infrastructures. In 2006, more exhaustive surveys listed 399 structures only in Nord-Pas-de-Calais and Picardie regions, both described in the present paper. Therefore, a tool becomes necessary to evaluate the transparency for wildlife of the whole French transport infrastructures.

The main objective of the study is to carry out a database to inventory the structures of transparency, define their effectiveness as fauna passage and share comparable information amongst transport stakeholders. This project responds to one of the actions of the linear transport action plan adopted by France in November 2005, planned within the framework of the preservation of biodiversity (French strategy adopted in 2004). The aim is the implementation of appropriate measures for preservation of biodiversity during construction, maintenance and exploitation phases.

In this paper, we describe the first stage of work conducted to identify the number and type of fauna passages (viaduct, bridge, pipe conduit, mixed, specific, overpass, underpass, etc.) on the French transport network (roads, railways and waterways). First results concern a pilot area - Nord-Pas-de-Calais and Picardie regions - which presented the most exhaustive data. They show many difficulties related to data heterogeneity, to old and partial data, and to distinguish structures and integrate them in the typology. Moreover, this step had to be delay because of the new management organization of the national road network (decentralization and reorganization of public authorities in charge).

Once the geo-localised database will be achieved, we will try to implement a monitoring system on field to specify the effectiveness of different types of passages. In addition, comparison between crossing structures map, biological corridor maps at departmental and regional scale, and non-fragmented territory map (MEDD, 2007) will allow us to identify future fragmentation black spots.

## Introduction

### One of the densest network in the world

The French roads network is one of the densest in the world with 1 million kilometres long, and an average of 1.8 km/km$^2$. 600.000 km of municipal roads and 380.000 km of departmental roads are managed by local authorities. 20.000 km of roads and motorways are placed directly under national authority, among which 8.000 km are conceded to private companies.

The railway network has 30.000 km of commercial lines primarily managed by RFF - Réseau Ferré de France (French Rail Network). It includes 1.550 km of High-Speed Link-HSL (LGV in French) (additional 450 km under construction), 16.104 km of double tracks or wider and 14.778 km of electrified lines.

The waterway network cover 8.500 km, primarily managed by Voies Navigables de France - VNF (French Inland Water, public organisation).

The expansion of the transport infrastructures greatly accelerate the habitat fragmentation, which is generally recognised as one of the prime cause of eroding biodiversity in the industrialized countries. Habitats isolated by barrier effect are “insularised”, creating continental islands. A direct consequences for wildlife is an increase of mortality during migration, affecting the dynamic of the population. Examples of others consequences are habitat degradation, habitat loss, pollution, change of microclimate, increase or human activity around infrastructures.

According to the French strategy for biodiversity (adopted in 2004), which ambitious objective is to stop the depletion of biodiversity by 2010, a specific action plan was made for linear transport infrastructures and adopted in November 2005. Its purpose is the implementation of appropriate measures for preservation of the habitats and species during construction, maintenance and exploitation phases. In addition, it imposes the biodiversity preservation and ecological engineering training for staff in charge of infrastructures.

The present study carried out by SETRA responds to the plan’s guideline no. 3 - “Knowledge of biodiversity” - which aim is to improve knowledge of biodiversity (fauna, flora, ecological corridors), according with those of the Ministry for Ecology. In addition, it also coincides with the more territorial ecological policies (region, county (French department), municipality) in favour of corridors conservation and rehabilitation.

The aim of the first step is to provide a tool improving biological connections on linear transport infrastructures, in particular by setting up a reliable database on crossing structures that can be use as fauna passages.

*A clear improvement in fauna passages in France*

When infrastructures alter biological continuums, fauna passages and other structures adapted to enhance their use by animals can mitigate the barrier effect of transport infrastructures. This structures, which must be adapted to the species encountered, have undergone numerous changes in France since their first built in the 60's (SETRA and CETE, 2006). Logic of conception have evolved from a logic of "game passages", based on road safety and cynegetic interest, to a much global approach of biodiversity conservation. In France, many innovative territorial policies are also locally developed in favour of an increase of the permeability concept, based on multiplication of fauna passages and adaptation of old crossing structures.

Every year, 200 to 300 serious accidents involving fauna on network (less than 1% of road fatalities on French roads) (SETRA data, 2005). Total collisions caused by large fauna are estimated at 20 000 a year (ONCF, 2005). It's worthy of note that the population of large wild mammals (stags, roe deer and wild boar) has increased fivefold since the 1980's. The crossing structures, which were initially designed as game passages, now satisfy a more wide-ranging demand for conservation of biodiversity while continuing to play their part in road safety.

With development of scientific knowledge and information about habitat fragmentation, density of fauna passages have increased in parallel of the significant increase of French transport infrastructures. In France, two handbooks published by SETRA for large fauna (SETRA-MEDD, 1993) and small fauna (SETRA-MEDD, 2005) have been published in order to provide the principles, methods and management processes helpful to define appropriate solutions for construction and maintenance of fauna passages.

*1st generation of fauna passages (1960–1970)*

Large fauna passages have been created a long time ago (figure 2). The first passage in France was built on the A6 motorway (in the forest of Fontainebleau, near Paris). These 1st generation of passages, undersized and often badly located were underused. Measures for fauna taken during 1960-1970's period responded to a necessity of maintaining habitat connectivity, but lacked of appropriate recommendations as those accumulated in existing handbook.

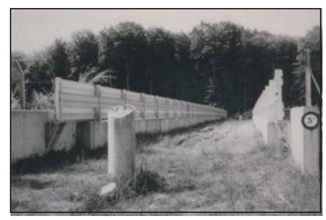


Fig. 2. 1st generation of fauna passages. Overpass at the A13.

*2nd generation of fauna passages (1970–1980)*

Their features were improved but lacked of completion. Despite their well-adapted characteristics to large fauna requirements, they still lacked of attractivity and effectiveness (figure 3). In addition, new materials were tested (such as wood) with mitigated results.

Fig. 3. 2nd generation of fauna passages. Underpass at the A5.

*3rd generation of fauna passages (1980–today)*

The last generation show more suitable characteristics, forms, and roadsides. New forms such as "parabolic shape" (figure 4) designed to minimise the tunnel effect for large fauna are favourable to a wide range of species,.

The small fauna is gradually take account since the 1980's. Pipes (Type I) designed for a large number of species show their effectiveness and are located every 300 metres (taking account of other structures usable by small fauna such as hydraulic widened passages, large fauna passages, agricultural or forestry passages). Specialized passages (Type II), are built for target species (otter, beaver) or a group of species (amphibian tunnels).

These structures can be used by several species, providing diversified crossing conditions.

The **notion of managing** fauna passages emerged only in the 1980's, with the first management plans that allow to check the effectiveness of measures. Experience has demonstrated the importance of monitoring and quality control to guarantee their sustainability and effectiveness and maintain their first purpose. Fauna passages are usually monitored by recording footprints wich provide indicators about the use of structures but not about the fauna behaviour. Photo- and video-surveillance offer interesting indications about the behaviour of animals using the structures. Currently, specialized passages are fairly well monitored, others more occasionally.

Fig. 4. 3rd generation of fauna passages. Parabolic shape at the A36. (Source: SETRA and CETE, 2006)

Significant progresses have been made in terms of location and construction of fauna passages. They are more integrated into the surroundings and built for local/regional target species in priority. Improvements need to be made about monitoring, roadsides facilities, their design and some methodological basis. In particular, it is recommended to erect fences as near as possible of the track to maintain a wide area for the animals, where vegetated roadsides may serve as movement corridor and habitat. They have an important function to guide the animals towards passages. Similarly, the placing of screening parapets that ensure animal and human safety, may be of different forms and improve the effectiveness of the passages.

New materials reveal to be very interesting for the construction as well as economic. Prefabricated elements offer an interesting option for fauna overpasses due to their greater resistance to soil and vegetation weight pressure. In addition, they present a better water drainage system than vegetated bridges.

The Wood and Furniture Technical Centre (CTBA) ) project the construction of large fauna passage made with wood. A wood overpass is faster to erect and it's also a sustainable source that traps carbon dioxide (CO2), one of the main cause of climate changes. However, technical specifications still need to be drawn up (durability, waterproofing, cost). Current and future constructions must ensure guarantees sustainable structures. Experiments are being made to test this new materials and their environmental impact (wood treatment).

*A fauna passages network still little known*

Surveys have been carried out across France during the last 20 years. The data on crossing structures (specific and potential), too old and/or partial, are insufficient to make a reliable assessment of the situation. Nevertheless, certain qualitative and quantitative items have been used.

In 2000, the number of crossing structures on French transport infrastructures was estimated at 400. In fact, 192 road passages and 12 railway passages could be inventoried in only 1/3 of France (Auvergne, Bourgogne, Franche-Conté and Rhône-Alpes areas).

The French transport infrastructure network continue to increase since 2000, so an additional assessment seemed necessary to evaluate the transparency for wildlife of the whole French transport infrastructures. Responding to the transport infrastructure action plan adopted by France in November 2005, planned within the framework of the national strategy of biodiversity, the aim of the present study is to locate fauna passages and specify the effectiveness. Comparison between locations of passages, biological corridor and non-fragmented territory will allow us to identify future fragmentation black spots.

This article describes the results obtained on a pilot area including the Nord-Pas-de-Calais and Picardie regions. First, we focused on main road and rail infrastructures, with an emphasis on the national network.

## **Methodology**

### Study Area

We focused only on conceded motorways, national roads, and new High Speed Lines - HSL. Waterways were not taking account in this paper. The departmental road network, that comprises recently built infrastructures, will be included soon. Additional results on national roads network recently devolved to the departments should be available later.

The study area investigated here, Nord-Pas-de-Calais and Picardie regions includes:

- National road network: 1.300 km of national roads managed by an Interdepartmental Hghway Directorate (DIR); 800 km of conceded motorways managed by SANEF (private motorway company);
- High Speed Lines: 320 km between Paris and Lille, and Eurostar lines managed by Réseau Ferré de France - RFF (French Railways Network, public organisation);
- Waterways: 1.350 km managed by Voies Navigables de France - VNF (French Inland Water, public organisation).

### Methods

The inventory of fauna passages uses different sources of data. A bibliographic inventory was made; database and asset management of the national roads (Infracoût, LAGORA…) were consulted. Seven CETE (Public Works Engineering Centres) interviewed the local infrastructures managers (Works Department Direction - DDE, DIR). The inventory of fauna passages located on conceded motorways was drawn up from surveys (see appended survey sheet) of the concessionary companies. RFF was contacted for similar information on the HSL network. The waterways were not specifically surveyed, the initial assessment being carried out using only biographical data.

Data were compared with old inventories, recently collected data and outputs retrieved from other databases. The precise location of fauna passages was confirmed with SETRA's geo-navigator (SIRNET). No quantitative comparison between the various transport networks was envisaged due to the disparity of the data. Indeed, the motorways or high-speed lines networks are recent infrastructures (motorways in the 60's; HSL in the 90's), whereas the other roads are essentially based on a very old network, as the Roman roads.

Identification of fauna passages types was made using the classifications contained in the French handbooks for large and small fauna (SETRA-MEDD, 1993 and 2005), and the European handbook *Wildlife and traffic - A European handbook for identifying conflicts and designing solutions* (Iuell and al. 2003). The structures taken into account include specific passages for wildlife but also other passages that could be used to restore ecological connections between habitats (mainly hydraulic structures) (table 1).

Table 1: Typology of fauna passages (SETRA-MEDD, 1993 and 2005, modified)

| Type of passage | Structures | Typology | | S/M | I/S | Structural characteristics of the passage | | | | Fauna category* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | RST* | Cost 341** | | | L (m) | l (m) | H (m) | Ø (mm) | PFa | PFb | MF | GF |
| **Single passage** | Duct, box culvert | **I** | 7.3.4 | **S** | I | <80 | 0.6 (box culvert) | 1 (box culvert) | 400-2000 (duct) | random | optimal | possible | impossible |
| **Batrachian passage** | Duct, box culvert with drainage collection system | **II** | 7.3.7 | **S** | I | <80 | 1 (box culvert) | 0,7 (box culvert) | 400-600 (duct) | optimal | possible | impossible | impossible |
| **Combined passage** (hydraulic passage) | Duct, arch, box culvert, bridge | **III** | 7.3.5 7.3.1 | M | I | | 1 medium=7 | | | possible | optimal | possible | random |
| | Submersible bench 0.4m | IIIa | | | | | =2 | =2 | =2 | possible | optimal | possible | impossible |
| | Bench 0.5-0.7m | IIIb | | | | | | >0.7 | | possible | optimal | possible | impossible |
| | Dry-standing areas 1.50m | IIIc | | | | | 2<l<7 | | | possible | optimal | possible | possible |
| | Extra widening of bank =3m | IIId | | | | | 7<l<25 | | | possible | optimal | optimal | possible |
| | Dry pipe | IIIe | | | | | | | =600 | possible | optimal | random | impossible |
| **Agricultural or forestry passage** | Bridge | **IV**a | 7.2.2 | M | I | | <7 (incl. = 3m stabilized) | H>L/10 (min. 4m) | | random | optimal | optimal | possible |
| | Bridge | **IV**b | 7.3.3 | M | S | | | | | random | optimal | optimal | possible |
| **Large fauna underpass** | Bridge | **V** | 7.3.2 | **S** | I | | 7<l<12-25 | H>L/10 (min. 4m) | | possible | optimal | optimal | possible |
| **Large fauna overpass** | Bridge Parabolic shape | **VI** | 7.2.1 | **S** | S | | 7-12<l<25 | | | possible | optimal | optimal | possible |
| **Viaduct** | Viaduct | **VII** | 7.3.1 | M | I | | >25 | > 8 | | possible | optimal | optimal | optimal |
| **Ecological bridge** | Cut-and-cover structure Tunnel | **VIII** | 7.2.1 | **S** | S | >25 | | | | optimal | optimal | optimal | optimal |
| **Overhead passage** | Open rope, walkway | **IX** | 7.2.3 | **S** | S | | | | | Climbing animals (possible) | | impossible | impossible |
| **Ladder for canals** | Ladders, ramps | Crossing structure | | **S** | S | | 0.40-1.5 | 0.8-1.5 | | impossible | impossible | possible | possible |

Grey background: new types of structures identified in this inventory.
RST: Scientific and Technical network (RST in French).
Cost 341: Cost 341 Habitat fragmentation due to Transportation Infrastructure. Fauna and traffic.
S/M: Specific (dedicated) / Mixed (common).
I/S: underpass / overpass.
Fauna category: PFa: small land fauna avoiding underground environments
PFb: small and medium fauna using underground passages
MF: medium and large fauna
GF: large fauna
Usage of passages by fauna:

| impossible | random | possible | optimal |
|---|---|---|---|

### Information Sheet

The density of fauna passages, their types (viaduct, bridge, duct, etc.), their specific purpose (multifunctional, large fauna, small fauna, etc.), their position (overpass, underpass), their dimension (length, width, diameter) and their management were collected. This step is necessary to assess the effectiveness of the structures, before a definition of appropriate solutions for construction or adaptation of the structures to increase the crossing by animals.

The information sheet used for the inventory of 2000 was modified to satisfy the requirements of the present study. All the data collected was first entered in a spreadsheet and will be soon entered in a geo-located database. The main interest of this tool is to share comparable information amongst transport stakeholders (structures of transparency, management, monitoring and modification). Three areas of interest were selected: identification and location of the structures, quantitative and qualitative characteristics and their monitoring and effectiveness. The effectiveness of the structures is not given here, but will be assessed later.

## Results

A very exhaustive inventory was carried out by DIREN Picardie (Regional Environmental Agency) in 1997, collecting key information on the description of structures. It covered all types of infrastructure, including the waterways, which are not specifically surveyed here. Few additional data was collected during the inventory in 2000. In 2006, 399 structures have been inventoried, doubling the previous counting made in 1997 and 2000 (145) (table 2 to 4). These variations can be explained by a significant increase of prospecting effort rather than an increase of constructions. Thus, the structures brought into service since 2000 make up only less than 10% of the total inventory (table 3).

### Conceded Motorways Network

The monitoring of structures located on conceded network (include in their statutory controls) provides detailed results on motorways. We can notice that the structures were gradually brought into service at the time of the construction of motorway sections: the A1 motorway in the 60's, the A4 motorway in the 70's, the A26 in the 80's, the A16 in the 90's, and the A29 in the 2000's. Almost all specific or mixed fauna passages of the SANEF network (60 structures) are (or have been) monitored in collaboration with hunting federations (public organisation). Screening parapets for overpasses, vegetated strips and recording footprints have been installed, thereby improving the effectiveness and the monitoring of structures.

The first wildlife-specific passages (type V or VI) were created in the 70's, with metallic pipes of 4 metres diameter. Current structures are more diversified and better suited to various types of fauna: parabolic shape 15 metres wide, cut-and-cover tunnels 800 metres wide for mixed use, creating an ecological bridge. The latest sections developed on motorways A16 and A29 guarantee great ecological transparency, in particular over valleys with construction of specialized passages or large viaducts (over 500 metres).

Table 2: Overview of fauna passages (mixed and specific) inventoried on Nord-Pas-de-Calais and Picardie transport infrastructures network

| Source | Total number | Conceded motorways | Non-conceded motorways and national roads | Departmental roads | Railway tracks | Inland waterways |
|---|---|---|---|---|---|---|
| | | **(A)** | **(RN)** | **(RD)** | **(VF)** | **(VN)** |
| RST inventory * (2000) | 13 | 12 | 1 | NC | NC | NC |
| DIREN Picardie inventory (1997)** | 144 | 41 | 6 | 1 | 6 | 90 |
| **TOTAL Previous inventories (1997, 2000)** | **145** | **42** | **6** | **1** | **6** | **90** |
| **TOTAL Current inventory (2006)** | **399** | **201** | **77** | **4** | **27** | **90** |

*: Scientific and Technical network (RST in French)

**: DIREN Picardie, 1997. Inventory of fauna passages in Picardie

Table 3: Historical background when structures were brought into service on Nord-Pas-de-Calais and Picardie transport infrastructure network

| Period | A | RN | RD | VF | VN | Total |
|---|---|---|---|---|---|---|
| **1960-1970** | 14 | | | | | 14 |
| **1970-1980** | 14 | 3 | | | | 17 |
| **1980-1990** | 71 | 13 | | | 15 | 99 |
| **1990-2000** | 78 | 12 | 1 | 27 | 35 | 152 |
| **Since 2000** | 24 | 3 | 3 | | | 30 |
| **Unknown** | | 46 | | | 40 | 86 |

Table 4: Typology of fauna passages on Nord-Pas-de-Calais and Picardie transport infrastructure network – Current inventory (2006)

| Name | RST Type | A | RN | RD | VF | VN | Total |
|---|---|---|---|---|---|---|---|
| **Single passage** | I | | | | | | - |
| **Batrachian passage** | II | | | | | | - |
| **Mixed hydraulic passage** | III | 93 (01) | 38 | 1 | 17 (2) | | 149 (03) |
| **Mixed agricultural or forestry passage** | IVa | 41 (10) | 27 | 1 | | | 69 (10) |
| | IVb | 23 (18) | | | 1 (1) | | 24 (19) |
| **Underpass for large fauna** | V | 7 (7) | 3 (3) | 1 | | | 11 (10) |
| **Overpass for large fauna** | VI | 13 (13) | 3 (3) | 1 (1) | 2 (2) | | 19 (19) |
| **Viaduct** | VII | 23 (10) | 6 | | 5 (1) | | 34 (11) |
| **Ecobridge** | VIII | 1 (1) | | | 2 (2) | | 3 (3) |
| **Overhead passage** | IX | | | | | | - |
| **Exits from waterways** | X | | | | | 90 (90) | 90 (90) |
| **Total** | | 201 (60) | 77 (6) | 4 (1) | 27 (8) | 90 (90) | 399 (165) |

Grey: Wildlife-specific passages.
() : Number of structures effective for wildlife. Include only checked and available information. Remaining structures are potential structures; their effectiveness must be confirmed.

### National Road Network

The recent decentralization and reorganization of public authorities in charge introduced a new national road network management system. Non-exhaustive data could be collected and further information should be provided in due course.

In the present state of our knowledge, 77 structures have been inventoried, including 6 passages (game, large or small fauna) having been monitored punctually. The state of other structures has not been estimated until now. The inventory includes agricultural or hydraulic passages (bridges or viaducts) that can be used by animals.

### Departmental Road Network

No particular survey of the departmental road network has been carried out. The data solely comes from the recently decentralized network, an old network reserved for secondary traffic on which a very few number of fauna passage structures were built. No structure intended for mitigate habitat fragmentation has been inventoried on the old network; only few passages (in particular 2 specific passages, 1 parabolic-shaped overpass 18 metres wide) are located on recent infrastructures such as urban bypasses.

### Railway Network

The construction of two HSL (LGV in French) in the 90's involved the creation of 27 potential structures for fauna passages. Height of which (2 specific and 6 mixed) have been monitored by departmental hunting federations. Two cut-and-cover tunnels and a specific passage 80 meters wide constitute remarkable permeability points. Many hydraulic structures are also included (17) but no data guarantee their effectiveness for fauna today.

### Inland Waterways

There are no specific structures designed for fauna on inland waterways. Only adaptations of infrastructures have been built to prevent animals from drowning by offering exits (ladders, metal or concrete ramps).

90 fauna exits were just inventoried in 1997 by DIREN Picardie; no detailed description was made. The lack of animal mortality in the Nord-Pas-de-Calais and Picardie waterways suggests that fauna exits are effective, but results are not based on regular monitoring in situ.

### Typology of Fauna Passages

The data obtained from the inventory of transparency structures for fauna in the Nord-Pas de Calais and Picardie regions enabled to test and adapt our previous typology (SETRA-MEDD, 1993 and 2005). A new type of over-pass, already described in a European handbook (Iuell and al. 2003, was added: the "overhead passage". Fauna exit structures on waterways were also included as "ladder for canals".

Most of the 400 structures inventoried in the Nord-Pas-de-Calais and Picardie regions are classified into type III (149 mixed hydraulic passages) and IV (93 agricultural and forestry passages). The ecological bridges type (VIII) is the fewest in number. Types I (single passage), II (batrachian passage) and IX (overhead passage) were not inventoried in these two regions.

Most of the hydraulic structures constitute potential crossing structures but have not been monitored. Their effectiveness must be proved yet. Similarly, types IVa and IVb (93 mixed agricultural or forestry passages) include many potential structures; only 29 have currently been identified as fauna passages. Out of the 34 inventoried viaducts (type VII), only 11 structures are recognized as fauna passages, whereas their dimensions would naturally be suited to great transparency.

Concerning the dimensions available, the span (width) of type V (underpass) varies from 2 to 10 metres (average noted in 2003: 7 m<width<12-25 m), that of type VI (overpass) from 7 to 20 metres (average 2003: 7-12 m< width <25 m) and is often parabolic-shaped. The cut-and-cover tunnels are 50-200 meters width, combine wildlife passages and human functions (road, agricultural or forestry tracks).

### Managing and Monitoring the Passages

40% of the 400 potential fauna passages inventoried in the Nord-Pas-de-Calais and Picardie regions have been more or less diagnosed in terms of effectiveness (under 25% excluding exits from waterways). Specialized passages are particularly investigated and almost have been monitored: 11 of the type V, 19 type VI (large fauna passages) and 3 type VIII (ecobridges).

The management have been set up with an external manager (often the hunting federation or the ONF-French forestry commission), more particularly for structures on motorways. We have little information on maintenance of fauna passages.

## Discussion and Conclusions

### Inventory of Fauna Passages: First Results and Necessary Readjustments

The long-term purpose is to improve the effectiveness of the passages through a better conception, management and monitoring. The definition of appropriate measures guarantees minimum impact of the fragmentation by transport infrastructure.

The study consists in carrying out a geo-localized database that inventory the fauna passages (effective and potential) on French transport infrastructure networks in order to locate all crossing structures. This database will also contain information about their characteristics, which are used to identify the type of fauna passage, according to the French typology drawn up by the Scientific and Technical network – RST (SETRA-MEDD, 1993 and 2005).

The present paper describe the first bibliographical stage conducted on a pilot area - Nord-Pas-de-Calais and Picardie regions - who presented the most exhaustive data. The inventory, which began in 2006, has given a good picture of the transparency of the infrastructures, and have highlighted the difficulties to obtain reliable data.

The motorway concessionary operator, for instance SANEF was contacted during autumn 2006. Very exhaustive data on wildlife-specific passages were collected and supplemented with data on hydraulic passages as suitable structures for fauna crossing. The CETE survey, conducted at the end of 2006 did not provided enough data as a result of the new organization of management of the national road network (decentralization and reorganization of public authorities in charge). Data on the railway network was obtained solely from bibliographical sources. Supplements from RFF and SNCF should be provided shortly.

The available results of our inventory of fauna passages have given an overview of the quality of data, the pertinence of the typology of passages and showed the necessary readjustments to give a reliable inventory of transparency structures.

This work reveals the facility to obtain detailed characteristics on the specialized fauna passages but the inventory of other structures remains complex. The general approach to evaluate the transparency of the infrastructures must be carried on and extended. Indeed, monitoring is currently limited to specific passages, while other facilities (viaducts, hydraulic structures) offer real potential for wildlife crossing. On the other hand, non-specialized structures can be adapted to increase the probability to be used by animals. Thus, 150 hydraulic structures and 93 mixed structures could be modified in the pilot region.

The inventory have also showed that additional field data should be collected, in particular to define the effectiveness of the passages or to set up monitoring systems. In addition, it appears necessary to clearly identify local correspondents that would provide comparable information usable by all the various organisations in charge. The personnel in charge of managing the national road network will update in situ the future-computing tool. It will require the development of a software interface compatible with existing systems (concessionary system; national road network management system), which allow the addition of a fauna passage's parameters.

The first typology applied to mixed structures has shown the difficulties to make the classification due to the lack of precision of the available data. There remain some difficulties in distinguishing certain structures: distinction between the sub-types of mixed hydraulic passages (type III), or distinction between types IIId (hydraulic passage with extra widening of bank) and VII (viaducts). So, we have fixed a maximum width limit of 25 meters for type-IIId passage and grouped all the hydraulic passages in the generic class III (150 units concerned).

This first step of the project was based on inventories of potential crossing structures and on wildlife-specific passage monitoring. The subsequent steps will be extended to all structures that should enable us to confirm the benefits of non-specific structures (mainly hydraulic) for wildlife.

**Preliminary questions that should be clarified**

Some preliminary questions summarized in recent SETRA and CETE report (2006) still need to be clarified in this initial stage of the inventory process.

*What objectives for fauna passage?*

The question is how the fauna passage and other potential crossing structures are used. They must be used for daily crossings (frequent go back and forth), or only for occasional crossings of a few individuals.

*What is the minimum rate of use to be considered effective?*

To answer this question, we should first clarify the purpose of the structure. The objective of frequentation can be very low with only few animals crossing during the year, or more ambitious with a daily crossing. The definition of the level of effectiveness is therefore a delicate practise. Moreover, we have noted a technical limit of the monitoring tools; the recent development of video- or photo-surveillance systems could answer such questions.

*Passages for which species?*

Ungulates (stags, roe deer and wild boar) are usually chosen as target species for fauna passages. But these species are among the less vulnerable species, colonise a large area and some of them are even growing rapidly (wild boar and roe deer). Passages built for large fauna are clearly a suitable measure; however the transparency should be extended to all groups of fauna. In this new approach, the recommendations and methods established ten years ago for ungulates remain valid and should be expanded.

*Frequency of passages?*

The decision of the number of passages required remains a major question in planning measures. It depends on the behaviour of species (covering great distances or smaller areas).

For small fauna, one passage every 300 metres is recommended (catchment area is at most 200-300 m). However, their vulnerability and the type of area can reduce this interval up to 30 metres. The probability of joint-use of agricultural, forestry or hydraulic structures must be assessed, particularly for small fauna. For large fauna, in woodland or highly diversified landscape, a crossing passage must be available every 2 kilometres. This may appear a costly measure, but this additional cost can become acceptable when existing structures (forestry and hydraulic structures), which can effectively replace the overpass and limit their construction. It is recommended to prefer existing structures and improve their attractiveness for fauna, less costly than specific passages.

**Acknowledgements:** We would like to thank the environmental engineers Agnieszka Bugajska-Rouzeau (SANEF), Jean Noël Saussol (CETE) and Jean Carsignol (CETE) who have participate to this work. Agnieszka Bugajska-Rouzeau who provide data on conceded-motorways, Jean Noël Saussol who have surveyed national roads, and Jean Carsignol (CETE) who contributed to this paper by his experiences on fauna passages.

## References

CETE Est, SETRA and COST 341. 2001. Fragmentation de l'habitat due aux infrastructures de transports. Rapport de la France. (Habitat fragmentation due to transport infrastructures. Report from France). 170 pp.

CETE Nord-Picardie and USTL. 1999. Les corridors biologiques liés aux problèmes de la fragmentation des espaces et des milieux naturels (tome 1). (Biological corridors and landscape fragmentation (vol. 1)). 85 pp.

CETE Nord-Picardie and USTL. 2001. Les corridors biologiques liés aux problèmes de la fragmentation des espaces et des milieux naturels (tome 2). (Biological corridors and landscape fragmentation (vol. 2)). 45 pp.

MTETM. 2005. Stratégie Nationale pour la Biodiversité. Plan d'action infrastructures de transports terrestres. Novembre 2005. (French Strategy for Biodiversity. Action plan for linear infrastructures (roads, railroads, navigable waterways). November 2005.). 19 pp.

SETRA and MEDD. 1993. Passages pour la grande faune (Passages for large mammals). 121 pp.

SETRA. 1996. Instruction, Prise en compte de l'environnement et du paysage dans les projets routiers. (Recommendations and factoring environment and landscape into road infrastructure project). 61 p.

SETRA and MEDD. 2005. Aménagements et mesures pour la petite faune (Facilities and measures for small fauna). 264 p.

SETRA and CETE Est. 2006. Route et passage à faune. 40 ans d'évolution. Rapport. (Roads and fauna passages. 40 years of change. Report). 57 p.

DIREN Picardie. 1997. Inventaire des passages à faune en Picardie (Inventory of fauna passages in Picardie). 140 p.

Iuell, B., Bekker, G.J., Cuperus, R., Dufek, J., Fry, G., Hicks, C., Hlaváč, V., Keller, V.B., Rosell, C., Sangwine, T., Tørsløv, N., and B. le Maire Wandall. 2003. Cost 341 - Habitat fragmentation due to Transportation Infrastructure. Wildlife and traffic. A European Handbook for identifying Conflicts and designing solutions. 20 p.

Cramer, P.C. and J.A. Bissonette. 2005. Wildlife crossing in North America: The state of the science and practice. In Proceedings of the 2005 International Conference on Ecology and Transportation 9: 442-447.

ONCFS. 2005. Réseau ongulés sauvages (Wild ungulate network). Newsletter 10. 11 pp.

VNF. 2004. Statistiques de la navigation intérieure (Inland navigation statistics) 2004. CD-Rom.

# Measuring the Success of Wildlife Linkage Efforts

**Christopher Servheen** (406-243-4903, chris_servheen@fws.gov), Grizzly Bear Recovery Coordinator, U.S. Fish and Wildlife Service and College of Forestry and Conservation, University of Montana, University Hall, Room 309, Missoula, MT 59812 USA

**Rebecca Shoemaker**, College of Forestry and Conservation, University of Montana, Missoula, MT 59812 USA

**Pat Basting**, Montana Department of Transportation, Missoula, MT 59801 USA

**Abstract:** Successful movement of wildlife across highways to effectively provide population-level wildlife linkage is usually viewed in one dimension - movement either exists or it does not. We believe that there are multiple ways to measure both the existence and value of such movement opportunities to better demonstrate success or failure of these efforts. The use of multiple methods to measure success will provide quantitative and qualitative values that can be used to better judge the effectiveness of wildlife movement across highways and to justify investment in the infrastructure to create such movement. Currently, many transportation agency administrators view investments in wildlife crossing infrastructure as outside their responsibility and as fiscal competition for highway projects of greater value to the traveling public. We believe this is a false paradigm that can be changed by enhanced measures of the values of wildlife highways crossing enhancement. Measures of success should include a wide range of factors that transcend wildlife issues. These factors should include biological impacts; economic impacts on highways, public lands, and private lands; public safety measures; social influences and acceptance; and political factors. Biological measures of success should include wildlife movement, gene flow measures, seasonal range access and dispersal opportunity, potential for re-occupancy of historic habitat, reduction in population isolation, effects on endangered species listing and management, and mortality reduction. Economic successes should include improved project planning efficiency, reductions in project time delays, reduced environmental review and court challenge costs, and improved land values adjacent to linkage areas due to healthy wildlife populations. Public safety measures should include road kill reduction, reduced probability of accidents and human injury, and improved speed limits. Social measures should include attitude surveys measuring public willingness to invest public funds to reduce wildlife collisions, public acceptance of the concept of linkage zones, and public awareness of the multiple benefits of wildlife population connectivity. Political measures should include measuring the knowledge and understanding of this issue by political interests, their willingness to appropriate funding for such projects, and legislation. We review the application of each of these measures of success to wildlife crossing enhancement and suggest a basic measurement approach to all wildlife crossing efforts. In the long term, successful wildlife linkage efforts associated with highways will require improved public understanding and support, improved agency willingness to accept wildlife crossings as part of their responsibility, and improved understanding of the multiple values and benefits that come from enhancing wildlife movement across highways.

## Introduction

The objectives of wildlife linkage efforts are to maintain or restore connectivity in wildlife populations. There are many biological factors to assess success of such efforts. These include measuring and monitoring individual movements, genetic flow, population range, and levels of wildlife mortality and conflicts within linkage areas. We cannot define success though without a consensus on the definition of connectivity. We can define connectivity as "…a measure of the ability of organisms to move among separated patches of suitable habitat" (Hilty et al. 2006:50), although the word "separated" in this definition presupposes that these patches of habitat are somehow disconnected. In natural systems where human activities are non-existent, most patches of habitat of value to species are contiguous and connected. Human linear transportation corridors such as highways and railroads, and the resulting human developments along such transportation corridors are the root cause of habitat and population fragmentation and the disconnection between habitat patches.

Most concerns about the impacts of highways and railroads and other linear human features on wildlife populations and ecological systems are related to the biological impacts of such features. As such, measures of success for efforts to enhance connectivity and reduce direct mortality are usually biological in nature. For example: does connectivity for wildlife and natural systems exist and to what extent; is mortality related to these linear features occurring and if so how much? For transportation agencies and corporations such as railroads, biological performance measures are usually viewed as being outside the scope of their authority and/or responsibilities. However, solutions to fragmentation and mortality due to linear transportation features lie with these agencies and corporations. If transportation systems are to be made more permeable to wildlife and mortality along highways and railroads is to be reduced, these agencies and corporations must invest in structures and other systems to increase successful movement. Therefore, anything that can more successfully translate the importance and value of investments in enhancing wildlife connectivity into the performance measures that resonate with transportation agencies and railroads will make such investments more likely. Marketing the need and value of such investments will be more successful by including comprehensive measures of success and performance of these investments beyond strictly biological measures. Efforts to expand measurement of success beyond biological measures will also improve agency, corporate, and public understanding of the benefits of connectivity and linkage efforts.

Linkage efforts across linear transportation features should include measures of success relating to multiple factors including biological measures at the population and ecosystem scale; economic measures at both the individual traveler scale as well as the community and agency/corporate scale; public safety measures at the individual traveler scale as well and the agency/corporate scale; social measures of acceptance and benefits to human quality of life; and political measures of acceptance and measurement of the political will to invest in such efforts and to support sometimes costly measures required for linkage across the landscape. Of these measures, biological, economic, and public safety measures of success are quantitative in nature and can be directly measured with appropriate numerical approaches. These quantitative measures are by their nature objective and easily comparable temporally and spatially within and between linkage efforts. However, social and political successes are qualitative in nature and their measurement is much more subjective. This does not make social and political measures of success any less important, but it does make measurement more difficult, less comparable temporally and spatially and subject to interpretation.

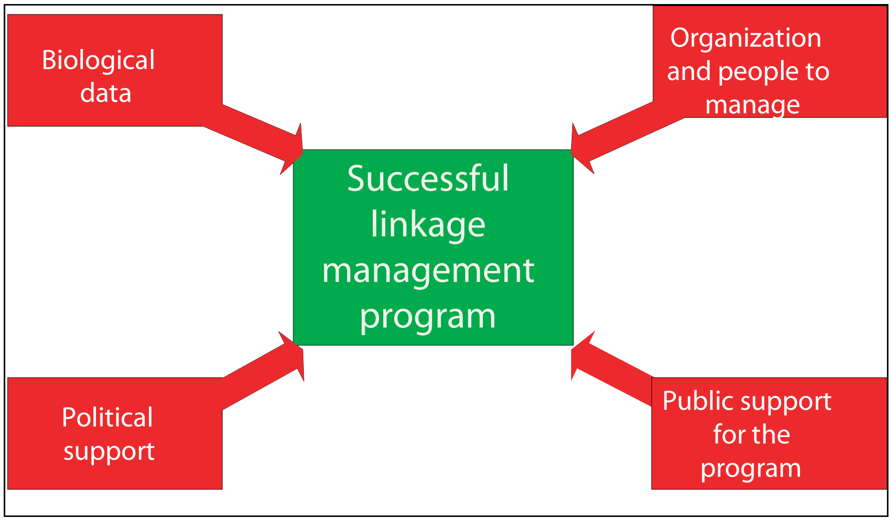



Figure 1. The four factors necessary for a successful linkage management program.

## Biological Measures of Success

Wildlife linkage and connectivity efforts are traditionally discussed within the context of biological success.  The need to maintain connectivity, after all, is rooted in biological concepts such as island biogeography and metapopulation theory.  These theories provide managers and researchers the impetus to consider connectivity in natural resource management decisions.  A successful wildlife linkage program requires information on four key issues: why crossing structures and resulting wildlife movement are needed; where the best locations are to maximize the benefits of linkage investments; the optimum design considerations of each linkage investment; and a description of the desired results expected to be achieved by the linkage investment at the population scale and at the ecosystem function scale. The question of why crossing or movement mitigation efforts are necessary is essentially the problem statement described in biological terms.  Locations for structures or movement mitigation effort are the stratification of the area to identify the locations of greatest biological impact and importance.  The design considerations are the specifics that the highway designer or land manager or land conservation group needs in terms of shape, length, location, and area size to meet the needs of the issue or species of concern.  Finally, and perhaps most importantly, there needs to be a detailed description of the expected results of the linkage investment. This description should be at both the population level for the species or groups of species of concern in the area, as well as the ecosystem level for functions that are expected to be restored or maintained as a result of the linkage investment.

Population-level expected results might be described in terms of sex-specific movements for reproduction or dispersal of young or continued occupancy and reproduction throughout a species' historic range.  Ecosystem function might be the expected multi-species predator/prey dynamics, or food web maintenance, or movement to and from seasonally important habitats, or access to habitats in response to climate change, or the need for range changes due to catastrophe such as wildfire.  The explicit description of the expected results of the linkage investment is important as it provides the benchmarks with which to design monitoring systems to judge the ecological success of the investment Without such clear definitions of success, there will be no clear measures available to demonstrate the biological importance of the linkage investment or justify the linkage investment.

A fundamental consideration when assessing movements and impediments to movements is the issue of scale. What might be a significant impediment to a small mammal such as a mouse or a vole may have no impact on larger mammals. Then there is the issue of individual level effects versus population or ecosystem level effects. For our purposes of measuring the success of wildlife linkage we will concentrate on the population and ecosystem scales. We will consider linkage efforts across linear human transportation features successful biologically at the population scale if they maintain and enhance the demographic and genetic viability of populations. We will consider linkage efforts across linear human transportation features successful biologically at the ecosystem scale if these actions enhance ecosystem function in terms of dispersal, historical connectivity, access to seasonal habitats and movement patterns, and maintain opportunities for metapopulation function between presently disjunct blocks of habitat.

The most intuitive measure of success regarding wildlife linkage efforts involves assessing whether individual animals are successfully moving across the landscape among public lands, private lands, and potential barriers or filters to movement such as highways and railroads. Using traditional radio-telemetry or more modern GPS radio-collars allows insight into individual movements. Movement data from individuals may be used to assess population-level movement patterns, overall population health, and ecosystem function. Such studies can provide evidence of population connectivity by demonstrating sex-specific movement across the landscape, dispersal success, and use of important seasonal habitats. The movements of females of some species like bears are sometimes more sensitive to potential barriers while males still navigate a landscape relatively unimpeded (Procter et al. 2005). Therefore, female use of a linkage area that traverses a potential barrier such as a highway or railroad may be considered the ultimate measure of biological success for certain species at the population scale. Biological success may be defined differently based on the objectives associated with individual projects and efforts. Some managers may consider a wildlife linkage effort a success if dispersal opportunities for individuals across the landscape are maintained. In fragmented ecosystems, inter-population dispersal, or connectivity, of both sexes may be important for population augmentation, rescue, or recolonization within natural (Hanski and Gilpin 1997) and human-caused (McCullough 1996) metapopulations. Because dispersal of young allows for genetic interchange, demographic rescue colonization of new habitats, and/or replenishment of sink habitats, it is an important biological measure of population connectivity and resilience. Seasonally important habitats are also a vital component of population connectivity because they may be required to access breeding grounds, calving grounds, migratory ranges, or seasonally available food and water. Long-term studies of individual movements can provide many population-level statistics regarding connectivity at both a local and landscape scale.

Genetic fragmentation is one of the primary concerns driving natural resource managers to maintain and reestablish connectivity in human-dominated landscapes. As populations become genetically isolated, they are increasingly vulnerable to losses in genetic diversity (due to genetic drift and inbreeding depression), disease, stochasticity, and extinction. Genetic factors are functional and quantitative measures of whether wildlife linkage efforts have been successful. Genetic measures of movement can be obtained non-invasively and are relatively conclusive when compared to other methods of data collection. Identifying individual animals can provide information on how far animals are moving, whether animals are using certain areas, and if genetic fragmentation is occurring. By establishing a grid system sampling design, individual animals may be detected at multiple locations. Such a grid sampling system can document genetic movement across an area over time but does not provide information about the actual movement locations or patterns. Non-invasive genetic sampling can also be used to establish the presence of animals in an area. Finally, genetic signatures can document the level of genetic fragmentation, or genetic distance, and immigration through assignment testing (Proctor et al. 2005 ) Genetic assignment testing can identify the proportional levels of interchange across barriers, where individual animals originated from, and comparative rates of movement or connectivity between different linkage areas and between different time periods in the same area.

The overall range and distribution of a population is also a good measure of success at the landscape scale. While presence of a species is indication of some level of movement, species persistence requires the presence of reproductive females and successful reproduction. This type of statistic can verify re-occupancy of currently unoccupied historical habitat, re-connection of isolated populations, and responses to environmental change such as global climate change. However, this type of measurement will vary depending on how the distribution is calculated. Presence and sex of animals can be documented by hair capture and DNA analysis (Woods et al. 1999; Taberlet et al. 1999), while documentation of reproduction is best documented by radio monitoring.

Preventing human/wildlife conflicts and human-caused mortality is essential to successful wildlife linkage efforts. As wildlife are forced to move through landscapes that are surrounded, occupied, and used by humans, the potential for conflicts and subsequent wildlife mortality increases. This mortality can come in many forms, including poaching, management removals, legal hunting, and animal-vehicle collisions. Because a successful wildlife linkage area has mortality risk equal to or lower than adjacent suitable habitat patches, quantifying wildlife conflicts and mortality before and after linkage efforts are implemented is a valuable way to measure success of those efforts. One way to measure successful linkage areas will require long-term monitoring of differential mortality of animals that use linkage areas versus those that do not use linkage areas. Another measure of success that is straight-forward is to analyze conflict and mortality data before and after linkage efforts are implemented. Analyzing proportions of populations that cross linear human feature and the number of animal-vehicle collisions before and after mitigation measures is also a useful tool to examine the success of linkage efforts in relation to wildlife mortality (Hardy et al. 2007).

Documentation of the biological success of wildlife linkage efforts is usually expensive and time-consuming to assess with certainty. To judge the success of a linkage area, we need to know not only the number of animals using the mitigation measure, but also the proportion of the population of animals in the area that use the linkage zone successfully. Measurement of proportional use requires having a representative sample of the local population marked and documenting the proportion of these marked animals moving between habitat units. Individual animals can be marked through physical markers (e.g., radio-collars, ear tags, etc.) or genetic analysis. To make valid inferences and conclusions, biological responses to wildlife linkage efforts must be measured for long periods of time and possibly at multiple times in the future (Clevenger and Waltho 2003, Hardy et al. 2007). Long-term studies reduce the chances that environmental stochasticity explains the variation observed more than the mitigation measures. However, more simplistic approaches such as comparing before and after animal-vehicle collision data or documenting presence in or use of an area using passive-infrared cameras may be adequate depending on specific objectives.

Defining success with these measurements of biological factors will vary based on objectives. Because effectiveness is ultimately tied to values (e.g., personal, agency, group, cultural, etc.), there is no single value that determines success. Instead, raw data must be documented and people/agencies can determine for themselves if measures are effective. An animal lover may view crossing structures as effective if animal-vehicle collisions are reduced at any level. A biologist may view a reduction in animal-vehicle collisions as effective if the number of animals is biologically significant to the surrounding local population. Similarly, a Transportation Department official may view a reduction in animal-vehicle collisions as successful if the cost of the structure is less than the monetary value saved in insurance claims, medical bills, hunting fees, etc. as a result of that reduction. Even within the scientific community, there is room for interpretation. For instance, genetic connectivity may be achieved with only 1 or 2 effective migrants per generation but some wildlife managers would argue that population connectivity requires more movement than that to be considered successful.

- Movement across the landscape
- Gene flow (no differences in genetics across barriers)
- Seasonal range access
- Dispersal success
- Female movement
- Access to range expansion needs in response to climate change
- Reoccupacy of historic but unoccupied range
- Reconnection of isolated populations
- Access to resources such as water or food
- Sustainable mortality in linkage areas
- Reduction in wildlife/human conflicts in linkage areas


- Movement across the landscape
- Gene flow (no differences in genetics across barriers)
- Seasonal range access
- Dispersal success
- Female movement
- Access to range expansion needs in response to climate change
- Reoccupacy of historic but unoccupied range
- Reconnection of isolated populations
- Access to resources such as water or food
- Sustainable mortality in linkage areas
- Reduction in wildlife/human conflicts in linkage areas


Figure 2. Examples of direct measures of biological linkage success.

## **Economic Measures of Success**

Quantifying the economic benefits associated with wildlife linkage efforts is difficult because many of these are indirect. For example, addressing wildlife linkage needs in the planning stages of highway construction or reconstruction may lead to road or bridge designs that do not have to be renovated in the future. But how do you quantify this hypothetical financial savings? Other potential economic benefits associated with successful wildlife linkage efforts may be in the form of ecological services such as clean water, clean air, and healthy soil communities. Because many of these ecological services are difficult to link directly with specific wildlife linkage efforts, for the purposes of this paper, we review and examine direct economic benefits associated with successful wildlife linkage efforts.

The economic costs and benefits associated with wildlife linkage efforts are distributed among highway departments, public natural resource management agencies, private landowners, and private citizens. A cost-benefit analysis is a common tool used to quantify the potential impacts of a policy or decision in economic terms (Nunes et al. 2003). A cost-benefit analysis, in theory, includes all costs and benefits associated with a particular decision (Bateman et al. 2003). In general, if the benefits are greater than the costs, the policy or decision is a good economic choice.

The most direct way in which highway departments contribute to wildlife linkage efforts is through the installation of wildlife crossing structures. The goal of such structures is to get animals across the highway safely to reduce (or eliminate) animal-vehicle collisions. Hardy et al. (2007) present a method similar to a cost-benefits analysis for evaluating the effectiveness of highway mitigation measures along Hwy. 93 in Montana. They compare the costs of property damage, human injuries, human fatalities, deer fatalities, and removal of deer carcasses to the costs of constructing wildlife crossing structures and fencing (Hardy et al. 2007). This allows transportation departments to know how long it will take under varying scenarios of reductions in animal-vehicle collisions to result in a cost-effective decision. Hardy et al. (2007) found that crossing structures built along a 46 mile section of Hwy. 93 in Montana would pay for themselves in 10 years if a 90% reduction in animal-vehicle collisions was achieved or in 25 years if a 35% reduction in animal-vehicle collisions was attained. Given that the average life span of a wildlife crossing structure is roughly 75 years, highway departments can monitor reductions in animal-vehicle collisions with a clear objective of what economic success is.

Highway crossing structures provide economic benefits to the average citizen in the form of increased driver safety. The estimated cost in property damage caused by a deer-vehicle collision is $1,840 (Hardy et al. 2007). If human injuries are sustained, the cost of these injuries ranges from $10,000 (Wu 1998) to $206,000 (U.S. Department of Transportation 2002), depending on the severity of the injuries. Finally, the estimated monetary value of a human life ranges from $1,500,000 (Romin and Bissonette 1996) to $3,600,000 (Trawen et al. 2002) with estimates by Schwabe et al. (2002), and the U.S. Department of Transportation (2002) between these two values. Although the percentage of deer-vehicle collisions resulting in human mortalities is roughly 0.5%, this is a significant cost to consider, especially since many would argue that the worth of a human life is beyond quantification.

Public natural resource management agencies stand to benefit from wildlife linkage efforts in a number of economic ways. As planning becomes more interdisciplinary in scope, the conservation of wildlife linkage areas should lead to reduced environmental review and court challenge of land management decisions. By addressing ecological issues related to linkage at the planning stages of a project rather than at the end of the process, natural resource managers will achieve improved efficiency in project planning with minimal biological evaluation delays.

For private landowners, the economic benefits of wildlife linkage efforts are primarily manifest in increased property values and tax incentives. According to some reports, the proximity to open spaces and parks in urban areas can account for 15-20% of a property's value (National Association of Homebuilders 2002). This increase in property values occurs due to the perceived value of adjacent landscapes and native wildlife to wildlife linkage areas and the idea that for many people, location and proximity to recreational opportunities (i.e., open space) is an important factor determining where they buy houses (National Association of Homebuilders 2002). As landowners place parcels of their private property in conservation easements, they may also benefit from improved estate planning and tax incentives provided by federal and state governments.

## Public Safety Issues: The Scope of the Problem

Montana, along with most of the Rocky Mountain States, has unique problems in traffic safety. The Rocky Mountain States tend to have high numbers of roadway departure fatalities. A high percentage of miles traveled are at high speeds compared to more urban states, thus increasing the likelihood of fatal or incapacitating injury crashes. The makeup of the vehicle population is also different in the Rocky Mountain States. The percentage of registered pickups, SUV's and vans is very high in Montana as are fatal crashes involving these vehicle types. Factors such as long trips on rural roads, high travel speeds, lack of seat belt use, and a higher proportion of SUV's and pickups, push fatality rates upward in Montana and the surrounding states. These factors are much of the reason that states in the Rocky Mountain region show high fatality rates (MDT 2006).

There are several exposure statistics in the area of traffic safety. These include number and type of vehicles, number of licensed drivers by age and gender, physical road miles, population, and the number of vehicle miles driven. Vehicle Miles Traveled (VMT) is the exposure number that appears to have the greatest influence on the amount of traffic crashes that occur in Montana (MDT 2006). Annual VMT numbers have greatly increased over the past few decades. Changes in VMT over time are shown in figure 3.

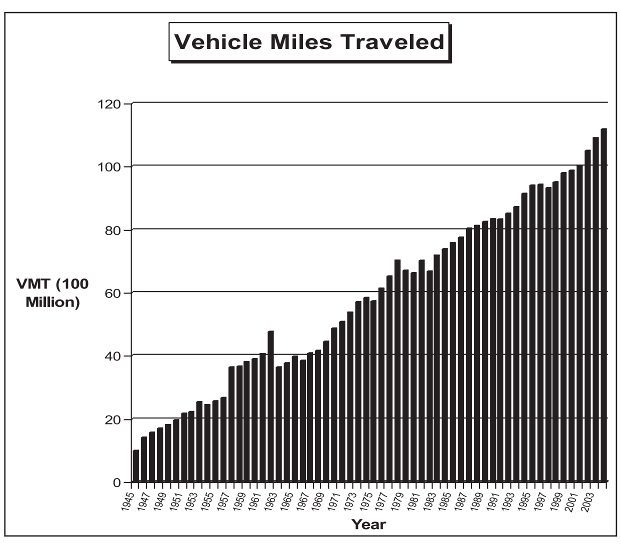



Figure 3. Vehicle miles traveled (VMT) in Montana 1945-2005. (MDT 2006).

### Collisions With Wild Animals or Avoidance

During the twenty year period from 1984 to 2003, the number of reported crashes involving wild animals increased from 468 to 2,012. The key word is "reported", since many animal crashes are not reported. The long-term trend in animal-vehicle collisions is shown in figure 4.

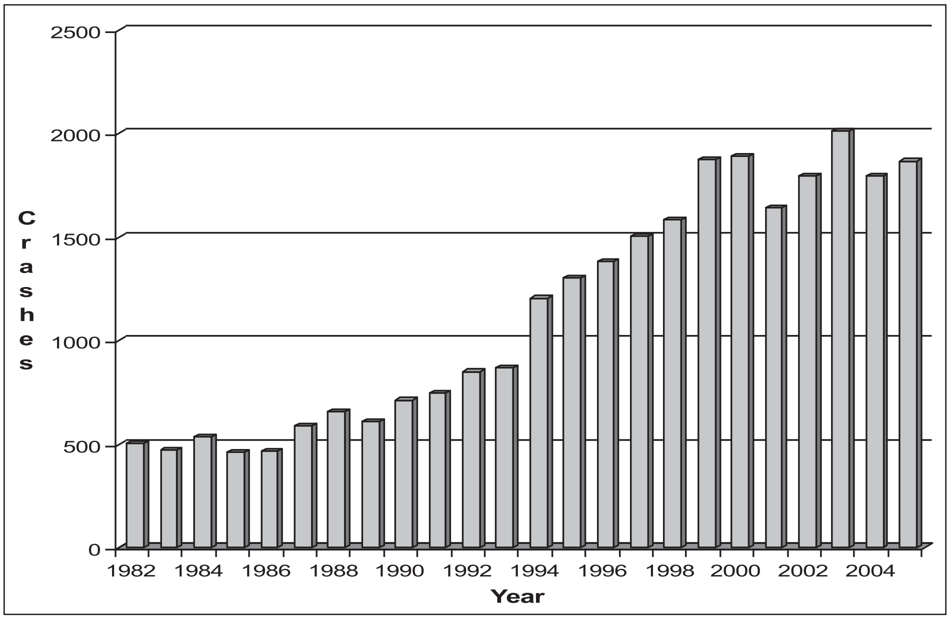



Figure 4. Reported animal-vehicle collisions in Montana, 1982-2005.

The Montana Department of Transportation keeps a database, which accounts for wild animals that are picked up off the roadways by the Maintenance Division. The assumption that these carcasses were the result of collision with motor vehicles would seem valid. This count of carcasses provides another estimate of the number of wild animal crashes. These numbers are from three to four times higher than reported crashes (MDT 2006).

Vehicle Miles Traveled (VMT) is the exposure number that appears to have the greatest influence on the amount of traffic crashes that occur in Montana. Note the rates of increase in VMT since 1982 and the number of reported accidents with wild animals over the same time period. Purely in numbers VMT from 1982 through 2004 has increased 40%. Reported wild-animal vehicle collisions during the same time period from 1982 through 2004 has increased by 72%. Also, in the Rocky Mountain States, a high percentage of miles traveled are at high speeds compared to more urban states, thus increasing the likelihood of incapacitating injury or fatal crashes; while at the same time, speed, and its reciprocal travel time, is an important measure of the quality of traffic service provided to the motorist. It is used as an important measure of effectiveness to define levels of service for many types of facilities, such as rural two-lane highways, arterials, and freeway weaving sections (ITE 1999). Speed appears to be one of the primary factors influencing numbers of animal vehicle collisions. According to Gunther et al. (1998), vehicle speed appears to be the most significant factor influencing the frequency of animal-vehicle collisions in Yellowstone National Park. Animal-vehicle collisions in Yellowstone Park occur much more frequently on straighter, wider roads where vehicles traveled faster, regardless of posted speed limits.

Recent research suggests that while the total number of all types of vehicle crashes per year in the United States has remained relatively stable, nationwide animal-vehicle collisions have steadily increased by about 50% between 1990 and 2004 (Huijser et.al. in prep). In the Rocky Mountain States, given the combination of: increasing human populations; increasing vehicle miles traveled; high vehicle speeds; high number of rural roads; stable to increasing wildlife populations; current predominant mode of new construction and reconstruction of roadways not incorporating wildlife mitigation; and wider road surfaces wildlife have to cross, the likelihood that there will be an increasing trend of animal vehicle collisions well into the future seems valid.

### Measuring Success Relative to Public Safety

Determinations of effectiveness or success of wildlife crossing mitigation can be measured on human safety values. For example, although monetary values have been placed on human life (Sielecki 2004, Schwabe et al. 2002, U.S. Department of Transportation 2002, Romin and Bissonette 1996), many would argue that a human life is priceless especially to the one who loses it. While it is possible to present measures of effectiveness, effectiveness is ultimately determined by an individual's or agency's values (Hardy et al. 2007).

The overall objective of wildlife mitigation measures is to increase the permeability of a transportation corridor to wildlife movement. Success reduces barrier effects and usually reduces road-kills (Forman et al. 2003). State departments of transportation (DOT's) that have incorporated wildlife mitigation such as crossing structures, wildlife fencing, and wildlife jump-outs, have not always developed clearly defined goals and objectives relating specifically to planned or desired percent reductions in animal vehicle collisions. Therefore, it seems reasonable that in order to assist administrators in defending and justifying expenditures for transportation improvement projects that incorporate wildlife mitigation measures, traffic safety engineers, biologists, researchers, and the public should work to develop common goals and objectives regarding expectations of reductions in animal vehicle collisions associated with various wildlife mitigation measures. Such a process could allow DOTs to compute a cost-benefit analysis of projects to improve safety and permeability.

Cost-benefit analysis has increasingly commanded the attention of professional engineers, government administrators and the judicial system. Criteria have been developed to evaluate public investments in the field of traffic safety (MDT 2007). The concept behind a planned benefit is:

1. The total economic loss as a result of traffic crashes at a specific location is determined by the severity of injuries and the number of crashes; and
2. Specific improvements will yield reductions in traffic crashes.

We believe that the existing formulas used for Safety Engineering Improvement Programs by state DOTs can be used or modified to evaluate projects that incorporate either spot improvements or roadway reconstruction projects that incorporate wildlife amenities.

In the Montana Safety Engineering Improvement Program, fatal and injury accident calculations are combined into a single quotient called "Q"; this complies with FHWA Technical Advisory T 7570.1 (June 30, 1988), Recommended Accident Costs (MDT, 2007). "Q" is used because fatality figures are relatively small and a matter of chance. The State of Montana combines fatal and injury totals to reduce the possibility of selecting an improvement project on the basis of chance. The ratio of injuries to fatalities will vary depending on the general class of locations under study. For example, the ratio for rural secondary roadways is different than the ratio for rural freeways (MDT 2007).

Since "Q" has been defined and fatalities and injuries can be combined, the initial Planned Annual Benefit Formula can be stated, (For purposes of this paper consider applying Animal Vehicle Collision Data into the formula):

Planned Annual Benefit (in dollars) = Q (Afi)Pfi + Cpd (Apd)Ppd

Where:

- Q = average cost per fatal and injury combined
- Afi = average number of annual fatalities or injuries combined
- Pfi = expected percent reduction in fatalities or injuries
- Apd = average annual property damage only accidents
- Cpd = cost per property damage only accidents
- Ppd = expected percent reduction in property damage only accidents

To account for changes in traffic volumes over time, the ratio of the projected annual average daily traffic after improvement to the annual average daily traffic before improvement is computed as follows:

$$\frac{ADT_a}{ADT_b} = \frac{(1.03)^L + 1}{(1.03)^{-S} + 1}$$

- L = number of years for life of the project
- S = number of years of crash records used in analysis

This formula accounts for an average annual traffic growth rate of 3 percent. The expected benefit formula now becomes:

$$B = \frac{ADT_a}{ADT_b} [Q\ (Afi)Pfi + Cpd\ (Apd)Ppd]$$

- B = expected Annual Benefit (in dollars)
- ADTa = projected Average Daily Traffic after improvement
- ADTb = Average Daily Traffic before improvement

This now becomes the working formula for planned benefit. For the expected percent reductions (Pfi and Ppd), the expected reductions are determined by several means. However, they are stated as specific objectives for the project under consideration and are derived from:

1. Actual experience with similar projects in other states.
2. Actual experience with similar projects in Montana.
3. Expert judgment or experience.
4. A combination of the above.

In order to calculate a projected Planned Cost:

1. The construction cost of each proposed improvement alternative must be readily calculated.
2. The increased cost of maintenance and operations must be established.

The formula for capital recovery factor is:

$$K = \frac{R(1 + R)^T}{(1 + R)^T - 1}$$

- R = Compounded interest rate
- T = Estimated service life

With the capital recovery factor explained, the formula for annual cost is:

Annual Cost = [C(K)] + M

- C = Capital costs
- K = Capital recovery factor
- M = Change in annual maintenance operations costs

Thus, the benefit – cost ratio becomes:

$$\frac{\text{Benefit}}{\text{Cost}} = \frac{\frac{ADT_a}{ADT_b}[Q\,(Afi)Pfi + Cpd\,(Apd)Ppd]}{[C(K)] + M}$$

The formula above is used for the Traffic Safety Improvement Program and is typically applied to spot improvements over a 0.5 mile segment of roadway. We believe this formula can be used with a broader application when evaluating reconstruction projects that incorporate wildlife mitigation measures.

There are many factors that go into decision making when considering expenditure of public money for transportation related improvement projects. Cost-benefit analysis is only one of them. What this formula does is give an administrator a ratio of the expected or planned benefit in dollars versus the cost in dollars spent. This will also shift the mode of thinking that wildlife mitigation is an add-on cost to the project. By including wildlife mitigation measures into the planning and cost-benefit analysis, transportation agencies will be addressing safety as part of a comprehensive approach through incorporation of goals and objectives that clearly lay out targets for cumulative safety benefits throughout a reconstruction project.

Obviously, relative to wildlife vehicle collisions this formula does not take into account biological benefits, or social or political aspects. It should not be viewed in seclusion but part of the larger picture recognizing that departments of transportation can really only effectively control what happens within the highway right of way limits. Confounding variables outside of the highway right of way (land management, land use changes, land use laws (i.e. zoning), game management, re-colonization of predator species) and outside of the control of DOTs can and will influence how much use wildlife crossing structures receive and by which species. However, application of this method would give transportation decision makers another tool to consider when prioritizing projects. As many states work towards mapping linkage areas, obviously there is not enough funding to address all needs. Better tools are needed to assist in prioritizing projects. This approach could help define desired or planned goals and objectives while laying the ground work for comparison of pre- and post- treatment accident analysis.

This leads us back to the precept that success relative to wildlife mitigation measures will be dependent upon how well people work together regarding management and development of public lands, private lands, wildlife populations, and transportation corridors. It requires bigger picture thinking, broader perspectives and people working together. It is hoped that this paper will provoke thought and discussion in order to clearly and adequately define goals and objectives when planning, designing and implementing wildlife amenities into transportation projects and appropriate methods to measure their success.

## Social Values Involved in Maintaining Wildlife Linkage Zones and Measures of Success

Social values associated with maintaining wildlife linkage zones are similar to those attributed to the necessity of maintaining wilderness areas, open space within our communities, and diverse wildlife populations. There is an inherent value to these conservation efforts, but it is difficult to quantify comprehensive social values of such efforts because social values drive economic decisions and political legislation. Thus, social values are inextricably intertwined with economic and political policies and the decisions society makes.

Historically, public natural resource managers have been conditioned to respond to values expressed by political and social systems that were very sensitive to the economic values derived from resource use and development. Laws or budgets are political system expressions of natural resource values. Wild land use, license sales, effectiveness of nongame wildlife contributions on state tax forms, or newspaper editorials are primarily social system expressions of natural resource values. Of course these values are rarely expressed solely through one system. For example, an Audubon chapter (in the social system) may lobby a state legislature (political system), obtain financial endorsement of corporations (economic system), and encourage its members to write legislators (social and political systems) to increase a state's non-game management budget (Kennedy and Thomas 1995). Yet today, the economic system is of increasing importance in expressing wildlife values (Kennedy and Thomas 1995). This is reflected in landowner payments for participation in block management hunting programs, wildlife viewing tours, auctioning of trophy big game permits and the outfitting industry providing guided hunts to name just a few. A half century after Leopold and others proposed economic inducements for landowners, their profession and state agencies increasingly are supporting this policy. As in the past, most American wildlife values are still expressed socially and politically through examples such as state and federal laws guiding game and non-game management, stream restoration and wetland restoration projects that restore wildlife values to enhance or diminish others (Kennedy and Thomas 1995).

Some of the more common attributes related to humans that can be associated with linkage zones are quality of life, ethical and moral considerations, recreational values, economic values, and those social values associated with reducing the potential for state or federal intervention while relying more on local initiatives and local land use decision making. A value that is seldom discussed but will be touched upon here is associated with local groups taking action regarding identification and mapping of linkage zones, focal species associated with these linkage zones and sharing of this information with county commissioners, local land use planners, state and federal game management and land management agencies and transportation agencies. Through this investment of time and energy these local groups build "Social Capital" (Pretty and Ward 2001). We will give a brief discussion of how social and human capital, embedded in participatory groups within rural communities can be a central measure of success in maintaining linkage zones necessary for continued persistence of local and regional wildlife populations.

### Background on Common Social Values

The following discussion of common social values associated with linkage zones has been taken and/or adapted from Duerksen et al. (1997):

- *Quality of Life*: Most people realize that the presence and protection of wildlife improves the quality of their lives, even though the actual value is difficult to assign. This is true even if they never see the protected wildlife. The mere knowledge that wildlife is nearby and that we have contributed to its conservation often improves the quality of our lives.
- *Ethical and Moral Considerations*: Many people feel an ethical and moral imperative to protect wildlife and its habitat from the growing impacts of human development. This thinking goes more in line with the "biocentric world view that accepts intrinsic values in the natural world, independent of utilitarian or direct human value endowment", (Kennedy and Thomas 1995).
- *Recreational Values*: The conservation of wildlife also contributes substantially to the recreational opportunities available to people. Birdwatching, wildlife hikes, fishing and hunting are only a few of the many recreational activities that depend upon the availability of wildlife and their habitat.
- *Economic Importance*: The protection and preservation of wildlife also contributes to the economic health of a state through tourism and otherwise. Using Colorado as an example, in 1990, an economic impact model developed by the Colorado Chapter of the Wildlife Society estimated that direct spending on hunting and fishing totaled over $570 million (excluding spending by the Colorado Division of Wildlife itself) within the state. When all direct and secondary spending was counted, the figure rose to over $1.3 billion. The $1.3 billion did not include the fact that the opportunity to view wildlife was considered to account for about 20 percent of all general tourism in Colorado.
- *Local Initiatives, State and Local Governments stepping forward, reduced Federal Government intervention and Local Land use Decision making*: Local governments have begun to emerge as prime partners and implementers of effective wildlife preservation programs. This trend is the result of citizens being increasingly involved and vocal with habitat conservation issues at the local level. Because the preservation of wildlife and their habitat contributes to the perceived quality of life for many residents, generates significant revenue through sports and passive tourism, and fulfills a growing sense of a moral obligation to protect wildlife, state and local governments have stepped into the field of habitat protection. Instead of relying on federal wildlife programs,

local citizens, city councils, county commissioners and state legislators have often agreed to take on the same aims at the local level. A prime example of this in Montana is the passage of local open space bonds to protect open space at community and county levels (e.g. Missoula, Gallatin and Ravalli Counties), and Powell County's implementation of zoning in the Blackfoot Watershed Area which was promoted and endorsed by a local citizens group that is now nationally known for the conservation efforts as the Blackfoot Challenge.

**Social Capital and Local Citizens Groups**

Social and human capital, embedded in participatory groups within rural communities can be a central measure of success in maintaining linkage zones necessary for continued persistence of local and regional wildlife populations. In this paper we will link social and human capital in the context of natural capital in the form of linkage zones.

Social and human capital captures the idea that social bonds and social norms are an important part of the basis for sustainable livelihoods (Pretty and Ward 2001). Unlike conventional capital, natural capital (nature's goods and services – cf. Costanza et al. 1997) tends to be at least partially a public good – more correctly, they are complex mixtures of public, club and private goods and so rarely have a market value (Pretty and Ward 2001). Like all public goods, it is difficult to say who is at fault when natural capital declines. Without rules, individuals tend to overuse and under invest in it. They are tempted to take the benefit without contributing anything themselves – in effect, to free-ride (Hardin 1968). When such public goods and services are considered free and so valued at zero, the market signals that they are only valuable when converted to something else. So the profit from converting forest or pastureland into subdivisions is counted on the developer's balance sheet, but all the lost services (wild foods, fodder grasses, climate regulation, and biodiversity) tend not to be subtracted. Social institutions based upon trust and reciprocity, and agreed norms and rules for behavior, can mediate this kind of unfettered private action (Pretty and Ward 2001). While there are many different descriptions of social capital, Pretty and Ward (2001) identified four central aspects: relations of trust; reciprocity and exchanges; common rules, norms and sanctions; connectedness, networks and groups.

- *Relations of Trust*: Trust lubricates co-operation and reduces transaction costs between people or agencies. There are two primary types of trust: the trust we have in individuals whom we know; and the trust we have in those we don't know, but which arises because of our confidence in a known social structure.
- *Reciprocity and exchanges*: Coleman (1990) and Putnam (1993) identified two types of reciprocity. Specific reciprocity refers to simultaneous exchanges of items of roughly equal value; and diffuse reciprocity refers to a continuing relationship of exchange that at any given time may be unrequited, but over time is repaid and balanced.
- *Common rules, norms and sanctions*: Common rules, norms and sanctions are the mutually agreed or handed down norms of behavior that place group interest above those of individuals (e.g. zoning densities or setbacks required for developments). They give individuals the confidence to invest in activities with predictability, reduced time delays and legal challenges. Mutually agreed sanctions ensure that those who break the rules know they will be punished. These are sometimes referred to as internal morality of a social system (Coleman 1990), the cement of society (Elster 1989).
- *Connectedness, networks and groups*: Connectedness, networks, groups and the nature of relationships are a vital aspect of social capital. Connectedness manifests itself in different types of groups at the local level and implies connections to other groups in society, from both micro to macro levels (Pretty and Ward 2001; Uphoff 1993; Grootaert 1998; Woolcock 1998; Rowley 1999).

The social and human capital necessary for sustainable and equitable solutions to natural resource management comprise a mix of existing endowments and that which is externally facilitated. External agencies or individuals can act on or work with either individuals or communities to create conditions for the emergence of new local associations with appropriate rules and norms for resource management. If these lead to the desired natural capital improvements, then this again has positive feedback on both social and human capital. For citizens to invest in these approaches, they must be convinced that the benefits derived from group or collective approaches will be greater than those from individual ones. External agencies, by contrast, must be convinced that the required investment of resources to help develop social and human capital, through participatory approaches will produce sufficient benefits to exceed the costs (Pretty and Ward 2001).

In Montana, local citizens groups are examples of the application of social and human capitol to the issue of wildlife linkage and they demonstrate social, and to some extent political success, in the support of wildlife linkage. These citizen groups have have formed in the Bitterroot Valley (Bitterroot Wildlife Focus Group), in Mineral County (Mineral County Private Lands Wildlife Movement Working Group), in Missoula County (the Ninemile Wildlife Working Group),and the Blackfoot Challenge. Some of these groups were specifically formed with the assistance of the Interagency Grizzly Bear Committee (IGBC) private lands task force to identify local wildlife movement areas in local communities and across transportation corridors. The Bitterroot Wildlife Focus Group formed as part of the Citizens Advisory Committee associated with an EIS for the Lolo – Hamilton transportation corridor. The Blackfoot Challenge on the other hand is a diverse landowner driven organization that was created to address challenges that local landowners saw coming over 20 years ago. The Blackfoot Challenge has multiple sub-committees that address a multitude of issues, one of which is associated with issues facing local wildlife populations and the valley's residents.

The advantages of working with local citizens groups to identify, design and manage linkage zones include the following measures of success:

- “Buy in” by local people to build support for common social values or sanctions (zoning regulations in the form of density regulations of subdivisions, setbacks from important linkage features or wildlife movement areas, mitigation for impacts).
- Acceptance of the concept of linkage by local citizens and local political interests (county commissioners, city councils) which can also elevate this support to state and national political levels.
- Involvement of local people in the refinement of linkage areas over time as conditions change on the ground.
- Locally developed and driven information pushed upward and shared with local county planners who conduct subdivision reviews, state and federal land and wildlife management agencies so that they take this information into consideration when making management decisions that could affect a local linkage area, and finally transportation agencies so that as projects come on-line consideration is given to making the roadway more permeable to local and regional wildlife while improving safety to the traveling public through reductions of animal vehicle collisions.

Through interaction with local citizens groups in Montana, we have witnessed first hand that investment in social and human capital can empower and enhance capacities of local communities working toward solving public problems. In the short term (past 5 years) we have seen applied successes forged by all of these local groups. For example, the Bitterroot Wildlife Focus Group cooperated with the Montana Department of Transportation to recommend locations for wildlife crossing structures during the reconstruction of US Hwy. 93 south of Missoula, Montana. The Mineral County Private Lands Wildlife Movement Working Group mapped and ground-truthed wildlife movement areas on private lands near I-90, then created brochures and maps that were distributed to state and federal land management agencies, game management agencies, transportation agencies, local governments, and planning offices for consideration in their respective planning and decision making processes. In fact, county commissioners recently denied a subdivision in Mineral County partially due to the importance of the land as winter range for elk and local residents' values. Similarly, the Ninemile Wildlife Movement Areas Workgroup mapped wildlife movement areas throughout the valley and across I-90, initiated public education and outreach, created brochures mailed to all local residents, and distributed maps based on local resident knowledge of important wildlife movement areas to state and federal land management agencies, wildlife management agencies, transportation agencies, local governments, and planning offices for consideration in their respective planning and decision making processes

In the long run, local groups' viability and success will depend on their ability to prevent the “burn-out'' feeling that investments in social capital are no longer paying. It is vitally important that agencies and non-governmental organizations continue to seek ways to provide support for the processes that both help groups to form, and help them mature along the lines that local people desire and need, and from which natural environments will benefit. Greater investments in local citizen groups (social goods) can lead to improvements in natural capital.

**Political measures of success**

Political measures of success involve both funding support, recognition of this as an issue, and legislative actions to assist in implementation. Political success also involves the administrators and transportation boards of state DOTs and their willingness to support linkage investment. Three levels of political support are necessary: state DOT administrators and the state transportation boards, county government officials, and Congressional involvement. These can be described as follows:

- Support for linkage planning and management in budget and personnel decisions by DOT administrators and state transportation commissions.
- County planning board considerations of wildlife linkage in long-term county planning and subdivision approval considerations.
- County commissioner support for linkage planning and implementation as valuable to county residents.
- Congressional support for linkage area identification and management in federal agency budgets.
- Congressional support for linkage area monitoring and evaluation in federal agency budgets.

**Summary**

In the long-term, successful implementation of linkage action that meets the needs of wildlife and fish populations and the ecosystems they depend on as well as the needs of transportation planners and the traveling public depends on collaboration and partnerships and the implementation of multiple actions and investments to benefit multiple resources and the public. Such collaboration will benefit multiple interests, not just biological interests. The application of multiple measures of success beyond just biological measures to each linkage investment will promote agency buy-in and acceptance of the investments necessary to create successful linkage and help to build public and political support for this important need.

## References


Bateman, I.J., A.A. Lovett, and J.S. Brainard. 2003. Applied environmental economics: a GIS approach to cost-benefit analysis. Cambridge University Press, New York, New York, USA.

Clevenger, A.P. and N. Waltho. 2003. Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in permformance studies. Pages 293-302 in *Proceedings of the International Conference on Ecology and Transportation*, 24 August-29 August 2003, Lake Placid, New York, USA.

Clevenger, T. 2006. Personal communication. PhD. Transportation Research Ecologist. Western Transportation Institute and Parks Canada.

Coleman, J. 1990. Foundations of social theory. Boston, MA: Harvard University Press.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neil, R. V., Parvelo, J., Raskin, R. G., Sutton, P., & de van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. Nature, 387:253-260.

Cramer, P. 2007. Personal communication. PhD. Transportation Research Ecologist. USGS, Utah State University.

Duerksen, C. J., D. L. Elliott, N. T. Hobbs, E. Johnson, and J. R. Miller. 1997. Habitat Protection Planning – Where the Wild Things Are. American Planning Association. Planning Advisory Service Report Number 470/471.

Elster, J. 1989. The cement of society: A study of social order. Cambridge: Cambridge University Press.

Forman, R. T. T., D. Sperling, J. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road Ecology: Science and Solutions*. Island Press, Washington. 481 pp.

Grootaert, C. 1998. Social capital: The missing link. World Bank Social Capital Initiative Working Paper No 5. Washington DC: The World Bank.

Gunther, K.A., M.J. Biel & H.L. Robison. 1998. Factors influencing the frequency of road-killed wildlife in Yellowstone National Park. Pp. 32-36. In: G.L. Evink, P. Garrett, D. Zeigler & J. Berry (Eds.). *Proceedings of the International Conference on Wildlife Ecology and Transportation*. FL-ER-69-98. Florida Department of Transportation, Tallahassee, Florida, USA.

Hanski, I. and M. Gilpin. 1991. Metapopulation dynamics: Brief history and conceptual domain. *Biological Journal of the Linnean Society* 42: 3-16.

Hardy, A.R., J. Fuller, M.P. Huijser, A. Kociolek, and M. Evans. 2007. Evaluation of wildlife crossing structures and fencing on US Highway 93 Evaro to Polson Phase 1: preconstruction data collection and finalization of evaluation plan. Final Report. Western Transportation Institute, Bozeman, Montana, USA.

Hilty, J.A., W.Z. Likicker Jr., and A.M. Merenlender. 2006. Corridor ecology: the science and practice of linking landscapes for biodiversity conservation. Island Press, Washington, D.C., USA.

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith & R. Ament. In prep. Wildlife-vehicle collision study: literature review. Report for Federal Highway Administration. Western Transportation Institute, Montana State University, Bozeman, MT, USA.

Huijser, M. 2007. Personal communication. PhD. *Transportation Research Ecologist*. Western Transportation Institute.

Institute of Transportation Engineers, 1999. *Traffic Engineering Handbook*, Pulication No. TB-010A, 5th edition, James L. Pline, editor.

Kennedy, J.J. and J.W. Thomas. 1995. Managing Natural Resources as a Social Value. In: A New Century for Natural Resources Management. Ed. by Knight, Richard L. and Bates, Sarah F. Island Press, Washington, D.C. This was adapted from a draft distributed with permission on the Human Dimensions of Fisheries Research listserve.

McCullough, D.R. 1996. Spatially structured populations and harvest theory. *Journal of Wildlife Management* 60:1-9.

Montana Department of Transportation (MDT). 2006. Traffic Safety Problem Identification Report FY 2007, July 25, 2006. http://www.mdt.mt.gov/safety/safetyprg.shtml.

Montana Department of Transportation (MDT). 2007. Benefit Cost Analysis. Pierre Jomini, P.E. Safety Management Engineer, March 6, 2007. Internal Memorandum.

National Association of Homebuilders. 2002. Smart growth, smart choices. Available online at http://www.nahb.org/publication_details.aspx?publicationID=15&sectionID=154

Nunes, P.A.L.D., J.C.J.M. van den Bergh, and P. Nijkamp. 2003. The ecological economics of biodiversity. Edward Elgar, Northampton, Massachusetts, USA.

Pretty, J. and H. Ward. 2001. Social Capital and the Environment. World Development Vol. 29, No. 2, pp. 209-227, 2001.

Proctor, M.F., B.N. McLellan, C. Strobeck, and R.M.R. Barclay. 2005. Genetic analysis reveals demographic fragmentation of grizzly bears yielding vulnerably small populations. Proceedings of the Royal Society, Series B 272:2409-2416.

Putnam, R. D., R. Leonardi, and R.Y. Nanetti. 1993. Making democracy work: civic traditions in modern Italy. Princeton, NJ: Princeton University Press.

Romin, L.A. and J.A. Bissonette. 1996. Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. *Wildlife Society Bulletin* 24:276-283.

Rowley, J. 1999. Working with social capital. London: Department for International Development.

Schwabe, K.A., P.W. Schuhmann, M.J. Tonkovich, and E. Wu. 2002. An analysis of deer-vehicle collisions: the case of Ohio. Pages 91-103 in L. Clark, editor. Human conflicts with wildlife: economic considerations. National Wildlife Research Center, Fort Collins, Colorado, USA.

Sielecki, L. E. 2004. WARS 1983-2002: Wildlife Accident Reporting and Mitigation in British Columbia. Special Annual Report. Ministry of Transportation. Victoria, British Columbia, Canada. 222 pp.

Taberlet, P., L. P. Waits, and G. Luikart. 1999. Non-invasive genetic sampling: look before you leap. Trends in Ecology and Evolution 14:323-327.

Trawen, A., P. Maraste, and U. Persson. 2002. International comparison of costs of a fatal casualty of road accidents in 1990 and 1999. Accident Analysis and Prevention 34:323-332.

Uphoff, N. 1993. Grassroots organizations and NGO in rural development: opportunity with diminishing stakes and expanding markets. World Development, 21: 607-622.

U.S. Department of Transportation. 2002. Considering safety in the transportation planning process. U.S. Department of Transportation, Washington D.C., USA.

Woods, J. G., D. Paetkau, D. Lewis, B. N. McLellan, M. Proctor, and C. Strobeck. 1999. Genetic tagging of free-ranging black and brown bears. *Wildlife Society Bulletin* 27:616-627.

Woolcock, M. 1998. Social capital and economic development: towards a theoretical synthesis and policy framework. Theory and Society, 27:151-208.

Wu, E. 1998. Economic analysis of deer-vehicle collisions in Ohio. Pages 43-52 in G.L. Evink, P. Garrett, D. Zeigler, and J. Berry, editors. Pages 293-302 in *Proceedings of the International Conference on Wildlife Ecology and Transportation*, 9 Febrary-12 February 1998, Fort Meyers, Florida, USA.

# North American Decision Guidelines for Mitigating Roads for Wildlife

**John Bissonette**, Ph.D. (435-797-2511, john.bissonette@usu.edu), Research Scientist/Leader, USGS Utah Cooperative Research Unit, Utah State University, USGS Coop Unit, College of Natural Resources, Logan, UT 84322-5290, Fax: 435-797-2443 USA

**Abstract**

Our primary purpose was to develop, to the extent that data are available, and as part of a web-based wildlife and roads resource, clearly written decision guidelines for: 1) the selection, configuration, and location of crossing types; 2) the monitoring and evaluation of crossing effectiveness; and 3) for maintenance.

Until recently, concerted and purposeful activity towards linking transportation and ecological services into a context-sensitive planning, construction, and monitoring process has not been attempted. We began a 3 year project in June 2004 funded by the National Cooperative Highway Research Program (National Academy of Sciences and Engineering, Transportation Research Board) and titled NCHRP Project 25-27, Evaluation of the Use and Effectiveness of Wildlife Crossings. We consider landscape permeability the foundation for effective wildlife-road mitigation and the guiding principle for this work. Our primary purpose was to develop, to the extent that data are available, and as part of a web-based wildlife and roads resource, clearly written decision guidelines for: 1) the selection, configuration, and location of crossing types; 2) the monitoring and evaluation of crossing effectiveness; and 3) for maintenance. The decision guidelines are based on the premise that understanding and establishing landscape permeability leads to effective landscape connectivity and the restoration of ecosystem integrity. At the same time, the guidelines must allow for efficient and cost-effective transportation infrastructure mitigation. In the decision guidelines, we describe seven steps that can be used to assist in effective wildlife mitigation, including: 1) consideration of the ecological and safety needs for mitigation early in the planning process, 2) decisions regarding the types of structures needed based on species-specific requirements, 3) the placement of those structures, and 4) their configuration on the landscape, 5) information on monitoring and evaluating crossing effectiveness, and 6) the long term maintenance of those structures. The final step (7) is the compilation of end products that are summarized in a final plan for mitigation with references, diagrams, pictures, and website addresses for the user to take from the website and use for additional consultation. The decision guidelines will be based on available data. It is clear that continued research efforts will be needed to fully develop aspects of the decision tool. The guidelines can be accessed at the URL www.wildlifeandroads.org. They are based on relevant research and effective mitigation practices from around the world, including 7 studies we conducted expressly for this project. The website includes descriptions of several methodologies that can be used to identify wildlife-vehicle collision hotspots, as well as suggestions for effective mitigation measures. The site also provides the ability to search databases for pertinent information. For example, the site includes an interactive map of wildlife passages across North America where, for example, the user can search by state and species and return a listing of pertinent references, a list of available pdf reports and papers accessible from the site, a listing of the wildlife crossings in that state, a listing of pertinent URL addresses that have wildlife-road related data, and a list of images with descriptions that can be freely downloaded. Alternatively, the user can search the entire database for a specific type of crossing and return all data across North America about that subject. The web site and decision guidelines will be continually developed and become a resource that provide practical information to help practitioners develop appropriate mitigation that will provide for effective landscape permeability for wildlife and safer roads for people.

# Overcoming the Barrier Effect of Roads – How Effective Are Mitigation Strategies?

## An international review of the use and effectiveness of underpasses and overpasses designed to increase the permeability of roads for wildlife.

**Rodney van der Ree** (61 3 8344 3661, rvdr@unimelb.edu.au), Ecologist, Nadine Gulle, and Kelly Holland, Australian Research Centre for Urban Ecology, Royal Botanic Gardens Melbourne, School of Botany, University of Melbourne, 3010 Australia

**Edgar van der Grift**, Alterra, Wageningen University and Research Centre, Wageningen, The Netherlands

**Cristina Mata** and **Francisco Suarez**, Grupo de Ecologia y Conservacion de Ecosistemas Terrestres, Department of Ecology, Universidad Autonoma de Madrid, E-28049 Madrid, Spain

**Abstract:** Roads, railways and other linear infrastructure are pervasive components of most landscapes throughout the world. Combined with the effect of vehicles, they have the potential to cause mortality in wildlife, severely disrupt animal movement and increase the risk of local extinction. Management agencies and conservation organisations currently spend considerable amounts of money annually on engineering solutions to increase the permeability of roads for wildlife. We evaluated the use and effectiveness of wildlife crossing structures (e.g. tunnels, culverts, overpasses) by reviewing studies published in the refereed scientific literature, conference proceedings and consultant reports. We evaluated the scientific rigour and methodology of studies, the extent to which studies demonstrated an increase in permeability, the detail included in the reporting and the extent to which population, community and ecosystem effects were shown. One hundred and twenty three studies were reviewed and all except two found an effect at the level of the individual animal. Two studies demonstrated a positive effect for the population and thus overall, the effectiveness of mitigation measures at reducing the risk of population extinction remains unclear. The level of scientific rigour, amount of replication and description of adjacent habitat and animal populations varied considerably among studies, in many cases limiting the level of inference that could be made. In the context of evaluation, we propose that a clear distinction be made between "use" and "effectiveness" of a wildlife crossing structure. The use of a structure may be broadly defined as the rate of detections of individuals or species, while effectiveness relates to a specific question or the goal of mitigation. A large amount of effort has conclusively shown that crossing structures are used by many species of wildlife. The long-term success of mitigation will ultimately depend on their effectiveness – i.e. to what extent have they mitigated the barrier effect of roads and has this prevented the local extinction of populations due to road effects? The next phase of research must focus more explicitly on quantifying their effectiveness, relative to location- and species-specific goals.

### Introduction

Roads and traffic are pervasive components of landscapes throughout the world. There is a growing recognition of their deleterious impacts on the natural environment and the need to quantify and mitigate these impacts (Spellerberg 1998; Forman *et al*. 2002; Donaldson and Bennett 2004; Davenport and Davenport 2006). The effects are diverse including many direct and indirect impacts, such as the loss and degradation of habitat; incursion of weeds, disease and feral animals; direct mortality of wildlife due to collision with vehicles; disruption of movements due to the creation of barriers; altered microclimatic conditions; and changes to the acoustic environment.

Road construction and management agencies around the world are currently investing large amounts of money quantifying the ecological effects of roads and traffic and investigating numerous mitigation techniques. Within the field of road ecology, the role of roads as barriers to the movement of wildlife and the effectiveness of measures to facilitate wildlife crossings have received considerable recent attention. This research has primarily focussed on quantifying the number and locations of road-killed animals (e.g. Rosen and Lowe 1994; Groot Bruinderink and Hazebroek 1996; Huber *et al*. 1998; Haxton 2000; Shuttleworth 2001; Malo *et al*. 2004) and the rate of use of tunnels, culverts, and overpasses by wildlife (e.g. Foster and Humphrey 1995; Yanes *et al*. 1995; Clevenger and Waltho 2000; Ng et al. 2004; Clevenger and Waltho 2005). Prompted by human-safety issues, the highly visible nature of road-kill carcasses and the potential conservation implications, agencies responsible for road construction and management have attempted to reduce the number of roadkills by preventing animals from accessing the road and facilitating crossing by constructing tunnels, culverts and overpasses. There has been considerable effort to document the use of these crossing structures by wildlife, and studies have been conducted in Europe, North America and Australia (e.g. Mansergh and Scotts 1989; Rodriguez *et al*. 1996; Clevenger and Waltho 2000; Clevenger *et al*. 2001; Ng *et al*. 2004).

The broad aim of this review is to assess the use and effectiveness of mitigation measures intended to decrease the barrier effect of roads and other linear infrastructure. It is timely to review current practice and provide direction for future works and studies to ensure best-practice. The missed opportunity costs of installing ineffective or insufficient mitigation structures may be significant. We focus on distinguishing between the use of a structure and its overall, long-term effectiveness, and assess methodological approaches and issues. Our focus on methodology is because we wanted to assess the scientific basis of published results and attempt to identify strengths and weaknesses in current approaches.

#### How Effective Are Mitigation Strategies?

It is helpful to define various terms and concepts to help clarify the direction and intent of this review. The Oxford English Reference dictionary definition of **mitigate** is "to make milder or less intense or severe"; **effectiveness** is "having a definite or desired effect"; and **use** (as a noun) is the "act of using or the state of being used". Our working definition of a **wildlife crossing structure** is ‘a physical structure that increases the permeability of the road or other linear infrastructure by facilitating the safe passage of animals over or under it and in the case of roads and railways, preventing collision with vehicles’. Wildlife crossing structures may be purpose built for wildlife or may primarily serve other functions (e.g. water drainage or access by humans). In the literature there is considerable confusion and interchangeable use of terms when describing mitigation structures. We have developed the following terms and definitions (table 1) to reduce confusion and provide consistency when describing the mitigation structures. In essence, we propose that a mitigation measure be described according to its specific structure, rather than its intended use. We propose to use the terms “underpass” and “overpass” as general terms that describe a collection of structures. We invite comment from practitioners in other countries as to the appropriateness of these terms.

In this review we have classified all structures in the studies according to their dimension and form, irrespective of the names given them by the authors. When we were unable to classify mitigation structures into one of our specific categories based on structure and size, we used the terms given by the original authors, or given the general term of ‘underpass’ or ‘overpass’.

Table 1: Definition of engineering options to mitigate the fragmentation effects of linear infrastructure

| Structure | Description |
|---|---|
| **OVERPASS*** | **Allows passage of animals above the road** |
| Land bridge | Also known as eco-duct or wildlife bridge. This is a (typically) wide (30 – 70 metres) bridge that extends over the road. The bridge has soil on it, and is planted with vegetation and enhanced with other habitat features (e.g. logs, rocks, water-body etc). |
| Overpass (small roads) | This bridge above the major linear infrastructure is typically to allow human/stock access across the road. This overpass is typically narrow and not hourglass shaped. The road on the overpass is typically a minor road – it may be unsealed, single lane etc |
| Canopy bridge | This is a rope or pole suspended above the traffic, either from vertical poles or from trees. Typically installed for arboreal and scansorial species. |
| Glider pole | These are vertical poles placed in the centre median or on the road verge, and provide species that glide intermediate landing and launch opportunities. |
| Local traffic management | Devices to reduce the speed or volume of traffic – e.g. road closures, chicanes, crosswalks, lighting, signage. |
| **UNDERPASS*** | **Allows the passage of animals below the major linear infrastructure** |
| Culvert | Culverts are typically square, rectangular or half-circle in shape. They are typically pre-cast concrete cells or arches made of steel. They may be purpose built for fauna passage or drainage, or a combination of both. |
| Tunnel | Tunnels are typically round pipes of relatively small diameter (e.g. < 1.5 metres diameter). May also be termed “ecopipe”. |
| Bridge | A bridge is a structure that maintains the grade of the road or elevates the traffic above the surrounding land, allowing animals the opportunity to pass under the road. When used to mitigate the barrier effect of linear infrastructure, the primary function is often to facilitate water drainage or the movement of local human traffic, and secondarily to facilitate the passage of wildlife. |

* There was considerable overlap in use of terms to describe crossing structures, particularly for underpasses. The definitions in this table are an attempt to reflect their design, rather than their potential use.

### Literature Sources

The information for this critical review was sourced by searching the ISI Web of Science database in March 2007 using the terms ‘underpass, overpass, culvert, tunnel and barrier’ in combination with the terms ‘road, wildlife and fauna’. Extensive reference lists from a number of general ‘road ecology’ reviews (Bennett 1990; 1999; Forman et al. 2002b; Davenport and Davenport 2006) and from each article we reviewed were also searched. Consultants reports were included when these were obtainable within the time constraints and conference presentations were included if published in a proceedings. There is a notable bias towards a comprehensive set of reports from Australia, Spain, France and The Netherlands, which reflects the geographic bias of the authors place of work and residence. We welcome the inclusion of reports from other regions of the world for future publications. Only studies that presented new data on the use or effectiveness of wildlife crossing structures were included in the critical review. Papers that summarised published data, gave an overview of projects within their jurisdiction, or discussed projects that were in the planning or construction stages were excluded from the review. Studies that included other aspects of road ecology and wildlife (e.g. rate or location of road-kill, effectiveness of exclusion fencing, animal behaviour or survival after translocation) were only included if they also included data on use of crossing structures.

## Results

### Number of Papers and Geographic Location of Study

One-hundred and twenty-three studies that fitted our search criteria for structures used as wildlife crossings by fauna were found and reviewed. These 123 studies included:

- all publications in English, Dutch, Spanish and French-language scientific refereed journals;
- all consultants reports from Australia, the majority of reports from The Netherlands, Spain and France, and some from the USA and Canada;
- a subset of papers published in the 1996, 1998 and 1999 ICOWET conferences, the 2001, 2003 and 2005 ICOET proceedings, and the proceedings from the Habitat Fragmentation and Infrastructure (1995) and Toads and Roads (1989) conferences.

The studies were conducted in Denmark, Brazil, Sweden, Finland, and Portugal (n = one study each), two in the United Kingdom, four in Germany, nine in Canada, 14 in Spain, 15 in the Netherlands, 16 in France, 29 in Australia and 30 in the United States of America.

### Number and Types of Structures

A total of 1864 structures were reported on and the majority were underpasses (83%), and specifically culverts (40% of 1864). The underpasses included culverts (742 examples); bridges (130); underpasses of unknown type (333); and tunnels (340). Overpasses included land bridges (68); overpasses with small roads (112); canopy bridges (8); glider poles (1); and other devices such as crosswalks, and signage (35). The total number of crossing structures is not an accurate measure of the total number in existence because the same structures may have been reported on in two or more publications. Nevertheless, it gives an indication of the relative proportions of each type of structure.

The mean number of crossing structures investigated per study was 9.9 (range 1 – 186), with 41 of the studies focusing on one (n = 19), two (n = 14) or three (n = 8) structures.

### Type of Linear Infrastructure

Structures to enhance connectivity have been constructed across a number of different types of linear infrastructure. The majority of the 122 studies focussed on mitigating the effects of roads and traffic (n = 113); railway lines (5); one on road and railway lines; one on an oil pipeline; and two on a water canal. We did not locate studies that attempted to measure the mitigation of the fragmentation effects of powerlines or other utility easements. The majority of the 114 road studies focused on mitigating the barrier effect of major roads (e.g. highway, freeway or motorway).

It was rare to find that the road and/or traffic were fully described. Road conditions were fully described in 13 studies (partially in 66) and traffic conditions were fully described in 24 (partially in 6). The road was typically described in terms of its classification and number of lanes (e.g. “major highway”, “4-lane interstate highway”, or “4-lane divided highway”). This is a potential source of confusion, especially when attempting international comparison. A full description of road and traffic conditions is important because it allows international readers to place the study (and indeed their own mitigation project) into context. For example, a species may be more willing to use a certain type of structure if the road is narrower and has fewer cars than if the same structure traverses a wide, multi-lane highway. Data on road width, number of lanes, presence, width and vegetation characteristics of a median strip are the minimum road features that should be described. It may be possible to infer road width to some extent from the length of the structure used in mitigation. However there was a pronounced variation in the length of structures, even on the same road or train-line, thus limiting the utility of this approach (e.g. Hunt *et al*. 1987; Clevenger and Waltho 2000; Ng *et al*. 2004).

### Design, Timing and Duration of Study

The majority of studies measured the rate of use/frequency of detections of animals using crossing structures and came to conclusions about the factors influencing crossing rates. This was most rigorously achieved by relating the rate of use to habitat, landscape and physical characteristics of the mitigation structures by using a correlation and/or regression approach.

A 'before-after' comparison approach was evident in 15 of the 122 studies, which included rates of road-kill before and after mitigation (e.g. Dodd *et al*. 2004). Mansergh and Scotts (1989) conducted an assessment of population sex ratios and over-winter survival before and after mitigation. Other researchers assessed the effectiveness of fencing to funnel animals towards the structures (e.g. Rodriguez *et al*. 1997; Cain *et al*. 2003). Most studies commenced after the structures had been built and were therefore unable to include a rigorous assessment of the pre-mitigation scenario. Similarly many studies that investigated faunal use of existing non-wildlife passages (e.g. drainage culverts) did not include a pre-mitigation analysis. A number of studies implied that there were elements of a 'before and after' approach, but this was not conclusive or clear from their methods or results. Three sequential studies (Singer 1978; Singer and Doherty 1985; Pedevillano and Wright 1987) reported on the use of the same structures over time, and in combination the three studies provided a before and after approach. One study used a novel approach to test small mammal preferences by translocating animals across the road in the vicinity of different structures, and provided excellent replication by using many animals near multiple structures (McDonald and St Clair 2004). Controls were reported in 29 of the 122 studies, with approximately half of the controls acting in a before-after approach. A small number of studies had true controls, with some experimental treatments and other areas remaining untreated (e.g. Singer 1978; Lehnert and Bissonette 1997; McDonald and St Clair 2004).

Most studies were not explicit about the timing of their surveys in relation to structure or road completion. The earliest use of a structure after construction was recorded for the Mountain Pygmy Possum *Burramys parvus* which used a tunnel two weeks after completion (Mansergh and Scotts 1989). Similarly, Golden Lion Tamarins were reported to use a canopy bridge "as soon as it was assembled" (Valladares Padua *et al*. 1995).

The duration of monitoring varied across studies, ranging from 4 nights (Jackson and Tyning 1989) to 20 years (van der Ree *et al*. in preparation). Excluding this 20-year study (which utilised a 20-year census data set collected for other reasons) the mean duration of monitoring across the 121 studies was 1.7 years (range 4 nights – 8 years). The frequency of monitoring within each study was extremely variable, and included daily (Reed *et al*. 1975), once per week (Clevenger et al. 2001), and 15 – 22 days per month (Rodriguez *et al*. 1997). The frequency of monitoring depended in part on the survey technique selected.

**Description of Populations of Wildlife and Habitats Adjacent to Roads**

Most studies (78 of the 122) gave some description of the vegetation or landform in their study area. Description of the vegetation, landform and geography is important for readers unfamiliar with the study area to gain appreciation of the region. Furthermore, it is critical for readers who want to make an independent assessment of the likelihood of a certain species occurring in the area, and thus being potentially available to use the crossing structure.

Less than half of the studies (56 of 122) incorporated some assessment of the presence or abundance of their target species into their evaluations. The most comprehensive was a calculation of expected crossing rates based on relative animal abundance in adjacent habitats (Clevenger and Waltho 2000; Clevenger et al. 2001). Various methods were used to investigate occurrence or abundance in adjacent habitat, including radiotracking (e.g. Foster and Humphrey 1995, Australian Museum Business Services 2001e, Cain *et al*. 2003); track or camera counts (e.g. Gloyne and Clevenger 2001; Braden *et al*. in press); and studies that used detailed census data of their target species (Mansergh and Scotts 1989; Guyot and Clobert 1997, van der Ree *et al*. in preparation). Literature sources (e.g. previous studies) and museum databases were used in 20 studies to evaluate habitat preferences and seasonal fluctuations in abundance. An assessment of animals in adjacent habitat was not relevant in studies that focused primarily on the behaviour of animals using the tunnels (Reed et al. 1975; Singer 1978; Reed 1981; Singer and Doherty 1985; Pedevillano and Wright 1987) or in the single study that used a translocation approach (McDonald and St Clair 2004).

**Survey Technique**

A range of techniques was used to identify the use of crossing structures by wildlife. The most common technique was tracking pads (74 studies), where a substrate (e.g. sand, soot, ink) was used to record animal footprints, from which the species, direction of travel and number of crossings could be inferred. Thirty-six studies used video or remotely triggered infra-red still cameras; radiotracking (7 studies); direct observations (13); game counters or sensors (6); trapping (12); collection and identification of scats (16) or hair (8); and other techniques used included dusting with fluorescent pigment and pitfall traps.

**Quantification of the Negative Impact of the Road and Traffic**

The negative effect of the linear infrastructure or traffic on wildlife was evaluated in approximately 50% of the 122 studies. The majority of these referred to previous studies or used general ecological principles to predict that the linear infrastructure was likely to reduce connectivity.

**Assessment of Factors Influencing Rate of Use**

Most studies included an assessment of factors influencing rate of crossing (98 of 122). Of these 98 studies, 24 explicitly used a quantitative approach (e.g. regression modeling, correlations) to assess the influence of different parameters (e.g. dimensions of structure, rate of use by humans, traffic volume, and presence of vegetative cover at the structure entrance) on the rate of crossing by wildlife. The remaining studies that made conclusions about the factors influencing rate of use, typically including qualitative judgments and incorporated the results of other studies.

A range of variables was identified as influencing the rate of use of the mitigation structures by wildlife. Commonly cited variables that positively influenced rates of use include abundant and high-quality habitat near to the entrance of the structures; dirt or "natural" floors; large "openness" ratios (length x width x height of underpass); absence or low rate of use by humans; and presence of "furniture" such as logs, rocks and vegetation on or in the structure. However, it should be noted that the direction and magnitude of the effect of these and other variables are likely to be species or species-group specific, and were shown to vary from location to location. Furthermore, the effect of correcting for local abundance at each crossing structure (sensu Clevenger et al. 2001) will further refine the identification of important variables.

### Extrapolation or Study of Effect at Population Level

Five publications reported on a population-level study or effect and an additional 23 studies implied or alluded to population-level effects such as increased viability or prevention of a population sink. Population-level effects were shown for the Mountain Pygmy-possum *Burramys parvus* in south-east Australia where the use of an under-road tunnel led to a measurable increase in the viability of the population (Mansergh and Scotts 1989; van der Ree et al. in preparation) and for Badgers *Meles meles* in The Netherlands (van der Grift *et al*. 2003).

## Discussion

### Aim and Effectiveness of Wildlife Crossing Structures

Forman et al. (2002b) proposed that the overall objective of wildlife crossing structures is to 'increase the permeability of a road corridor' (p. 161). They list a series of six criteria against which to measure effectiveness, namely: i) reduce rates of road-kill; ii) maintain habitat connectivity; iii) maintain genetic interchange; iv) ensure biological requirements are met; v) allow for dispersal and re-colonisation; and vi) maintain meta-population processes and ecosystem services. We propose that an explicit and fundamental measure of the effectiveness of wildlife crossing structures is the long-term viability of local populations or prevention of likely reduction in viability (in the case of a road widening or upgrade).

According to at least some of the six criteria proposed by Forman et al. (2002b), all of the studies we reviewed were likely to be considered successful at the level of the individual animal. The vast majority of wildlife crossing structures monitored increased the permeability of the road by allowing individual animals to move more safely across the road. In this sense, the crossing structure was successful for the individual, at the time it was recorded using the structure. However, it has been noted that use of structures does not necessarily equate to conservation gain (Ng et al. 2004). In other words, have the negative effects of the road been reduced to the point where the risk of extinction is at a satisfactory level? Are road construction and management agencies actually doing enough to mitigate the negative effects of roads and traffic? Are populations declining in size due to road effects, even though we observe them using the crossing structures? The answer to these questions remains largely unanswered, despite an extensive body of work over the past two decades.

### Study Design and Methods

The mitigation works must have a clearly defined and measurable goal. The six criteria proposed by Forman et al (2002) and our goal "to increase population viability" should be seen as guiding principles only, and not the actual goal against which success can be measured. The goal for each project must be specific to the location, species of concern and nature of the problem. We recommend use of the 'SMART' approach (Specific, Measurable, Achievable, Realistic, and Timeframed) to set a specific goal and thus facilitate more comprehensive evaluation of mitigation measures. An ecological goal for a road through habitat might be to "maintain the risk of extinction of a species to less than 5% over the next 100 years". Alternatively the broad goal of maintaining connectivity could be made more specific such that "more than 90% of individuals within the population that approach the road successfully cross-over". The identification of specific goals for each project is likely to alter the emphasis of the mitigation. In one area the focus may be on reducing road-kill, while for another species it may be on maintaining daily movements.

The design of a study is critical to the inferential strength or reliability that may be obtained. A rigorous scientific approach relies on clearly articulating a specific question, and then designing the study to answer that question with maximum efficiency and achieving maximum clarity of results. Most of the studies we reviewed were retrospective, in that they investigated the occurrence of crossing structures by wildlife after construction, typically without controls. Depending on the initial question posed, this approach may be satisfactory. However, we would argue that the next phase of research into the use and effectiveness of wildlife crossing structures should elucidate the probability of population persistence as a function of mitigation. Trade-offs exist between the perfectly-designed study and reality, and in the case of studying road effects it may not be possible to include the "before" situation, adequate replication and randomisation may not be feasible, and resources may be limited (Roedenbeck et al. 2007). Road agencies need to invest in manipulative and experimental studies that provide maximum inferential strength. Roedenbeck et al (2007) provide an excellent and thorough discussion of the various study designs, their strengths and weaknesses and financial cost in evaluating road effects. It is important to note that the relative cost to undertake a thorough evaluation of structure effectiveness is likely to be less than the costs to build the structure, and indeed significantly less than the overall costs of road construction and management.

One approach to evaluating wildlife crossing structures is to compare the effects of post-mitigation vital rates (e.g. dispersal, gene flow, birth rate, survival) with the pre-mitigation situation and the non-road situation using population viability analyses (van der Grift and Pouwels 2006). If the age or sex structure, survival, patterns of dispersal, and gene flow before mitigation are not known, then it is difficult to assess whether these parameters have improved after mitigation. We are not suggesting that a detailed field assessment of the actual impacts of every road for every species be undertaken prior to mitigation. However, the reliability of population viability models at predicting and assessing potential impacts and success of mitigation rely on thorough and realistic population parameters. It may be possible to substitute data from other locations or species in order to build population models.

There is a need to more fully identify and quantify the negative effect of roads and traffic. For example, the number of animals killed after collision with vehicles is clearly a major issue and a cause of concern for both human safety and conservation. Nevertheless, road-kill is just one aspect of the negative effect of roads and there are likely to be many others that need to be considered. Therefore, studies evaluating the effectiveness of mitigation measures should not rely solely on measuring the rate of road-kill as an index of crossing-structure success. Ironically, the absence of a species in the road-kill tally may be due to a lack of suitable habitat or that other effects of the road (e.g. noise, light or chemical pollution) are deterring animals from even reaching the road or that the local population has become sufficiently rare that it can no longer be detected, rather than a successful mitigation. This highlights the need for information on the status of populations in adjacent habitats.

A lack of statistical replication in many studies has likely limited the quantitative evaluation of factors influencing rates of use. Even Yanes et al. (1995) who investigated the rate of wildlife crossing within 17 tunnels in Spain lamented that their small sample size prevented them from drawing conclusions about the importance of particular design features for wildlife. Adequate replication is critical because the natural environment is variable and an unrepresentative picture may be obtained if all the structures are coincidentally placed in areas with high or low population sizes, with high or low densities of predators, with high or low density of geographic or landscape features that encourage or discourage use.

Numerous studies have shown an increase in the rate of use of mitigation structures over time as animals become accustomed to the structures, as disturbance due to construction is rehabilitated and as vegetation cover increases. Furthermore, seasonal variation in rate of use is also evident, and this is unlikely to be detected in short studies. There appears to be a trend for longer-term studies being undertaken in recent years, which include pre-mitigation studies to develop a baseline; monitoring during construction; and then post construction monitoring.

**Survey Method**

Remotely-triggered cameras and tracking pads were the most commonly used techniques to survey use of crossing structures. While these methods are effective at detecting large species and those with diagnostic tracks, they are less efficient at detecting smaller and more cryptic species. The method of survey will also influence the type of inference that can be made; however these biases were rarely acknowledged. For example, the number of tracks of a certain species does not necessarily equate to the total number of individuals using the structure. It may be that a dominant individual has established a territory and its frequent use of the structure prevents access by other individuals. Finally, recording the presence of an individual within a structure (e.g. recording footprints at one end of a structure) does not always equal a successful crossing. Therefore, the minimum standard for recording a successful crossing might be a set of tracks travelling in the same direction recorded at both entrances to the tunnel or overpass (e.g. Gloyne and Clevenger 2001; e.g. Ng et al. 2004). A combination of survey techniques should always be employed, and new techniques such as genetic techniques and the use of remote data-loggers with PIT tags offer potential new insights. Greater effort to detect smaller and less diagnostic species from tracking pads (perhaps using a finer substrate such as ink or marble dust) are also recommended.

Other survey techniques, although more labour-intensive, may allow the purpose of use of a tunnel or overpass to be elucidated. The type of use (e.g. occasional or dispersal passage, daily as movement within a home range or migration) is likely to have implications on population persistence. For example, a concurrent radiotracking study of tunnel crossings under Highway I-75 in Florida USA for the Florida Panther found that of the 10 reported crossing only two individuals were involved, and use was related to the home ranges of the panthers (Foster and Humphrey 1995). For some migratory species, the direction of travel and time of year is strong evidence that the crossing structure is used in migration. Similarly, the daily use of underpasses by mountain goats to access a salt lick (Singer 1978; Singer and Doherty 1985; Pedevillano and Wright 1987) is convincing evidence how the structure is being used. The use of crossing structures may be sex-specific, as there is some evidence that road-crossing ability may also be sex-dependent (van der Ree 2006). In most situations, it is unknown if animals dispersed across the road and established new territories, used the structure daily to access resources or used it for some other purpose.

**Importance of Study of Animals in Adjacent Habitat**

The rate of use of crossing structures is related to the abundance of animals in adjacent habitat (e.g. Yanes et al. 1995). Thus, studies that draw conclusions about the suitability of certain types of structures without considering animal abundance may give an incomplete assessment of suitability. One interesting approach calculated an expected rate of crossing based on animal abundance in adjacent habitat and compared the expected rate of use to that observed (Clevenger and Waltho 2000; Clevenger et al. 2001). At the very least museum and wildlife atlas records can provide a list of species that probably occur in the study area. However, this should be considered the very minimum at which the pool of potential species be estimated. Estimates of crossing rates relative to local abundance (with local abundance preferably estimated simultaneously) will more fully elucidate the effectiveness of certain structure types.

### Improving Knowledge Transfer

In this review we assessed information published in the refereed scientific literature, consultants reports and conference proceedings. To our knowledge, we have the majority of Australian, Spanish, French and Dutch reports, but only a small proportion of reports from North America. This bias is due to our own geographic locations and we welcome the opportunity to include reports from North America and elsewhere in a more comprehensive review to be published in the future. The primary literature sources that are most accessible to road engineers and consultants around the world are likely to be international peer-reviewed journals and some recently completed agency reports. For example, three recently published studies that we reviewed (Cain et al. 2003; Taylor and Goldingay 2003; Ng et al. 2004) all cited three of the earliest papers published in journals on the use of underpasses (Reed et al. 1975; Reed 1981; Singer and Doherty 1985). Therefore, accessibility is enhanced when published in journals. The peer-review process will also potentially improve the scientific rigour and reliability of inferences and conclusions. The additional costs involved in writing up the findings for publication in a reputable journal would be relatively small compared with the cost of the research itself, and should be factored into commissioned studies. An alternative suggestion is that road agencies should stipulate that the findings of commissioned studies be prepared for submission to scientific journals.

To further improve the efficient and accurate transfer of knowledge, we suggest a series of minimum criteria be reported in all studies. This is critical for the reader to gain an understanding of the overall configuration of the linear infrastructure; the surrounding vegetation; road and traffic conditions and the mitigation structures. The overall configuration of the linear infrastructure includes the number and width of vehicle lanes, particulars on service and access lanes, and details of central median. The presence and type of vegetation adjacent to the road (and within the central median) may act as potential habitat and therefore should be described. The road traffic conditions require clarification. Pertinent factors include mean vehicle speed, and variations in vehicle speed, traffic volume, and times of peak traffic flow. The characteristics of each mitigation structure should be clearly described. We support a recent memo from the ICOET organising committee outlining a recommended terminology for structure dimensions (length, width, height); cross-sectional shape (e.g. round, rectangular); intended function (drainage, wildlife passage); and mode of construction and materials (e.g. pre fabricated concrete box culvert). This is important to avoid potential confusion due to inconsistent nomenclature across regions and studies. We suggest an international working party convene to present a final set of standard definitions of structures that can be adopted by the wider field.

## Conclusions

Many agencies around the world are constructing and modifying roads to have less environmental impact. The amount of money spent on mitigating the barrier and other effects of roads and traffic are relatively small compared with the overall construction and maintenance budgets of state and national road agencies. Furthermore, the funds required to fully evaluate the effectiveness of mitigation actions is comparatively smaller. Given the recent surge in research and expenditure on minimising the ecological effects of roads and traffic it is pertinent and timely to evaluate the effectiveness of mitigation measures and comment on the direction that future research and monitoring should take. The studies we reviewed clearly demonstrate that most measures designed to increase the permeability of roads for wildlife were successful at the level of the individual animal. The detection of an animal in a tunnel or overpass indicated that on the occasion it was detected it may have made it safely to the other side. However, the extent to which the population has benefited from that successful crossing is unclear. There is insufficient information and analysis in the majority of studies to evaluate whether the viability of the population has increased to an acceptable level.

The rate of use of a wildlife crossing structure is an important and essential first step in evaluating effectiveness. After 20 years of such evaluations, it is apparent that research at the next level of complexity is required. The rate of detections of animals within a structure is information that must feed into an analysis of whether the population is likely to exist in 20, 50 or 100 years time. In other words, have the negative effects of the road been sufficiently mitigated that population persistence has been sufficiently enhanced to ensure long-term survival? This is a critical question that road agencies must be able to answer in the positive if they are to comply with strict legislation that aims to conserve biodiversity. Finally, the barrier effect of roads is just one potential impact on fauna, and mitigation that addresses this may only increase viability within the limits posed by other effects.

**Biographical Sketches:** Rodney van der Ree is an ecologist at The Australian Research Centre for Urban Ecology, a division of the Royal Botanic Gardens of Melbourne. He obtained his PhD in wildlife ecology by studying the influence of landscape geometry on arboreal marsupials. The effects of fragmentation and barriers were central to his thesis, sparking the interest in road ecology. Rodney is currently leading a collaborative research project with VicRoads (the Victorian State road agency) entitled "quantifying and mitigating the barrier effect of roads".

Edgar A. van der Grift studied biology at Wageningen University and is working in the field of road ecology for over fifteen years. As a research ecologist at ALTERRA he is currently involved in a variety of studies that focus on the ecological impacts of roads and railroads, the effectiveness of mitigation measures such as wildlife crossing structures, and the implementation of ecological knowledge in national and regional transportation policy. He is member of the board of Infra Eco Network Europe (IENE), a platform for policy makers, road planners and road ecologists with the aim to share knowledge and best practices and encourage (international) collaboration.

Kelly Holland and Nadine Gulle are Research Assistants at the Australian Research Centre for Urban Ecology. Nadine completed her Honours degree at The University of Melbourne investigating the barrier effect of roads on the spatial organisation and dispersal of the Common Brushtail Possum. Kelly has been involved in a variety of flora and fauna survey projects, as well as possessing extensive experience in compiling literature reviews and reports. These have included a diversity of topics, such as vegetation dynamics and management, rare plant translocation, and flora and fauna invasion biology.

Francisco Suárez are both from Terrestrial Ecology Group of the Ecology Department of the Universidad Autonoma de Madrid. Francisco is a lecturer and Cristina is a researcher, and their current areas of investigation cover aspects of environmental impact assessment, the design and evaluation of mitigation measures and the development of automatic systems for tracking fauna.

## References


Cain A. T., Tuovila V. R., Hewitt D. G. and Tewes M. E. (2003) Effects of a highway and mitigation projects on bobcats in Southern Texas. *Biological Conservation* 114, 189-197.

Clevenger A. P., Chruszcz B. and Gunson K. (2001) Drainage culverts as habitat linkages and factors affecting passage by mammals. *Journal of Applied Ecology* 38, 1340-1349.

Clevenger A. P. and Waltho N. (2000) Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology* 14, 47-56.

Clevenger A. P. and Waltho N. (2005) Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation* 121, 453-464.

Davenport J. and Davenport J. L. (2006) (Ed.)^(Eds) 'The ecology of transportation: managing mobility for the environment.' Environmental Pollution (Springer: Dordrecht, The Netherlands)

Dodd C. K., Barichivich W. J. and Smith L. L. (2004) Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. *Biological Conservation* 118, 619-631.

Donaldson A. and Bennett A. F. (2004) 'Ecological effects of roads. Implications for the internal fragmentation of Australian Parks and reserves.' (Parks Victoria: Melbourne)

Forman R. T. T., Sperling D., Bissonette J. A., Clevenger A. P., Cutshall C. D., Dale V. H., Fahrig L., France R., Goldman C. R., Heanue K., Jones J. A., Swanson F. J., Turrentine T. and Winter T. C. (2002) 'Road Ecology. Science and Solutions.' (Island Press: Washington)

Foster M. L. and Humphrey S. R. (1995) Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin* 23, 95-100.

Groot Bruinderink G. W. T. A. and Hazebroek E. (1996) Ungulate traffic collisions in Europe. *Conservation Biology* 10, 1059-1067.

Haxton T. (2000) Road mortality of Snapping Turtles, Chelydra serpentina, in Central Ontario during their nesting period. *Canadian Field-Naturalist* 114, 106-110.

Huber D., Kusak J. and Frkovic A. (1998) Traffic kills of brown bear in Gorski Kotar, Croatia. *Ursus* 10, 167-171.

Hunt A., Dickens H. J. and Whelan R. J. (1987) Movement of mammals through tunnels under railway lines. *Australian Zoologist* 24, 89-93.

Jackson S. D. and Tyning T. (1989) Effectiveness of drift fences and tunnels for moving spotted salamanders *Ambystoma maculatum* under roads. In 'Amphibians and Roads'. (Ed. TES Langton) pp. 93-99

Lehnert M. E. and Bissonette J. A. (1997) Effectiveness of highway crosswalk structures at reducing deer-vehicle collisions. *Wildlife Society Bulletin* 25, 809-818.

Malo J. E., Suarez F. and Alberto D. (2004) Can we mitigate animal-vehicle accidents using predictive models? *Journal of Applied Ecology* 41, 701-710.

Mansergh I. M. and Scotts D. J. (1989) Habitat continuity and social organisation of the mountain pygmy-possum restored by tunnel. *Journal of Wildlife Management* 53, 701-707.

McDonald W. and St Clair C. C. (2004) Elements that promote highway crossing structure use by small mammals in Banff National Park. *Journal of Applied Ecology* 41, 82-93.

Ng S. J., Dole J. W., Sauvajot R. M., Riley S. P. D. and Valone T. J. (2004) Use of highway undercrossings by wildlife in southern California. *Biological Conservation* 115, 499-507.

Pedevillano C. and Wright R. G. (1987) The influence of visitors on mountain goat activities in Glacier National Park, Montana. *Biological Conservation* 39, 1-11.

Reed D. F., Woodard T. N. and Pojar T. M. (1975) Behavioral response of mule deer to a highway underpass. *Journal of Wildlife Management* 39, 361-367.

Rodriguez A., Crema G. and Delibes M. (1996) Use of non-wildlife passages across a high speed railway by terrestrial vertebrates. *Journal of Applied Ecology* 33, 1527-1540.

Rodriguez A., Crema G. and Delibes M. (1997) Factors affecting crossing of red foxes and wildcats through non-wildlife passages across a high-speed railway. *Ecography* 20, 287-294.

Roedenbeck I. A., Fahrig L., Findlay C. S., Houlahan J. E., Jaeger J. A. G., Klar N., Kramer-Schadt S. and Van der Grift E. A. (2007) The Rauischholzhausen agenda for road ecology. *Ecology and Society* 12, 11. [online] URL: http://www.ecologyandsociety.org/vol12/iss1/art11/.

Rosen P. C. and Lowe C. H. (1994) Highway mortality of snakes in the Sonoran desert of southern Arizona. *Biological Conservation* 68, 143-148.

Shuttleworth C. (2001) Traffic related mortality in a red squirrel (Sciurus vulgaris) population receiving supplemental feeding. *Urban Ecosystems* 5, 109-118.

Singer F. J. (1978) Behavior of mountain goats in relation to US Highway 2, Glacier National Park, Montana. *Journal of Wildlife Management* 42, 591-597.

Singer F. J. and Doherty J. L. (1985) Managing mountain goats at a highway crossing. *Wildlife Society Bulletin* 13, 469-477.

Spellerberg I. F. (1998) Ecological effects of roads and traffic: a literature review. *Global Ecology & Biogeography Letters* 7, 317-333.

Valladares Padua C., Cullen Jr L. and Padua S. (1995) A pole bridge to avoid primate road kills. *Neotropical Primates* 3, 13-15.

van der Grift E. A. and Pouwels R. (2006) Restoring habitat connectivity across transport corridors: identifying high-priority locations for defragmentation with the use of an expert-based model. In 'The Ecology of Transportation: Managing mobility for the Environment'. (Eds J Davenport and JL Davenport) pp. 205-231. (Springer: Dordrecht, The Netherlands)

van der Grift E. A., Verboom J. and Pouwels R. (2003) Assessing the impact of roads on animal population viability. In 'Proceedings of the 2003 International Conference on Ecology and Transportation'. Lake Placid, New York, USA. (Eds CL Irwin, P Garret and KP McDermott) pp. 173-181. (Center for Transportation and Environment, North Carolina State University)

van der Ree R. (2006) Road upgrade in Victoria a filter to the movement of the endangered Squirrel Glider *Petaurus norfolcensis*: Results of a pilot study. *Ecological Management and Restoration* 7, 226-228.

van der Ree R., McCarthy M. A., Heinze D. and Mansergh I. M. (in preparation) Under-rood tunnel restores population dynamics of endangered pygmy-possum. *In prep*.

Yanes M., Velasco J. and Suarez F. (1995) Permeability of roads and railways to vertebrates: the importance of culverts. *Biological Conservation* 71, 217-222.

## Behavioral Responses of White-tailed Deer to Vehicle Mounted Sound-Producing Devices

**Sharon A. Valitzski** (706-296-9048, valitzskis@warnell.uga.edu), Graduate Research Assistant;
**Gino J. D'Angelo** (gjd4985@warnell.uga.edu), Ph.D. Candidate;
**David A. Osborn** (osborn@warnell.uga.edu), Research Coordinator;
**Karl V. Miller** (kmiller@warnell.uga.edu), Professor, Wildlife Ecology and Management; and
**Robert J. Warren** (warren@warnell.uga.edu), Interim Dean and Meigs Professor, Wildlife Ecology and Management, The University of Georgia, D.B. Warnell School of Forestry and Natural Resources, Athens, GA 30605 USA
**George R. Gallagher** (ggallgaher@berry.edu), Professor of Animal Science, Director, Rollins Ruminant Center Berry College, Mount Berry, GA 30149-0326 USA

**Abstract**

Deer-vehicle collisions are on the rise and are a costly side-effect of increasing deer populations and expanding transportation systems. We evaluated the efficacy of sound as a deterrent for reducing deer-vehicle collisions by observing the behavioral response of captive and free-ranging white-tailed deer (*Odocoileus virginianus*) to 5 pure-tone sound treatments: 0.28 kHz, 1 kHz, 8 kHz, 15 kHz, and 28 kHz. We conducted preliminary trials with semi-tame deer at the University of Georgia Captive Deer Research Facility. We exposed 8 deer in a 0.25-ha outside paddock and 5 deer in individual stalls (2.7 m x 4.8 m) to the various treatments at >70 dB Sound Pressure Level. We recorded 406 observations and determined that the behavior of captive deer did not change when presented with any of the 5 pure-tone sound treatments. We also conducted field trials at Berry College Wildlife Refuge, Georgia and gathered 319 behavioral observations of free-ranging deer relative to a moving automobile (56.45 kph). The automobile was fitted with a sound-producing device and speakers that emitted one of the pure-tone sound treatments or no sound treatment as a control. For the 1 kHz, 8 kHz, 15 kHz, and 28 kHz sound treatments, we observed no change in deer behavior relative to the control. When exposed to the 0.28 kHz treatment, deer reacted in a manner more likely to cause deer-vehicle collisions. Our results indicate that deer within 10 m of roadways did not alter their behavior in response to the pure-tone sound treatments we tested in a manner that would prevent deer-vehicle collisions. Commercially available wildlife warning whistles (aka deer whistles) are purported to emit similar consistent, continuous sounds as pure tones at various frequencies within the range of those presented in this study. Our data suggests that deer-whistles, as they are purported to operate, are likely not effective in preventing deer-vehicle collisions.

# Construction of a Highway Section Within a White-Tailed Deer Winter Yard Near Near Québec City, Canada: Mitigation Measures, Monitoring, and Preliminary Results

**Yves Leblanc** (418-871-2452, yves.leblanc@tecsult.com), Tecsult, Inc., 4700, boul. Wilfrid-Hamel, Québec City, Québec G1P 2J9, Canada

**Jacques Bélanger** (418-839-7978, jacques.belanger@mtq.gouv.qc.ca) Direction Chaudière-Appalaches, Ministère des Transports du Québec, 1156 boul. de la Rive-Sud, Saint-Romuald, G6W 5M6, Canada

**Sylvie Desjardins** (418-832-7222, sylvie.desjardins@fapaq.gouv.qc.ca), Ministère des Ressources naturelles et de la Faune du Québec, 8400, avenue Sous-le-Vent, Charny, QC, G6X 3S9, Canada

**Abstract:** The construction of a new 10.4 km (6.5 mi) section of HWY Robert-Cliche (73) south of Québec City, Canada, integrated an unprecedented number of mitigation measures to maintain connectivity between a bisected white-tailed deer winter yard and minimize apprehended deer-vehicle collisions. In this paper we present mitigation measures planned and complete as well as the monitoring approach to document deer use and movements in the winter yard before, during and after the construction. Some preliminary results regarding the impact of this project on the deer winter use of the project area also will be presented and briefly discussed.

We conducted 4 years (1999-2002) of winter track surveys along the projected centerline of the new highway section and aerial surveys done in mid-winter of 2003 and 2004 to document movements and to delineate boundaries of the Calway deeryard. Mitigation measures were then proposed and integrated in the project design for the bisected deeryard. It included wildlife fencing for more than half (6.2 km or 3.9 mi) of the new highway section and combining it with 5 underpasses: one concrete box culvert, two open-span bridges over two major rivers and 2 open-span bridges over 2 rural roads. Before and during construction deer were captured each year in January and fitted with radio-collars. Yearly aerial surveys were also conducted to determine spatial use in relation with the construction phases. Around 20 deer were radio-collared each winter and telemetry data showed that about one-third of deer were long distance migrants (> 10 km) between their winter and summer home range, another one-third were short distance migrants (1 to 10 km), whereas the remaining were yearly residents of their winter range. All radio-collared deer monitored for more than a year consistently traveled between the same winter and summer home ranges. However some marked deer moved elsewhere to winter.

Two primary deer crossing structures were located at the Doyon Creek and Calway River and three secondary ones were available to deer. The design and specifications of three required underpasses were modified to facilitate use by deer. As of October 2006, four underpasses were completed, as well as 5.1 km (3.2 mi) of wildlife fencing and 21 jump-outs. An additional 6 escape ramps will be built before construction ends to allow trapped deer to escape from the fenced rights-of-way (ROW). Motorists were not yet allowed to use paved sections but they will be after project completion in fall 2007.

During the 2006 spring migration, about twenty deer were trapped within the 1.6 km (1.0 mi) fenced section and did not find the hole at the jump-outs. Adjustments were made on existing ramps to allow the deer to see the opening and not be reluctant to jump out to the adjacent forest. Also, new drawings and specifications were made to eliminate fence angles and reduce the height and slope of the ramp for the remaining one to build. Weekly visits from January to March 2007 showed that numerous deer were using both primary and secondary deer crossing structures to access both sides of the deeryard. Data from the aerial survey showed that the fenced highway section induced a light shift in the spatial use of the deeryard during the 2007 winter. Telemetry data provided evidence that deer with split winter home ranges continued to use both sides of the new section of highway despite a 5.1 km stretch of deer-proof fencing.

## Introduction

Construction of new highways and public roads may reduce or alter both the quantity and quality of wildlife habitat. Construction activities, presence of construction workers and noise may also disrupt daily and seasonal movements of wildlife. Once constructed highways and public roads and their associated vehicular traffic can affect wildlife populations by traffic mortality, permanent habitat loss or resource inaccessibility (Jaeger et al. 2005, Forman and Alexander 1998).

Roads and highways can also be hazardous for people, particularly when large mammals such moose (*Alces alces*) or white-tailed deer (*Odocoileus virginianus*) inhabit the proximity of transportation corridors. Vehicle-ungulate collisions have recently increased in North America and Europe causing an increase numbers in human injuries and deaths, as well as considerable material damage (Forman et al. 2003). There were 204 reported human fatalities from animal-vehicle crashes in 2004 in the U.S. only (http://deercrash.com/states/national_data.htm).

In this paper we share information and preliminary results related to planning mitigation measures and monitoring use of deer crossing structures in a new build highway that bisected a northern deeryard. The main objectives are (1) to present mitigation measures planned and built to reduce impacts of the construction of a new highway section in a northern winter yard of white-tailed deer and human safety and (2) provide preliminary data obtained from monitoring underpasses and escape ramps.

## Study Area

Our project took place in the Beauce region, located 60 km (37 mi) south-east of Quebec City near the Appalachians (fig. 1). The study area covered approximately 1,000 km$^2$ (386 mi$^2$) where rolling landscapes, numerous streams, and 4 rivers dominate the landscape. Altitude varies between 213 m (777') and 487 m (1598'). Snow cover appears in early

December and persists until mid-April. Annual precipitation averaged 1000 mm (39’’) of which 25% fell as snow. The mean monthly temperatures vary between 18 °C (64 °F) and -12 °C (10.4 °F).

The landscape is mostly forested with some highly dispersed and patches of agricultural lands. The study area is located within the ecological region of the northern mesic hardwood forest. Intensive forest harvesting has a great effect on the actual forest structure and composition. Forests are mostly under private ownership and currently harvested for firewood, paper and lumber production. In 1995, only 25% were considered mature stands while the remaining ones were either young (36%) or regenerating (39%). The forest canopy is mainly composed of deciduous and mixed stands of sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), yellow birch (*Betula alleghaniensis*), balsam fir (*Abies balsamea*), white spruce (*Picea glauca*), red spruce (*Picea rubens*) and white pine (*Pinus strobus*).

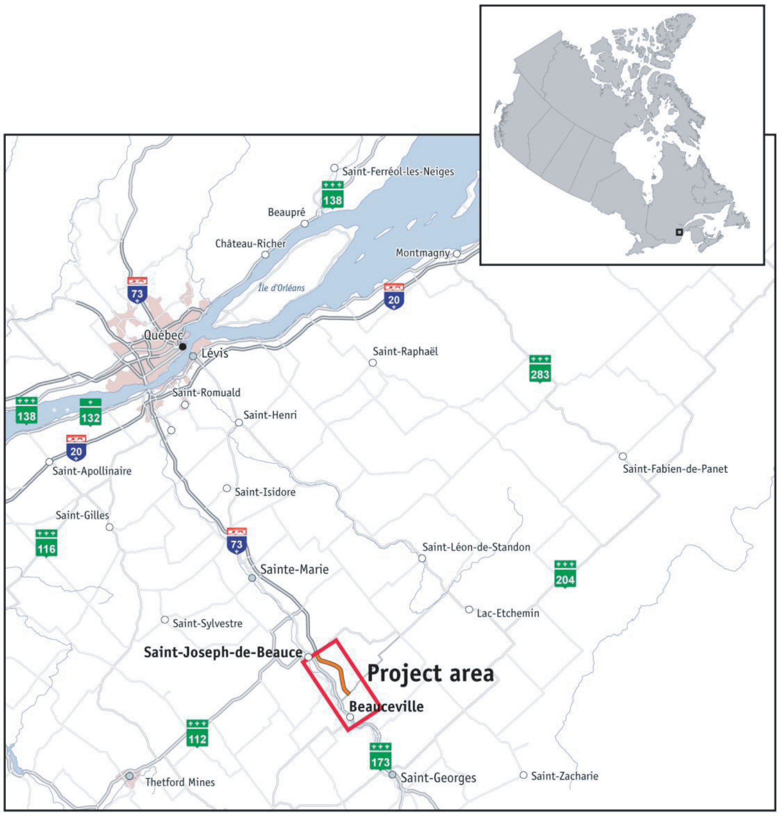



Figure 1. Location of the study area and HWY 73 in the Beauce Region, Province of Québec, Canada.

White-tailed deer is the most abundant large mammal species in the area. Deer density has been estimated at 6.7 deer per km of habitat in 2001 (Desjardins et al. 2001). Moose and black bear are also present but only occur in limited numbers. As it is the case in most of its northern range, yarding behaviour is much prevalent among this population. It induces well-known migrations in the area from summer to wintering areas although some deer do not and others do only during severe winters but not in mild winters (Messier and Barrette 1985, Van Deelen et al. 1998). Deer have established a winter yard in the area in 1989 along the Calway River. It size has grown from 4 km$^2$ (1.54 mi$^2$) in 1989 to near 15 km$^2$ (5.8 mi$^2$) in 1998 (Hébert, 2003). It is worthwhile to note than the Chaudière River, the Road 173 and agricultural land act in some ways as a barrier or a filter to westward movement by terrestrial fauna.

## Highway Project Description

Construction of HWY 73 began in 1973 and aimed at connecting the City of St-Georges to the urban population of Québec City. The uninterrupted movement of people, freight and business is deemed essential to the economic vitality of the Beauce region. It is an important link connecting Central Quebec to the State of Maine, USA. A total of 62 km (38.5 mi) has been built and is currently open to vehicular traffic. This project will add a 10.4 km (6.5 mi) section of HWY 73 from St-Joseph-de-Beauce to Beauceville. The annual average traffic volume was estimated at 7 300 vehicles per day in 2003 at the southern end of HWY 73 (QMOT, unpublished data).

Construction of the new section has been split in three phases started from the northern to the southern end. The first phase started during summer 2004 and the completion of the third phase is scheduled for fall 2007. The first 6.0 km (3.7 mi) section of HWY 73 is a two-lane infrastructure. The remaining part is a four-lane divided section. The project includes one concrete box culvert, 4 bridges (2 over major rivers and 2 over low volume rural roads) and several small concrete boxes or creek crossing structures. The cross section of the two-lane part consists of two 3.7-m lanes, two 3-m outside shoulders and around 15 m of adjacent rights-of-way (*sensu* roadsides). Road characteristics for the four-lane divided section are identical to the two-lane highway section except that inside shoulders will be separated by a grass median of 20 m (66') and a total right-of-way width of about 105 m (344').

## Methods

### Planning and Implementing Mitigation Measures

From the early stage of planning and environmental assessment of this project, the presence of a traditional wintering area for deer bisecting the corridor became an important issue. To circumvent this area it would have required substantial project concept modifications, increased travelling distance, and reduced traffic flow for motorists and truckers due to major slope constraints. In addition, the estimated cost of such design modification would have been very expensive. Given this situation, the need for mitigation measures for deer arose early during the engineering studies and project design activities by the proponent. Deer fencing and wildlife crossing structures were readily considered and planned to reduce risks of deer-vehicle collision and allow deer to access to the entire deeryard during winter.

In order to determine the placement of mitigation measures, we conducted yearly winter tracks and trails surveys in mid March 1999, 2000 and 2001 and every 3 weeks between December 19, 2001 and April 2002 along the projected centerline before forest clearing of rights-of-way started. Surveys only occurred ≥2 days after snowfall to ensure a minimum of detectable tracks and trails. Tracks and trails counts were conducted on snowshoes. Snow and sinking depths were also recorded every 200 m (656') along transects. Each track or trail was either considered to have crossed or to have paralleled the projected centerline. We used a GPS with a 6-10 m accuracy to obtain track and trail locations.

An aerial inventory of deer was also conducted on February 14, 2002 to estimate the number of deer wintering in the Calway deeryard. The double-count technique was used (Potvin et al. 2004). Two other aerial surveys were conducted on February 17, 2003 and March 13, 2003 to delineate the spatial extent of the deeryard and to determine spatial use during pre-construction phase. To illustrate spatial distribution of deer used from these aerial inventories, we used the Density (Kernel) function of the Spatial Analyst program extension in ArcView. Search radius was set to 1000 m (3281') and the following weights were attributed: 1 for a single track, 2 for a single trail, 3 for a network of tracks and 3 for seen deer.

With this information in hand, the Quebec Ministry of Transportation (QMOT) environmental specialists and independent wildlife biologists reviewed the project and discussed with project engineers. Deer fencing recommendations were put forward as a safety and a wildlife mitigation measure. This planning process led to adjustments in bridge and creek crossing structures designs to provide adequate sites for safe deer crossing along the bisecting highway. We identified and prioritized the location of deer fencing and mitigation passages for deer based upon our tracks and trails surveys as well as aerial inventories. We located two primary and three secondary deer crossing structures. Design guidelines were based on available literature, personal contact with other deer specialists and our knowledge of deer movements and ecology in the area.

### Monitoring Program

Once the mitigation measures accepted and integrated in the project, the QMOT and the Québec Ministry of Natural Resources and Wildlife (QMNRW) set up a 6-years monitoring program (1) to determine if the new highway and its fenced section change patterns of space use and migratory movements toward and out of the Calway deeryard, (2) to determine use and identify factors facilitating deer passage through available crossing structures and (3) to estimate the proportion of migratory and non-migratory deer using the Calway deeryard.

Starting in 2003, deer were captured in January using Stephenson box traps placed along known trails and on each side of the proposed highway corridor (2003 and 2004) or of the newly cleared rights-of-way sections (2005, 2006, and 2007). Traps were baited with white cedar foliage and commercial feeds. All deer were immobilised in a net, sexed and fitted with an ear tag and a radio collar. Between 20 and 22 deer were radiocollared each winter because not all of them survived or returned to the Calway deeryard to the next winter. The number of marked deer available for telemetry monitoring each winter is given in table 1. Deer were located from the ground twice a week by triangulation between January 1 and March 31 and from the air once or twice during summer and fall. We used the minimum convex polygon (MCP; 100% confidence area) to estimate winter home range of each deer. We only used deer that had 15 or more locations.

Aerial surveys were conducted once or twice during winter depending upon prevailing snow conditions on the ground to locate and determine the spatial use of the Calway deeryard. Two surveys were conducted in 2003, and one per year in 2004, 2005, 2006, and 2007 using an Highlander plane, a Bell 206, or a R44 helicopter.

We started monitoring every week four completed deer crossing structures using tracks surveys and wildlife infrared sensor cameras from January 2007 to April 2007 following the near completion of deer-proof fencing in fall 2006. Escape ramps and a strip of 150 m (492') at the northern ends of the fence section were also checked weekly for tracks and movement toward the fenced rights-of-way.

Table 1: Number, sex and age of usable radio-collared deer per year

| Winter | **Adult deer** | | **Immature deer** | | **Total** |
|---|---|---|---|---|---|
| | **Male** | **Female** | **Male** | **Female** | |
| 2003 | 3 | 3 | 4 | 2 | **12** |
| 2004 | 6 | 8 | 9 | 5 | **28** |
| 2005 | 5 | 15 | 1 | 8 | **29** |
| 2006 | 3 | 16 | 3 | 9 | **31** |
| 2007 | 3 | 17 | 6 | 9 | **35** |

## Results

### Chronology of the highway construction project

*Summer 2004*

A total of 6-km (3.7 mi), 55 (180') to 65 m (213') wide strip of forests were cleared within the rights-of-way to accommodate the new section of highway north of the Calway Road. Preliminary grading work started but stopped in late fall. Most of this section was located outside of the Calway deeryard and the forest clearing operations barely affected the northwest edge of the deeryard.

*Summer 2005*

The construction of one of the two primary deer crossing structures started at the Doyon Creek (fig. 2). Part of the deer-proof fence (2.4 m or 8' high and constructed of woven wire) was installed at the northern end of the deeryard and on each side of this structure for a total length of 1.8 km (1.1 mi). Eight escape ramps were also built within the fenced section for deer. Construction of the Calway River Bridge started but stopped in late fall. This open-span bridge is considered at the heart of deeryard and is the second primary deer crossing structure. The construction of the Calway road bridge also started during the summer. This structure is considered a secondary deer crossing underpass because deer often use this very low-used gravel road during winter to travel within the deer yard. In early fall, the completed section of the highway was paved and roadsides seeded for a length of 5 km. No vehicular traffic was allowed except for construction workers.

*Summer 2006*

The Calway River Bridge was completed (fig. 3) and deer-proof fences were tied into the bridge abutments. Another section was cleared, graded and paved with an average right-of-way width of about 100 m. Deer-proof fences were installed on another 3.3 km (2.1 mi) section adjacent to the previous fenced section. A total of 13 escape ramps were also put up. Construction of the Carrière road bridge started and was completed by fall 2006. This underpass is considered a secondary deer crossing structure. The Carrière Road is a privately-owned gravel road and is seldom used during winter when deer are using the Calway deeryard. Clearing and grading started for the third and last section of highway. Construction of the open-span Des Plantes River bridges also started and some drilling operations lasted until early March 2007. Adjustments were made on previously built escape ramps during spring and summer 2006. Again, no vehicular traffic was allowed on paved surfaces except for construction. Two primary and two secondary crossing structures combined with deer-proof fencing funnelling deer toward the underpasses were therefore available at the onset of fall migration into the deeryard for winter 2007.

*Summer 2007*

Construction of the Des Plantes River Bridges will be completed and will represent the fifth and last deer crossing structure available to deer. Deer-proof fencing will be completed and tied into the bridges abutments. Six additional escape ramps will also be constructed to allow trapped deer in right of way to return to forested areas. The remaining section will be graded and paved for public opening of the highway section during fall 2007.

*Dimensions and description of deer crossing structures*

Table 2 provides technical information on crossing structures available in this new section of HWY 73. Deer-proof fencing will be put up between kilometre markers 3+400 and 9+600.

Table 2: Location and description of crossing structures on the new section of HWY 73

| Kilometer marker | Structure | Type | Year completed | Span (m) | Rise (m) | Length (m) | Openness ratio |
|---|---|---|---|---|---|---|---|
| 3+920 | Doyon Creek | Concrete box culvert | Fall 2005 | 10 (32.8') | 5.0 (16.4') | 13.4 (44.0') | 3.7 |
| 5+300 | Calway River | Open-span bridge | Summer 2006 | 120 (394') | 10.9 (35.8') | 14.3 (46.9') | 91.5 |
| 5+600 | Calway road | Open-span bridge | Summer 2006 | 27.5 (90,2') | 5.0 (16.4') | 14.3 (46.9') | 9.6 |
| 7+340 | Carrière road | 2 open-span bridges | Fall 2006 | 12.6 (41.3') | 5.1 (16.7') | 12.6 (41.3') each | 5.1 |
| 8+800 | Des Plantes River | 2 open-span bridges | Fall 2007 | 177 (581') | 14 (45.9') | 12.6 (41.3') each | 196.7 |

Figure 2. Doyon Creek concrete box culvert before tree and shrub planting.

## Salient Features on the Spatial Use of the Calway Deeryard

*Pre-construction Phase*

Spatial use of the Calway deeryard was variable from one year to another depending on snow depth and timing of storm events. Table 3 provides the results of the tracks and trails survey of mid-March conducted along the projected center line between 1999 and 2002 before construction. Abundant snow precipitation in winter 1999 and 2001 limited deer movement outside well used trails. However, traveling conditions for deer were much better in 2002 when snow cover was light and contained a hard crust formed after heavy rains in February. Combined data surveys in the winter 2001-2002 showed that deer trails were most abundant on both sides of the Calway River, between kilometre markers 4+300 and 5+800 (fig. 4). Tracks were more widely distributed that trails and high numbers were observed between kilometre markers 3+800 and 5+800 (fig. 5). Unlike previous years, a group of deer used a section located between markers 1+200 and 1+800. We suspected that deer stayed around this area because of intense forest harvesting operations.

Figure 3. Calway River open-span Bridge before tree and shrub planting.

Table 3: Number of tracks and trails recorded during yearly surveys along the projected centreline of the new section of HWY 73 before construction

| Variable | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|
| Transect length (m) | 6296 | 6897 | 6909 | 9502 |
| Total number of tracks | 200 | 789 | 238 | 2117 |
| Total number of tracks/ 100m | 3.18 | 11.59 | 3.44 | 22.24 |
| Total number of trails | 27 | 72 | 117 | 70 |
| Total number of trails/100m | 0.43 | 1.06 | 1.69 | 0.74 |
| Average snow depth (cm) | 69 | 44 | 76 | 40 |
| Sinking depth of deer (cm) | 23 | 10 | 42 | 4 |
| Presence of a crust | Yes | Yes | No | Yes |

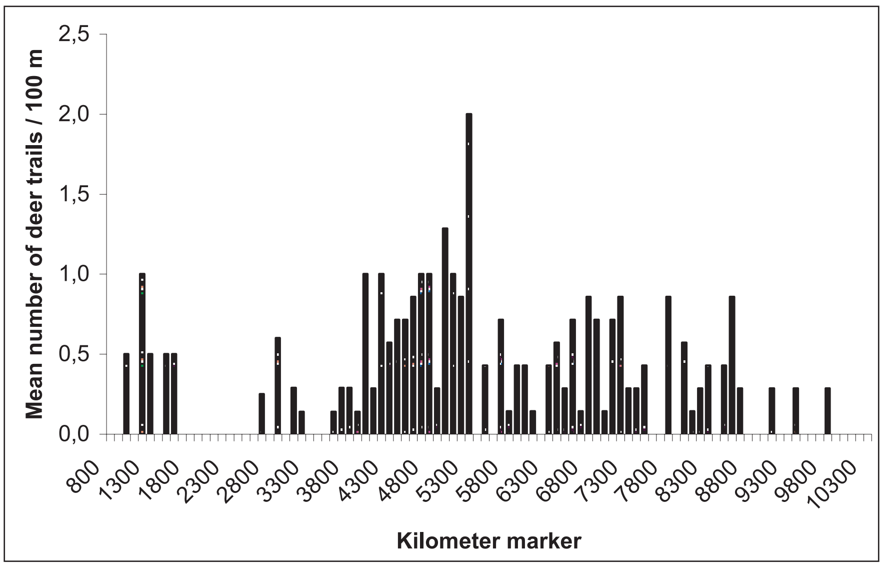



Figure 4. Mean number of trails per 100 m recorded over 7 surveys from mid-December 2001 to early April 2002 along the projected centreline of the new section of HWY 73 before construction.

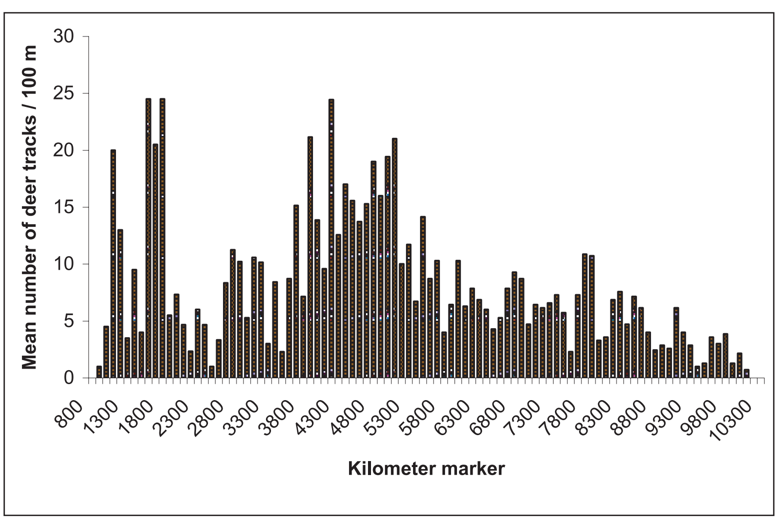



Figure 5. Mean number of tracks per 100 m recorded over 7 surveys from mid-December 2001 to early April 2002 along the projected centreline of the new section of HWY 73 before construction.

The aerial survey using the double-count technique conducted on February 14, 2002 provided an estimation of 315 deer in a delineated area of 36 km$^2$ (13.9 mi$^2$).The winter density averaged 8,8 deer/km$^2$ ± 44% and was considered a low-density population compared to nearby deeryards of density above 25 deer/km$^2$. Data from aerial surveys conducted on 17 February and 13 March, 2003 showed that deer occupied an area of 30.3 (11.7 mi$^2$) and 22.1 km$^2$ (8.5 mi$^2$) respectively. In February, large concentration of deer, tracks and track networks were located between kilometre marker 3+000 and 7+600. Snow and sinking depth were 50 and 46 cm respectively. Later in March, most deer had reduced their spatial use of the deeryard and they were particularly abundant in an area of 4 km$^2$ (1.5 mi$^2$) between Calway Road (5+620) and Doyon Creek (3+750) on each side of the projected centerline. The survey conducted on 12 February, 2004 provided different results. Deer and deer signs were much more concentrated and distributed toward the west side of the projected centreline. The deeryard occupied an area of 23.7 km$^2$ (9.2 mi$^2$), a 7 km$^2$ (2.7 mi$^2$) difference from the year before. Snow and sinking depth were very similar to that of the previous year with respective values of 55 and 44 cm. However, winter arrived earlier in 2004 and deer started to congregate much earlier to the center of the deeryard.

We located 36 deer 807 times from the ground between 1 January and 31 March in 2003 and 2004 to estimate mean winter home range of deer in the Calway deeryard. Average winter home ranges for marked deer were 269 ha in 2003 and 150 ha in 2004. These two years of telemetry have also shown that almost all deer using the Calway deeryard move to the east or the northeast for the summer. About one third remained within 1 km (0.62 mi) of their winter range. One third moved from 1 to 10 km (6.2 mi) away from the known winter home ranges. Finally, the remaining deer migrated a distance longer than 10 km (6.2 mi) to reach their summer range. Average distances between the summer location and the centroïd of the winter home range were 15.3 km (9.5 mi) and 13.7 km (8.5 mi) for males (N= 21) and females (N = 16) respectively. No differences were found between males and females.

*Construction Phases*

Use of the deeryard in winter 2005 was very similar to that of preconstruction phase despite a cleared right-of-way of more than 6.0 km long and 55 to 65 m wide at the northwest end of the project. Deer moved to the winter yard in December as usual. The average home range of radio-collared deer was 167 ha (N = 29) which was very similar to that of 2004. Deer used the entire deeryard (fig. 6) and were not impeded by the presence of a cleared strip. Deer and deer signs were again more abundant on the west side of the projected centerline. The deeryard occupied an area of 22.7 km$^2$ (8.8 mi$^2$). Snow and sinking depth were much lower than that observed in previous years, with respective values of 35 and 20 cm.

In 2006, we obtained similar results despite a 6-km completed section and 2-km of deer-proof fencing. The Doyon Creek concrete box was available for deer to go across the fenced portion. Although no monitoring was conducted on the use of this primary deer crossing structure, numerous tracks were detected during occasional visits to the site by QMTQ and MRNQ wildlife technicians and biologists. Pictures of deer using the passage were also taken from wildlife cameras installed on the inside walls of the underpass. The average home range of radio-collared deer was 152 ha (N = 31) which very similar to that observed during the previous winter. Deer used the entire deeryard but they seemed to be less present near the northeast side of the fenced portion and near the Calway River. They were still using the northwest part of the range like other years. The deeryard occupied an area of 18.1 km$^2$ (7.0 mi$^2$), which was slightly smaller than in 2005 and 2004. However, snow conditions were more severe with an average snow depth of 54 cm and a sinking depth of 30 cm.

However, during the week of 9 April 2006, when deer were presumably moving to their summer range, about 20 of them penetrated inside the fenced section from the southern end at the Calway River Bridge construction site. They spend an unknown amount of time walking along the fences and some of them succeeded in escaping through the escape ramps or jumps-out. However, a number of them did not find the openings and kept dashing into the wildlife fence at the edge of escape ramps, and specifically where there was a change of alignment in the wildlife fence. Use of the highway paved section by some construction workers probably induced panicking among deer that felt trapped in someway. Snow fences were quickly put up on the metallic fences on critical spots of escape ramps so that the deer will perceive it as a wall and keep walking toward the opening instead of trying to get across the fence that had suddenly and probably appeared as brushes. This event initiated a number of design modifications on specifications of escape ramps (height, slopes steepness, links with fences) and their positioning along the wildlife fencing.

In winter 2007, as most of the deer-proof fences were put up, deer occupied the same area of the yard, besides minor differences (fig. 7). Among them, there were less deer using the southwest part of the deer yard, probably owing to many factors such as the fact that construction activities took place until March 2007 at the Des Plantes River bridges construction site, the presence of newly cleared right-of-way and deer-proof fences, and large clear-cut areas in the vicinity. Distribution of deer was also more extended in 2007 than in previous year, especially toward the northeast. We believed that unusual light snow cover that last up to mid-February did not incite all deer to move to the core of the deeryard as in normal years. An area of heavy use by deer was also detected to the northwest part of the yard, but this phenomenon appeared related to forest harvesting activities that provided plentiful of browse from felled trees, at least during January and February 2007. The area occupied by deer covered 25.5 km$^2$ (9.8 mi$^2$) and snow depth tallied to 47 cm with a sinking depth of 43 cm.

Home range analyses were not completed for winter 2007, except for few deer followed since 2003 and 2004. Two examples are provided in figures 8 and 9 of two adult females that had their winter home range split by the new highway section. After construction of the deer-proof fences in fall 2006, deer #47 maintained its winter home range on each side of the new highway section. However this adult female has more than doubled its winter home range and moved slightly to the northwest in 2007. Deer #81 reacted similarly, but moved slightly its home range to the north in 2007. This deer was photographed crossing the Calway River underpass in both ways in many occasions. Table 4 shows yearly estimates of winter home range of these two radio-collared deer potentially and directly affected by this project. Greater winter home ranges in 2007 may partly be attributed to very light snow cover enabling deer to move easily throughout the area.

During the 2007 winter, starting 6 December 2006 and ending 29 March 2007, we monitored the four completed deer crossing structures once a week using snow track surveys and still cameras triggered by active infrared sensor. Table 5 shows preliminary results of the track surveys for all underpasses. These numbers must be considered as minimum values because snow precipitations erased tracks between days of data collection. Consequently, deer tracks could be recorded during 64 days only, over a period of 149 days. In addition, number of tracks observed underneath for the Calway Road and the Carrière Road bridges (fig. 10) must be considered minimum values because deer used snowmobile tracks or ATV trails to cross these structures, where they became undetectable following use of the trails by these vehicles. Nevertheless we believe the Calway River Bridge received the heaviest use by far. Peak use in this underpass occurred in December 2006 (2.5 deer/day) and the last week March 2007 (7.0 deer/day). The same pattern was observed in December at the Doyon underpass. Deer movement was linked to the fall migration to winter range. Newly designed and built escape ramps seem to work better as a total of 12 deer jumped over out of 21 that walked on the ramps during the 2007 winter track surveys each week.

Table 4: Estimates of annual winter home ranges of two radio-collared deer with home ranges split by the new highway between 2003 and 2007 in the Calway deeryard

| Winter | Winter home range of deer # 47 ($km^2$) | Distance of centroids between consecutive winters (m) | Winter home range of deer #81 ($km^2$) | Distance of centroids between consecutive winters (m) |
|---|---|---|---|---|
| 2003 | --- | --- | 0.93 | --- |
| 2004 | 1.98 | --- | 0.51 | 320 |
| 2005 | 4.29 | 385 | 0.51 | 162 |
| 2006[1] | 2.65 | 473 | 1.15 | 407 |
| 2007[2] | 3.61 | 1919 | 1.89 | 664 |

[1] deer-proof fencing partially completed (34%) and one deer crossing structure available

[2] deer-proof fencing almost completed (87%) and four deer crossing structure available

Table 5: Total number and direction of deer passing through each underpass for the 2007 winter (6 December 2006 to 29 March 2007)

| Deer crossing structure | East | West | Undetermined | Total | Number of deer crossings per day (n = 64) |
|---|---|---|---|---|---|
| Doyon Creek | 21 | 23 | 0 | 44 | 0.69 |
| Calway River | 67 | 42 | 11 | 120 | 1.88 |
| Calway road | 18 | 12 | 0 | 30 | 0.47 |
| Carrière road | 15 | 18 | 0 | 33 | 0.52 |

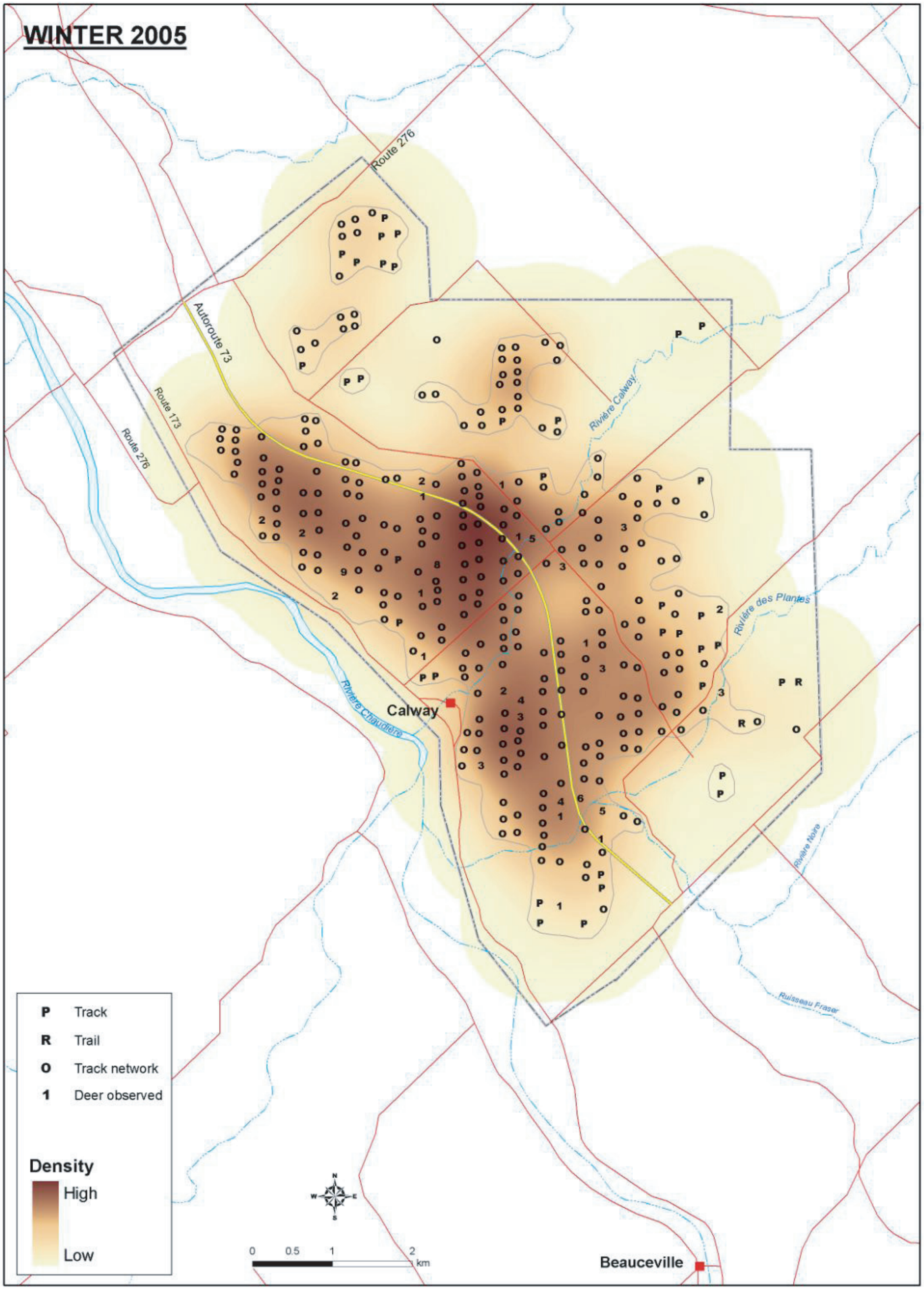



Figure 6. Spatial use of the Calway deeryard determined from an aerial inventory of deer signs on 25 February 2005 (darker areas show stronger use by deer, see methods).

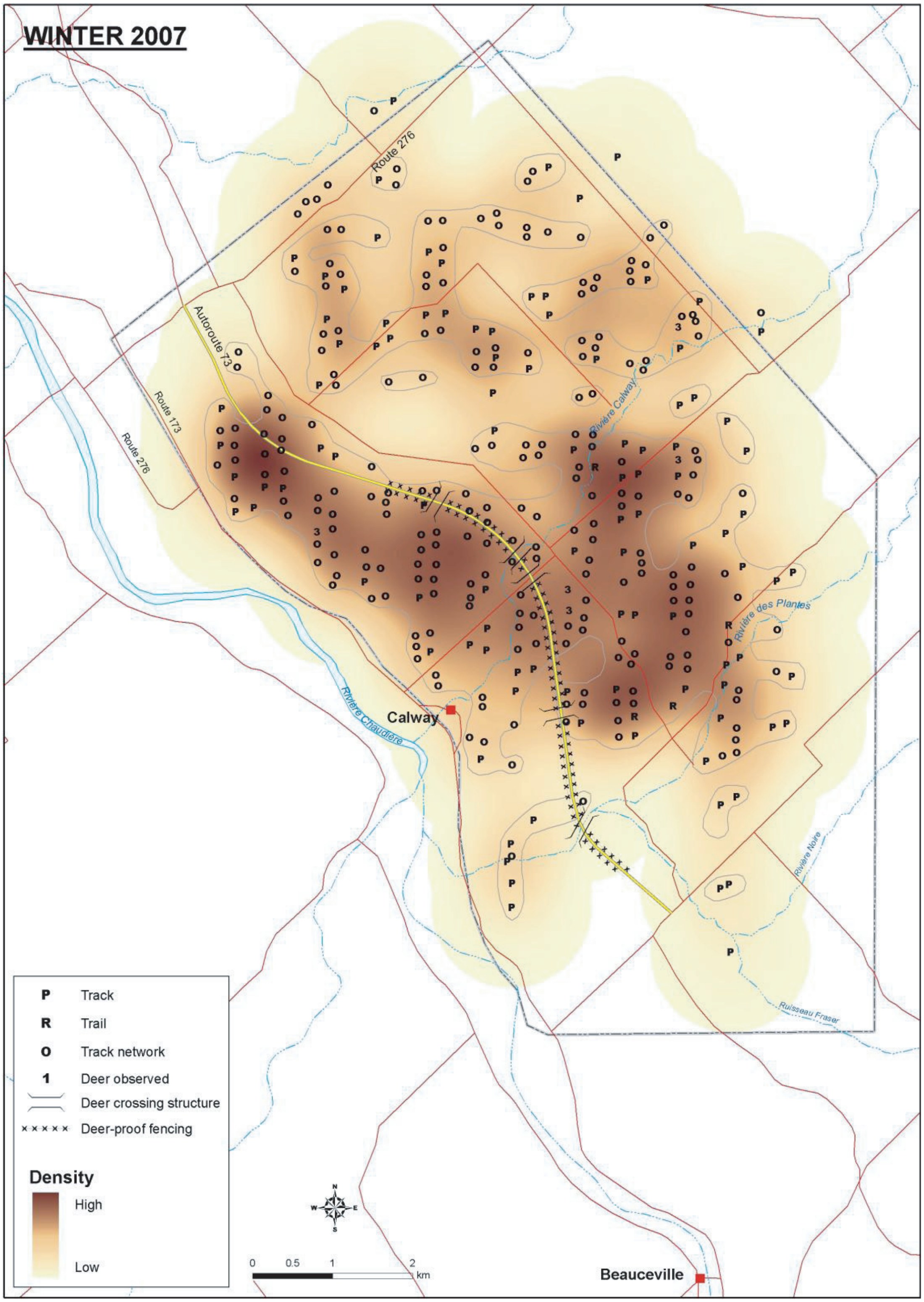



Figure 7. Spatial use of the Calway deeryard determined from an aerial inventory of deer signs on 28 February 2007 (darker areas show stronger use by deer, see methods).

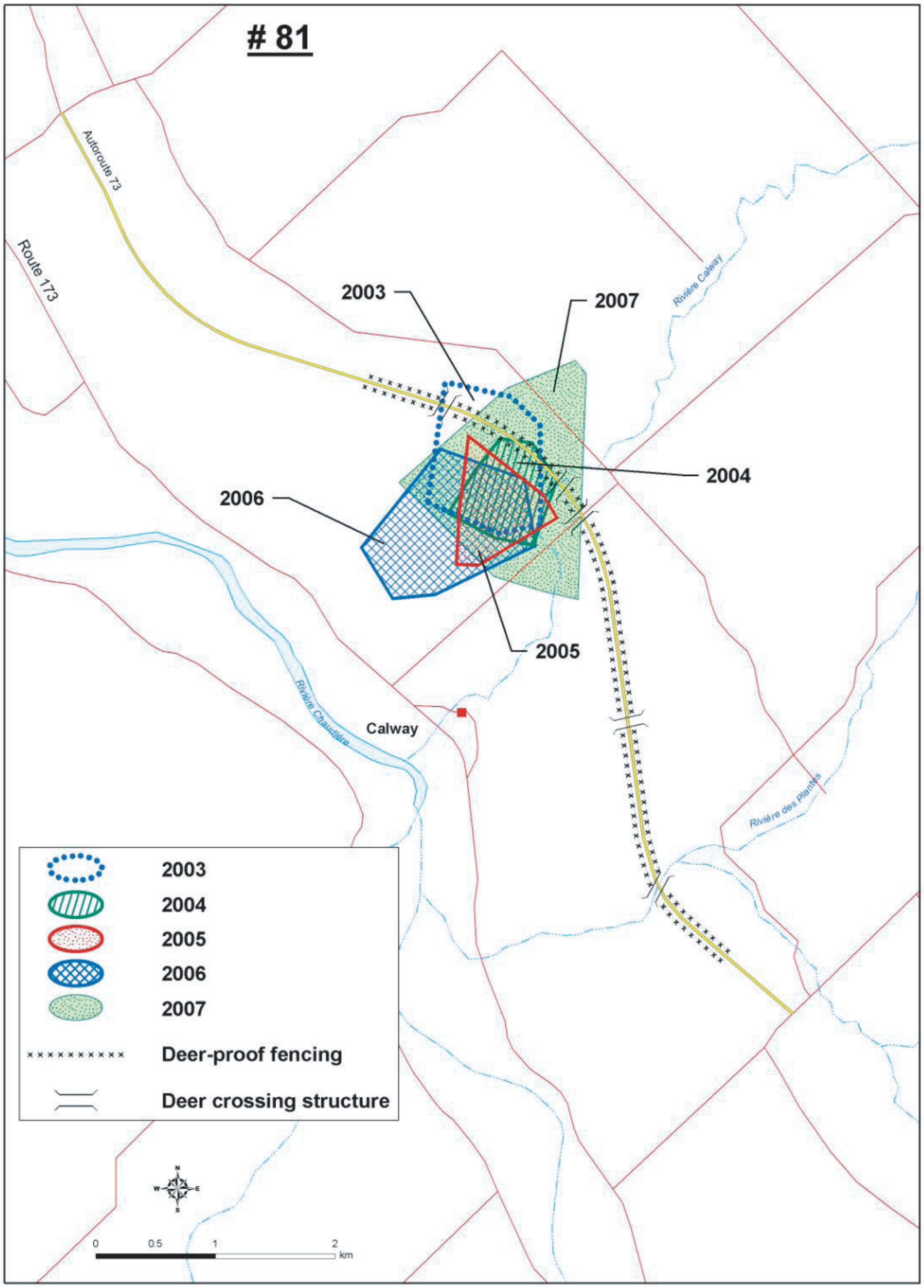



Figure 8. Location of winter home ranges of deer #81 between 2003 and 2007 in the Calway deeryard.

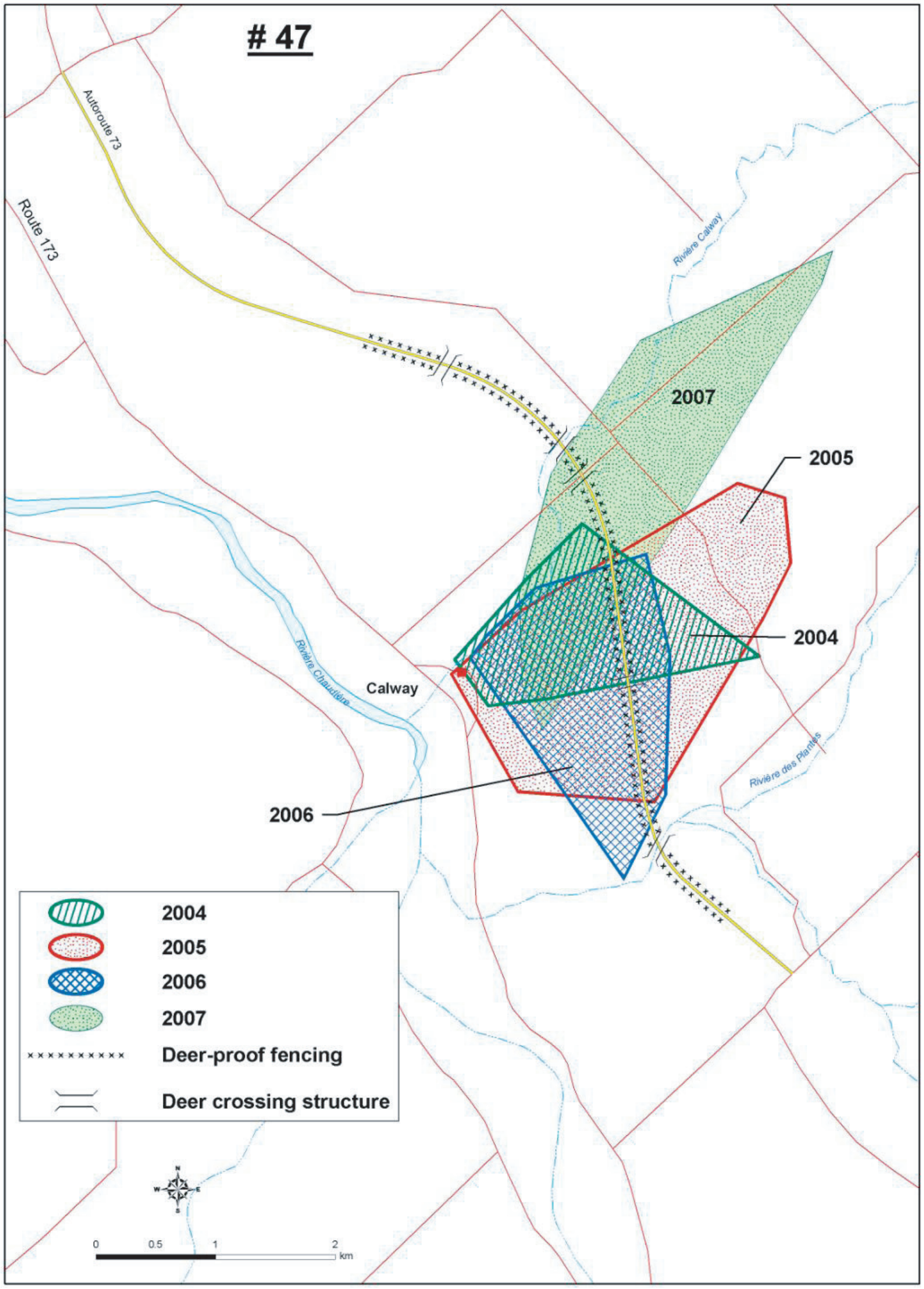



Figure 9. Location of winter home ranges of deer #47 between 2004 and 2007 in the Calway deeryard.

Figure 10. Six deer passing under the Carrière Road bridges, a secondary deer crossing underpass on 10 April 2007.

**Discussion**

Our study demonstrates that valuable information can be gathered during planning and before construction to locate the most suitable sites for wildlife crossing structures. Site-specific examples such as this project show the value of obtaining field data and the possibility of adjusting designs before final drawings and specifications to develop solutions to maintain habitat connectivity for wildlife.

In this particular case of a bisected northern deer winter yard, track surveys showed that a great proportion of movements occurred near the valley of the Calway River and to the north of it. Some other corridors like the Calway and the Carrière Roads also proved to be fairly well used by deer moving within the winter yard, probably due to low levels of human activity on these roads. The track and aerial surveys also helped us to determine where we had to make the greatest efforts to provide suitable crossing structures for deer while maintaining highway safety.

A number of decisions were therefore taken early at the planning and designing stages of these structures and their surrounding landscape to facilitate deer use of these underpasses even if some were classified as secondary crossing structures. Aerial surveys also showed that the size and the area used each year by deer in the Calway deeryard vary according to snow cover conditions, the timing of winter storm events, and forest harvesting activities. We therefore dealt with a deer population that already had and demonstrated flexibility on their use of the winter range.

Our preliminary results on weekly snow tracks inventories gathered in the 2007 winter when most fencing and crossing structures were completed clearly indicated that all available deer crossing structures have been used by deer to varying degrees. Given the number of recorded deer crossings in only three months (n = 227), the design of crossing structures met the species requirements (openness ratio) and they were adequately located. Observed crossing frequency obtained for the Calway River underpass during winter was very similar to the annual value reported by Donaldson (2006; 1.34 crossings/day at Site 2) for a similar bridge in Virginia, USA.

However, our crossing structures were used but their effectiveness (percentage of repels) is unknown as we did not gather data on repel rates using video monitoring. However, we believe that a significant portion of this population has been using the crossing structures, as we captured images of different radio-collared deer. The 2007 telemetry data have not been yet analysed, and therefore, the number of marked deer getting across the fenced portion of highway remains unknown.  Also we do not know yet if some deer have altered their movement patterns to cross the fenced portion through completed underpasses.

The similar spatial distribution of deer north of the Calway River before and during construction indicated that deer were successful into crossing structures. If the deer would have not been able to reach this portion of the deeryard, we would have recorded low density of deer signs and this was not the case. There was also repeated use of the Calway River underpass by deer during the 2007 winter. This crossing structure seems to be very effective in terms of facilitating deer passage, probably because 1) deer knew this area well and had used it heavily before construction and 2) the structural features of this underpass resulted into a very high openness index. Both location and landscape features (Beier and Loe 1992) and structural features (Clevenger and Waltho 2005) have contributed in determining the Calway River underpass's success.

The 2007 winter use of the area south of the Calway River has been somehow lighter than in pre-construction years. It's however hard to tell which factors contributed the most to this lesser use of this area. Construction and human activities that took place until March 2007 at the Des Plantes River bridges construction site may have repelled some deer to use this area. Also, the presence of new large clear-cuts may not have provided enough suitable cover and food for and may have forced deer to spend the winter elsewhere in the deeryard. The very late arrival of winter may also have altered the usual distribution pattern of deer. Finally, the presence of the deer-proof fence may also have had an impact on the use of the area of the deeryard. Further monitoring of the spatial distribution of deer in subsequent years is necessary to help us to better understand the effect of these yearly changes in spatial use of the Calway deeryard.

Lack of vehicle traffic, noises and disturbances on the ready-to-use completed section of HWY 73 may have contributed to facilitate use and familiarization of the crossing structures by deer. Monitoring during winter 2008 will give us the opportunity to determine if this factor can have a significant effect of the use of crossing structures. However, its effects might be confounded with the fact that deer had up to two years to learn the structures' locations and to become accustomed to it.

We also learned from this project that successful management actions implemented at one site may not give the same result in another area. Also, small detail in designing structures can make a difference to improve the efficiency of a given mitigation measure. This was particularly the case with escape ramps in which fence angles at the approach were eliminated and the height of the platform lowered by about 25 cm (10'').

In conclusion, the four completed crossing structures combined with deer-proof fencing have been readily and successfully used by deer and have so far contributed to maintaining access to the bisected deeryard. Further analyses and monitoring will provide detailed data regarding individual and population responses, expected increase of deer use of crossing structures (Clevenger and Waltho, 2006) and the effectiveness of escape ramps.

**Biographical Sketches:** Yves Leblanc. Yves Leblanc is a senior wildlife research biologist with Tecsult Inc. He is currently under contract with the Quebec Ministry of Transportation to assess and reduce moose and white-tailed deer vehicles collisions in different upgrading and new highway projects. Yves is also involved in many environmental impact assessment of major hydroelectric and road development on ungulates, waterfowl and fur bearing animals in northern Québec. He has also been involved in wildlife management and research projects with the Québec Ministry of Natural Resources and Wildlife on beaver, fisher and woodland caribou. Yves holds a B. Sc. in biology from Université Laval and a M. Sc. in Zoology from the University of Alberta.

Jacques Bélanger. Jacques Bélanger is an environmental specialist at a regional office of the Québec Ministry of Transportation. He is currently in charge of the environmental impact assessment of HWY 73 on the natural environment. He holds a B. Sc. in Biology from Université de Montréal.

Sylvie Desjardins. Sylvie Desjardins is a wildlife biologist at the Québec Ministry of Natural Resources and Wildlife since 1982. She is currently in charge of big game management in the Chaudière-Appalaches region that includes the project area. Sylvie holds a B. Sc. in Biology from Université de Sherbrooke.

**Acknowledgements:** The Ministère des Transports du Québec (QMOT), the Ministère des Ressources naturelles et de la Faune du Québec (QMNRW), and Tecsult Inc. provided funding for this project as well as numerous human and technical resources. We would like to extend our appreciation towards all wildlife specialists who helped us and still doing it all along. Claude Daigle (QMNRW), Normand Desbiens (QMOT), Benoit Langevin (QMNRW), and Sylvain St-Onge (QMNRW) provided important input into study feasibility and design, as well as contributed to a great part of the data collection. Réhaume Courtois provided important input in the initial stages of the project. François Hudon (QMNRW) and Jacques Fortin (QMOT) provided invaluable assistance into data collection. Thanks are due to Aïssa Sebbane for the GIS work and François Bolduc for reviewing a draft of this paper.

## References

Beier, P., and S. Loe. 1992. A checklist for evaluation impacts to wildlife movement corridors. *Wildlife Society Bulletin* 20:434-440.

Clevenger, A. P. and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of larger mammals. *Conservation Biology* 121: 453-464.

Clevenger, A. P. and N. Waltho. 2006.Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies. In *Proceedings of the 2005 International Conference on Ecology and Transportation*, Eds. Irwin C., Garrett P., McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp 293-302.

Desjardins, S., M. Cusson and B. Langevin. 2001. Inventaire aérien de la population de cerfs dans la region Chaudière-Appalaches à l'hiver 2001. Québec, Société de la faune et des parcs, Direction de l'aménagement de la faune de la Chaudière-Appalaches. 26 p.

Donaldson, B. 2006. Use of highway underpasses by large mammals and other wildlife in Virginia and factors influencing their effectiveness. In *Proceedings of the 2005 International Conference on Ecology and Transportation*, Eds. Irwin C., Garrett P., McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp 433-441.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road Ecology – Science and Solutions*. Island Press, Washington DC 20009. 481 pages.

Forman, R. T.T. and L E. Alexander. 1998. Roads and their major ecological effects. Annua. Rev. Ecol. .Syst. 29 :207-231

Hébert, F. 2003. Le ravage de la Rivière Calway. État de situation et recommandations d'aménagement. Québec, Société de la faune et des parcs, Direction de l'aménagement de la faune de la Chaudière-Appalaches, Projet pilote de mise en valeur du cerf de Virginie. 36 p.

Jaeger, J. A. G., L. Fahrig, and K. C. Eswald. 2006. Does the configuration of road networks influence the degree to which roads affect wildlife populations? In *Proceedings of the 2005 International Conference on Ecology and Transportation*, Eds. Irwin C., Garrett P., McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp151-163.

Messier, F. and C. Barrette. 1985. The efficiency of yarding behaviour by white-tailed deer as an antipredator strategy. *Can. J. Zool*. 63:785-789.

Potvin, F., Breton, L. & Rivest, L.-P. (2004). Aerial surveys for white-tail deer with the double-count technique in Quebec: two 5-year plans completed. *Wildlife Society Bulletin*, 32 (4), 1099-1107.

Van Deelen, T. R. H. Campa, M. III. Hamady, and J. B. Haufler. 1998. Migration and seasonal range dynamics of deer using adjacent deeryards in northern Michigan. *J. Wild. Manage*. 62 :205-213.

# Effects of Roadway Traffic on Wild Ungulates: A Review of the Literature and a Case Study of Elk in Arizona

**Jeffrey W. Gagnon** (928-522-8164, jeff_gagnon@yahoo.com) and Raymond E. Schweinsburg, Arizona Game and Fish Department, Research Branch, 2221 West Greenway Road, Phoenix, AZ 85023 USA

**Norris L. Dodd** (928-368-3017, doddnbenda@cybertrails.com), Arizona Game and Fish Department, Research Branch, Pinetop, AZ 85935 USA

**Abstract:** Roads have been recognized as a threat to wildlife species for over 80 years. Studies on the effects of roads on ungulates species did not begin till the 1970's. We identified 53 literature sources that suggested or examined traffic levels or road types and their effects on ungulate-vehicle collisions, ungulate distribution and roadway permeability. Seventy-one percent of these suggested an effect of traffic level on ungulates. Only 47% of the papers suggested deer (*Odocoileus spp.*) were affected by traffic while in contrast studies on elk (*Cervus elaphus*) and moose (*Alces alces*) were at 84% and 82%, respectively. In studies that suggested no effect of traffic, other factors such as ungulate populations, ungulate behavior, driver behavior, and landscape variables were generally considered reasons for fluctuations in collisions. Although several studies examined ungulate distribution along roads, very few adequately looked at fluctuating traffic levels along highways. Highways have a greater potential for ungulate-vehicle collisions and are more likely to provide a barrier to ungulates than low traffic roads. Our further understanding of ungulate movements and behavior in relationship to highways may be important in helping to mitigate ungulate-vehicle collisions and ungulate habitat fragmentation. Our State Route 260 project in central Arizona has provided a unique opportunity to examine elk movements in relation to traffic along a highway. We documented distinct shifts in distribution associated with fluctuating traffic levels as well as reductions in probabilities of at-grade crossings during increasing traffic levels. During the same study we found that increased traffic levels did not alter elk use of wildlife underpasses. Overall, properly designed wildlife underpasses and adequate funnel fencing adequately reduced elk-vehicle collisions while simultaneously promoting highway permeability during increasing traffic levels. Further research is needed to determine if these trends hold true for other ungulate species. Currently, research of fluctuating hourly traffic levels on ungulate behavior associated with highways is underway in Arizona, including American pronghorn (*Antilocapra americana*), mule deer (*O. hemionus*), Coues' white-tailed deer (*O. virginianus couseii*) and further research on elk along highways with different geographical areas and traffic level ranges.

## Introduction

Researchers as early as the 1920's and 30's began taking road trips and documenting wildlife-vehicle collisions associated with vehicle caused mortality (Stoner 1925, 1936; Gordon 1932, Warren 1936 *a,b*; Starrett 1938, Russel and Amandon 1938, Dickerson 1939). Very few of these early studies found ungulate casualties. Only Haugen (1944) and Davis (1939) documented a total of four pigs killed between the both of their studies. It was not until the 1970's that larger wildlife, such as ungulates, became a concern as traffic levels and vehicle speeds increased, leading to higher rates of ungulate-vehicle collisions. In the1970's researchers began to investigate the potential direct and indirect effects of roads and traffic on ungulates.

Roads and traffic have three primary affects on ungulates populations in the form of: 1) ungulate-vehicle collisions, 2) reduced habitat/resource selection, and 3) decreased movement across roadways leading to habitat fragmentation and potentially genetic isolation.

### Ungulate-Vehicle Collisions

In the United States alone, it is estimated that 700,000 (Schwabe & Schuhmann 2002) to >1 million (Conover et al. 1995) deer-vehicle collisions occur, with associated costs that exceed $1 billion (Conover et al. 1995) to $2 billion (Danielson & Hubbard 1998). In Europe an estimated 300 people are killed, and 30,000 injured in >500,000 ungulate-vehicle collisions annually (Groot Bruinderink & Hazebroek 1996). Although researchers disagree about whether increasing traffic levels are the primary reason for increasing ungulate-vehicle collisions (McCaffery 1973; Reilly & Green 1974; Allen & McCullough 1976; Case 1978; Romin & Bissonette 1996), many recognize traffic level as a component of this increase, along with other factors such as wildlife population fluctuations, wildlife behavior, driver behavior, and temporal and spatial environmental factors (Carbaugh et al. 1975, Bashore et al. 1985, Groot Buinderink & Hazebroek 1996, Haikonen & Summala 2001, Seiler 2004, Gunson and Clevenger 2003, Manzo 2006)

### Reduced Habitat/Resource Selection

Roads and the traffic associated with them have presumed effect on ungulate resource potentially reducing the amount of resources available to ungulates, or decreased "habitat effectiveness" (Lyon and Christensen 1992, Lyon 1983). Overall, areas near roads are inhabited less frequently by some ungulates, particularly as traffic levels increase (Rowland et al. 2000, Perry and Overly 1976, Gagnon et al. 2007*a*)

### Permeability/Habitat Fragmentation/Genetic Isolation

Increase in the overall number and width of roads throughout the world increases fragmentation of available ungulate habitat. This is particularly evident along roads with high traffic levels such as highways on wildlife are barrier and fragmentation effects resulting in diminished habitat connectivity and permeability (Noss and Cooperrider 1994, Forman et al. 2003). Highways block animal movements between seasonal ranges or other vital habitats (Trombulak and Frissell 2000). This barrier effect fragments habitats and populations, reduces genetic interchange (Epps et al. 2005, Riley et al. 2006), and limits dispersal of young (Beier 1995), all serving to disrupt viable wildlife population processes. Long-term fragmentation and isolation renders populations more vulnerable to stochastic events that may lead to extinctions (Hanski and Gilpin 1997).

The "road-effect zone" (Forman and Deblinger 2000) is "many times wider than the road itself"; traffic, or the "traffic effect zone" is a key component of the overall road effect zone and includes increases in visual stimuli, sound, vibration, and pollution with increases in traffic level. Many studies have identified distances of traffic effects on ungulates, primarily elk and deer. Early studies primarily focused on habitat selection by examination of pellet count densities (Perry & Overly 1976; Rost & Bailey 1979; Lyon 1979), or radio-telemetry locations within varying distances from roads (Witmer & deCalesta 1985). These early studies suggested that "habitat effectiveness" (the amount of habitat available to elk outside of the hunting season; Lyon and Christensen 1992:4) was reduced as road densities or road types (a surrogate for traffic levels) associated with different traffic levels (i.e., secondary, primary) increased. More recent studies (Rowland et al. 2000; Wisdom et al. 2005), have generally confirmed this pattern.

In this review we investigate various literature sources to examine the effect of traffic on ungulate-vehicle collisions, ungulate distribution along roadways and ungulate permeability across roads for various ungulate species. We also examine the traffic effect zone for ungulates associated with fluctuating traffic levels or different road types.

## Methods

We searched various sources for literature examining the relationships of traffic levels, or road type and ungulates. We used only papers that examined traffic level or road type as a factor, or suggested that traffic had a potential impact on ungulates along roadways. We assumed road type (i.e. primary, secondary) was a classification of roads with different traffic levels. We identified the genera each study identified and whether traffic had an assumed effect. We then identified and placed each study into three categories: collisions, distribution, or permeability. The criteria for assigning studies to each category are as follows:

- *Collisions* – Studies that examined or suggested traffic levels (or road types) as a potential effect/no effect on ungulate-vehicle collision rates or trends.
- *Distribution* – Studies that examined or suggested traffic levels (or road types) as a potential effect/no effect on ungulate distributions in relationship to the roadway "habitat effectiveness", or habitat/resource selection.
- *Permeability* – Studies that examined or predicted traffic levels (or road types) as a potential effect/no effect on road crossings, road crossing behaviors, habitat fragmentation, or genetic isolation.

To examine the "traffic effect zone" for ungulate species we combined data across all literature sources that identified an actual distances where there was decreased distribution or habitat effectiveness. We determined four different road types: 1) primitive, 2) secondary, 3) primary, and 4) highway/interstate. We attempted to place studies in a given road type based on actual traffic levels, or descriptions given in the study. We determined the mean road effect zone for ungulates along each road type as well as all road types combined.

## Results

### Traffic Effects on Ungulates

We found that 71% of the 53 studies we examined incorporated traffic levels (or road type as a surrogate for traffic levels) associated with ungulate collisions, distributions, or habitat fragmentation, suggesting an effect of traffic level on ungulates. Interestingly, only 47% of the papers that examined deer showed a traffic effect while in contrast studies on some of the larger ungulates, such as elk and moose, were at 84% and 82% respectively. A further breakdown of our results are listed in table 1.

Table 1: Summary of literature identifying traffic levels effect on ungulates by Genera. Studies examining multiple species or effects counted more than once

| Genus | N | % Suggested traffic effects on Ungulate: | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Collisions | | | Distribution | | | Permeability | | | **Overall** | | |
| | | Yes | No | % | Yes | No | % | Yes | No | % | **Yes** | **No** | **%** |
| Moose | 11 | 4 | 1 | 80% | 5 | 0 | 100% | 1 | 0 | 100% | **9** | **2** | **82%** |
| Pronghorn | 5 | NA | NA | NA | NA | NA | 100% | 5 | 0 | 100% | **5** | **0** | **100%** |
| Elk | 23 | 2 | 2 | 50% | 16 | 2 | 89% | 3 | 0 | 100% | **21** | **4** | **84%** |
| Deer | 17 | 6 | 6 | 50% | 3 | 4 | 43% | NA | NA | NA | **9** | **10** | **47%** |
| Bighorn sheep | 5 | NA | NA | NA | NA | NA | NA | 4 | 1 | 80% | **4** | **1** | **80%** |
| Caribou / Reindeer | 4 | 0 | 2 | 0% | 1 | 0 | 100% | 1 | 0 | 100% | **2** | **2** | **50%** |
| **Other** | 5 | 3 | 2 | 60% | NA | NA | NA | NA | NA | NA | **3** | **2** | **60%** |

Of the studies that showed no effect of traffic, other factors such as ungulate populations, ungulate behavior, driver behavior, and landscape variables were generally considered to be reasons for increases in collisions.

**Traffic Effect Zone for Ungulates**

Thirteen studies identified either an actual or distance from the highway believed to be the effect zone for the ungulates they studied. The mean traffic effect zone for all road types was 381 m (SE +/-40m), when road type was examined individually the mean road effect zones increased with presumably increasing traffic levels. A breakdown of each road type shows an increasing trend of road effect distance as road type (traffic level) increased (Primitive = 200 m, Secondary = 304 m, Primary=374 m, Highway=425 m; fig. 1).

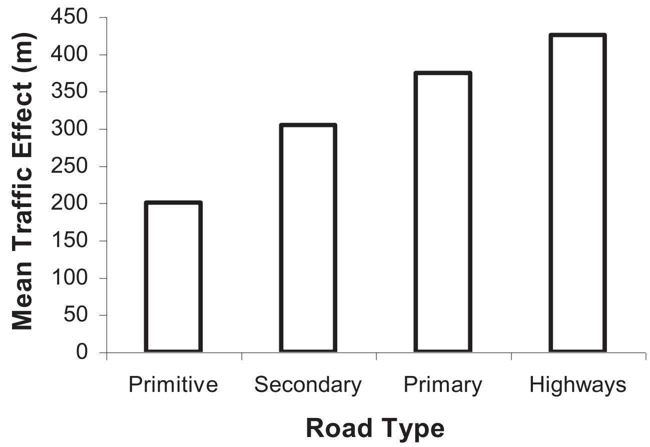



Figure 1. Mean traffic effect zone for all ungulates combined by road type, identified by 13 literature sources.

**<u>Effect of Fluctuating Traffic Levels on Elk: A Case Study in Arizona</u>**
*(Summarized from Gagnon et al. 2007.)*

Although several studies have documented elk response to relatively low-traffic-volume roads (Hershey and Leege 1976, Perry and Overly 1976, Rowland et al. 2000, Wisdom et al. 2005) previous studies have not examined the potentially greater effects of varying traffic levels on elk distributions and movements along highways (Ruediger et al. 2006). Furthermore, previous studies compared elk distributions among different areas of roadway, confounding the effect of traffic with potential differences in habitat, resource type and availability, and human disturbance. In this study, we examined the effects of fluctuating hourly traffic levels on the distribution and movements of Rocky Mountain elk (*C. e. nelsonii*) in central Arizona along a relatively high traffic-volume highway (2004 AADT = 8,700).

**<u>Methods</u>**

We used 38,709 fixes collected from December 2003 through June 2006 from 44 elk (*Cervus elaphus*) fitted with Global Positioning System (GPS) collars and hourly traffic data recorded along 27 km of State Route 260 to determine how traffic volume affected elk distribution and highway crossings. We combined these locations and movement to traffic levels estimated using a permanent traffic counter programmed to record and transmit mean hourly traffic levels, speeds, vehicle type, and direction of travel. The traffic counter was installed in December 2003 at the center of the study area. No major roads branched off the highway along the length we studied, therefore we assumed that traffic volume recorded by the counter accurately represented levels present along that stretch of highway during any one hour interval.

To examine effects of fluctuating traffic levels on distribution, we examined how the proportion of elk locations at different distances from the highway varied with traffic level by calculating the percentage of locations in each 100-meter distance-band, out to a maximum of 600 m. We considered elk within 600 m of the highway as this adequately accounted for prior estimates of the road effect zone for elk. To avoid bias due to differences in sample size (number of locations) for individual elk, we used the proportion of fixes occurring in each distance band for each elk as the sample unit, rather than total fixes. We then calculated a mean proportion across all 44 elk at varying traffic levels out to 600 m.

To determine the effects of fluctuating hourly traffic on highway permeability we used a multiple logistic regression approach. We included other factors identified in the literature as that potentially influence elk movement near roads or are associated with higher elk-vehicle collision rates such as presence of riparian meadow habitat adjacent to roadways (Ward 1976, Dodd et al. 2006, 2007a, Manzo 2006). 2) Season (Groot Bruinderink and Hazebroek 1996, Gunson and Clevenger 2003, Dodd et al. 2006, 2007*b*). Sex (Marcum and Edge 1991, Gunson and Clevenger 2003, McCorquodale 2003, Dodd et al. 2006). 4) Time of night (Groot Bruinderink and Hazebroek 1996, Haikonen and Summala 2001, Dodd et al. 2006). Our binomial response variable was determined once an elk came within 250m of the highway as: 1) subsequent movement resulted in a crossing and 2) all other non-crossing movement. We converted the logistic regression models into calculated probabilities, and then graphed them for ease of interpretation

## Results

Elk along State Route 260 showed a distinct shift in distribution associated with varying traffic levels. Elk were distributed closer to the road when traffic levels were less than 100 vehicles/ hr and shifted away from the road as these traffic levels increased (fig. 2)

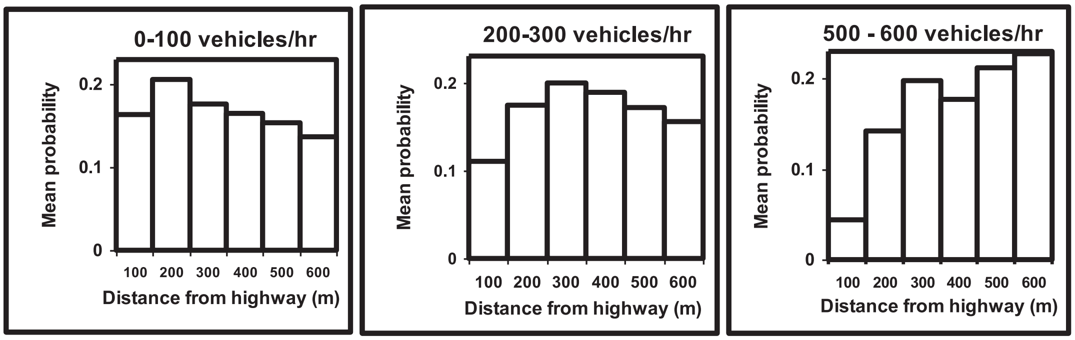



Figure 2. Probability of 44 occurring within a given distance to State Route 260 at selected traffic levels, 2003-2006, Arizona, USA. Modified from Gagnon et al. 2007*a*.

The most important factors in predicting a crossing selected through the logistic regression process included: 1) traffic level, 2) presence of riparian meadow, and 3) season. In this instance, time and sex were non-significant. The overall probability of a crossing decreased by approximately 20% when traffic levels increased to 1,500 vehicles/hr, however the magnitude of the effect of traffic on crossing probability was dependent on presence of riparian meadow as well as season (fig. 3)

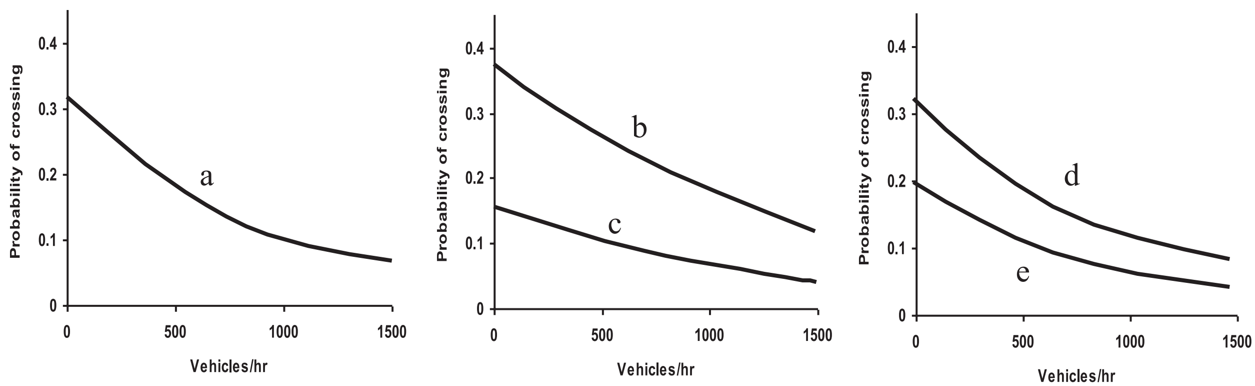



Figure 3. Probability of a successful highway crossing by 40 elk at increasing traffic levels: a) overall, b) with riparian meadow present, c) with riparian meadow absent, d) during non-migrational seasons, and e) during migration seasons. State Route 260, Arizona, USA, 2003-2006.

## Discussion

Studies of lower volume roadways have documented that elk distribution shifted away from areas with roads (Perry & Overly 1976; Lyon 1979, 1983; Rost and Bailey 1979; Witmer & deCalesta 1985; Rowland et al. 2000; Wisdom et al. 2005), in our study these shifts were temporary, with elk returning to utilize areas near the highway at times of reduced traffic. Most previous studies that have indicated roads resulted in reduced "habitat effectiveness" (defined as "percentage of available habitat that is usable by elk outside the hunting season"; Lyon and Christensen 1992:4), examined roads with traffic levels less than 10% of those in our study. Our data suggests that the reduction in habitat effectiveness is a function of the reduced amount of time elk spend near highways as traffic levels increase rather than an overall reduction in population densities.

We also found that although there were overall decreases in crossing probabilities associated with increasing traffic levels, the magnitude of this effect was determined by presence of preferred foraging opportunities or dependent upon season. These findings indicate the overall drive for meeting survival requirements, such as food and water, or seasonal needs (migration, calving, mating, antler development) somewhat offset the overall negative effects of traffic on highway permeability, at least at the levels we studied. Lower traffic levels along highways that are not adjacent to preferred resources may inhibit elk movement at higher rates.

## Ungulates and Traffic Level Thresholds

Iuell et al. (2003) and Trocme et al. (2003) report models that predict highways may become impermeable to many wildlife at 10,000 vehicles/day. We did not find this to be the case for elk along State Route 260 (Gagnon et al. 2007a) where traffic levels regularly reached 10,000 AADT. Not only are elk a highly mobile species that can make quick movements across the highway, on any given highway, traffic levels can vary seasonally, weekly and with time of day, allowing elk and many other animals to cross even high traffic-volume highways during periods of relatively low traffic flow.

Interstate 17 in northern Arizona appears to be reaching traffic levels that may significantly reduce the probability of a successful crossing through either road avoidance or elk-vehicle collisions (fig. 4). Traffic levels along this stretch of highway average around 17,000 AADT.

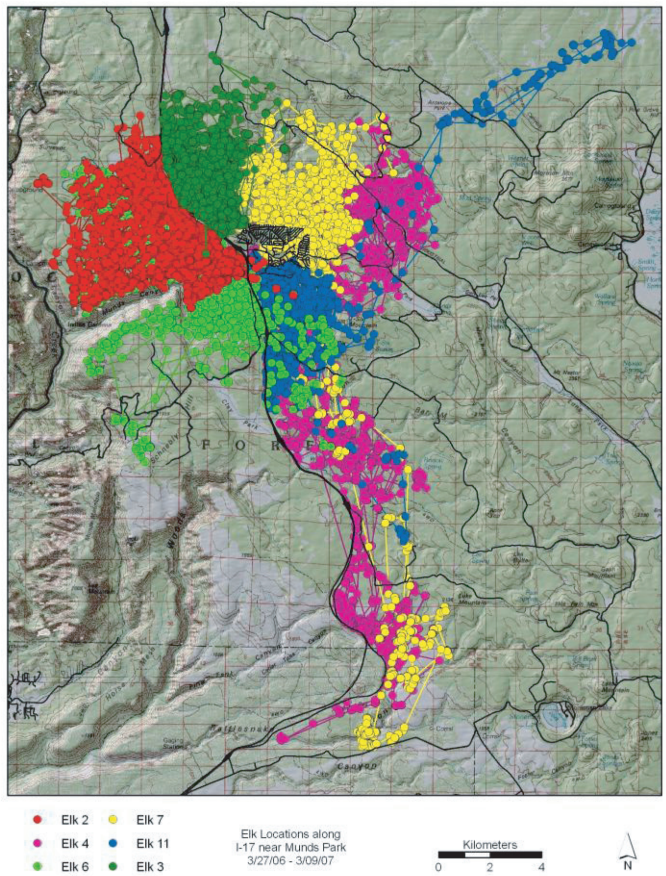



Figure 4. Preliminary movements of 6 elk along Interstate 17 (thick black line) in Arizona, USA, 2006-2007.

### Within Species Traffic Level Tolerances

Individual animals within a species likely exhibit differences in thresholds to traffic levels. The individual variation among animals along the same stretch of highway may vary greatly. Gagnon (2006) reported differences among individual elk in regards to traffic levels during highway crossings. Dodd et al. (2007a) reported an average of >90 crossings/elk during that study, however some individuals crossed >400 times during the same study period indicating there were individuals that may have learned to cross at opportune times. One problem however is that animals that do cross more often still have a higher risk for interactions with vehicles. Dodd et al. (2006) found that collared elk that crossed the road >0.4 times/day were responsible for a majority of the collisions involving collared elk.

Because many ungulates exhibit a herding behavior, much of the behavior associated with highway crossings and non-crossings may be driven by the individual tolerances a lead animals such as a “lead cow” or “herd bull” in the case of elk. As a result, the sensitivity to traffic of a relatively small subset of the population may have important repercussions for the remainder of the herd. If those lead individuals readily cross the highway to obtain resources, the entire herd may herd may risk a higher potential of interaction with vehicles.

Wildlife of the same species in different geographical areas may also vary in their responses to traffic. Many studies have shown elk respond negatively to traffic even at relatively low levels along forest roads, as well highways. The elk along each of these road types may exhibit a “baseline” traffic tolerance in different geographical area; extreme deviations from these baseline traffic levels may elicit a response. For example, elk along low traffic level forest roads may react to a sudden increase in traffic levels. Likewise, elk along a highway that averages 10,000 vehicles/ day may develop a tolerance for these traffic levels and respond in a similar manner if traffic levels increases dramatically on a given day. Elk along each of these roads may adjust their baseline tolerance to traffic levels if there are increases or decreases in traffic along the route they inhabit.

Location and orientation of highways in different geographical areas may also differ in their effects of traffic on wildlife. The State Route 260 highway alignment was designed to run adjacent to riparian meadows and drainages for ease of construction. These areas are relatively scarce in the arid southwest and are of major importance to elk and other wildlife species in this area. Ungulate tolerances to traffic levels may be lower in areas where preferred resources are not adjacent to the highway, or where necessary resources are evenly distributed on both sides of a given highway, reducing the need to cross. Another important factor may be the orientation of the highway in relation to ungulate migration routes. State Route 260 runs east to west while the seasonal migration movements of elk in this area are north to south. Traffic levels along highways oriented parallel to migration routes may show a more profound barrier affect, as ungulates do not need to cross the highway during long range seasonal movements. This may be adequate for reducing ungulate-vehicle collisions, but does alleviate the problems of habitat effectiveness or habitat fragmentation and genetic isolation.

### Between Species Traffic Level Tolerances

Differences between ungulate species and traffic levels they will tolerate are apparent according to previous studies. Deer appear to show the least response to traffic levels while many higher traffic roads are nearly impermeable to pronghorn.

One major factor of between species behavior associated with traffic may be the inherent nature of a species movements. Nocturnal species are likely to have greater crossing opportunities than diurnal species, due to the breaks in traffic during the middle of the night. For example, State Route 260 experiences traffic levels near 8,000 AADT, however traffic levels in the middle of the night regularly reach <50 vehicles/hr allowing crossings for many nocturnal species. A diurnal species along this same highway will endure much greater traffic levels, averaging close to 500 vehicles/hr during peak movement periods, thereby exacerbating the barrier effect of this road (fig. 5).

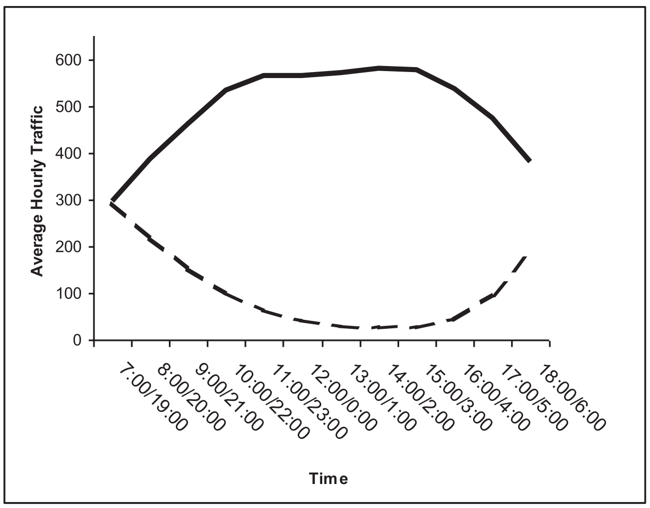



Figure 5. Traffic levels experienced by diurnal species (solid line; 0700-1800) versus those experienced by nocturnal species (dashed line;1900-0600) based on >6 million vehicles recorded in the State Route 260 Study Area from December 2003-June 2006, Arizona, USA.

## Importance of Wildlife Passage Structures in Mitigating Traffic Effects

Properly designed wildlife crossing structures may help to alleviate the barrier effect of roadways while reducing wildlife-vehicle collisions. Several studies have evaluated wildlife crossing structure use (Reed et al. 1975, Reed 1981; Singer and Doherty 1985; Foster and Humphrey 1995, Clevenger and Waltho 2000, 2005; Gloyne and Clevenger 2001; Sips et al. 2002; Servheen et al. 2003, Ng et al. 2004, Gagnon et al. 2006) and some have documented animal behavior during crossings (Reed et al. 1975, Reed 1981; Ward 1982; Singer and Doherty 1985; Sips et al. 2002, Gordon and Anderson 2003, Plumb et al. 2003, Dodd et al. 2007b, Gagnon et al. 2007b), most studies have not thoroughly examined the direct influence of variation in traffic and assume wildlife use of structures are related to the structural attributes of the underpasses. Although Singer and Dougherty (1985) documented decline in underpass use by mountain goats (*Oreamnos americanus*) when vehicles were present, traffic was not documented during these studies and, as Forman et al. (2003:276) point out, "the response of an individual animal to the movement of different types of vehicles remains an important research frontier."

Gagnon et al. (2007b) used video surveillance to simultaneously monitor elk crossing behavior associated with passing traffic (vehicles/min) during wildlife underpass use. Results from this study showed no overall effect of high traffic levels on elk use of wildlife underpasses. The only negative responses occurred at very low traffic levels, likely due to the dramatic change in ambient noise levels. Furthermore, data taken from the permanent traffic counter on State Route 260 showed a decrease in at-grade crossings as hourly traffic levels increased; while elk showed no real detrimental response to the same hourly traffic levels during below-grade crossings (fig. 6). These findings along with those of Dodd et al. (2007c) showed an overall increase in permeability following the completion of wildlife crossing structures and properly placed funnel fencing. The combined overall findings along State Route 260 indicate that properly designed and located wildlife underpasses, combined with adequate funnel fencing helped to overcome the potential negative effects of highway traffic on both permeability and collisions for elk in this area.

Gagnon et al. (2007a) showed that elk along State Route 260 moved farther away as traffic levels increased, suggesting that overall approach rates at underpasses may be lower at higher traffic levels. If so, high traffic may lengthen the amount time animals require locating and habituating to crossing structures. Given this effect, reducing noise and visual stimuli at underpasses could potentially guide animals to crossing structures, by creating a "gap" in the sound and visual "fence" traffic creates. These modifications could also reduce the sound of vehicles passing directly overhead, particularly semis, thereby reducing the probability that elk will retreat from underpasses and attempt to cross the highway at other locations where they could be a danger to motorists.

Although design and placement of crossing structures appear to far outweigh the negative effects of traffic for elk, more research is needed to determine if other wildlife respond negatively to passing traffic during use of wildlife crossings. Although elk showed very minimal response to traffic during below grade crossings, other wildlife may not cross through structures if traffic levels are too high. American pronghorn may be a good example of this; the ability to promote pronghorn passage with such structures has been limited to date, as is our knowledge (Sawyer and Rudd 2005). Though Plumb et al. (2003) documented 70 crossings by pronghorn at a concrete box-culvert underpass in Wyoming (81% in a single crossing), pronghorn overall exhibited reluctance to use the structure and most of the crossing animals accompanied mule deer through the underpass. As crossing structures for barrier sensitive species, such as pronghorn, are implemented throughout the world, it is important to understand their responses to traffic. Does the visual "fence" created by passing traffic reduce the probability of a species even approaching a given crossing structure? Once a given species attempts to use a crossing structure do vehicles elicit a negative response leading to unsuccessful crossings?

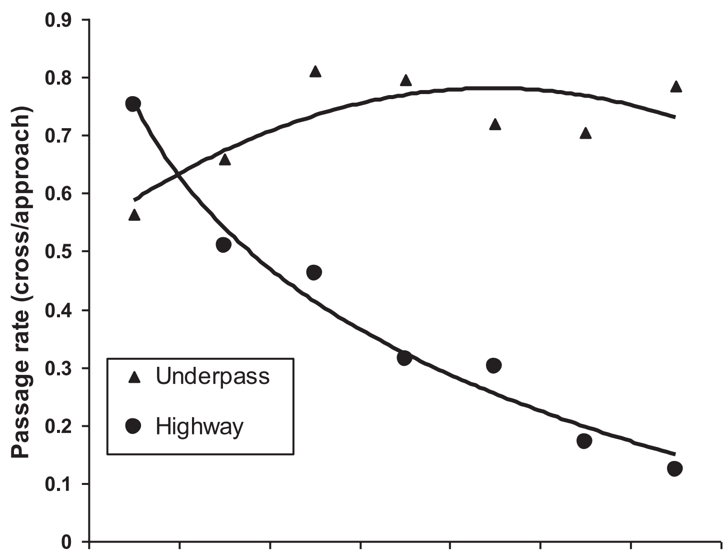



Figure 6. Elk passage rates at grade (highway) and below grade (underpass) at varying traffic levels during identical time periods along State Rout 260, 2003-2006, Arizona, USA.

## Current Research in Arizona

Although studies have examined fluctuating traffic levels on ungulate distribution, most of these were along very low traffic roads (Witmer and deCalesta 1986, Wisdom et al. 2005, Rost and Bailey 1979), very few of them adequately examined distributions along high speed, high traffic roads such as highways and interstates. These types of roads are increasing throughout the world, and are not only a safety issue to motorists and ungulates but also an increasing problem for resource selection and habitat fragmentation, potentially leading to genetic isolation. Our better understanding of ungulate-distributions and movements associated with various traffic levels and other factors may help us find ways to mitigate the effects of highways on wildlife.

Currently, Arizona has four separate wildlife-highway interaction projects along four different highways tied to hourly traffic counts. We are studying traffic effects on elk (State Routes 260 and 64, Interstate 17), Coues' white-tailed deer (State Route 260), mule deer (State Route 64), and pronghorn (US Highway 89 and State Route 64). These projects include highways with varying traffic levels. This research will add to the wildlife-highway "toolbox" by providing a better understanding of how fluctuating traffic levels affect different species of wildlife in different locations.

## References


Allen R.E. , and D. R. McCullough. 1976. Deer car accidents in southern Michigan. *Journal of Wildlife Management*. 40:317:325

Bashore, T. L., Tzilkowski, W. M., Bellis, ED. 1985. Analysis of deer-vehicle collision sites in Pennsylvania. *Journal of Wildlife Management*, 49(3):769-776

Beier, P. and S. Loe. 1992. A checklist for evaluating impacts to wildlife movement corridors. *Wildlife Society Bulletin* 20:434-440.

Beier, P. 1995.Dispersal of juvenile cougars in fragmented habitat. *Journal of Wildlife Management* 59:228-237.

Bellis, E. D., and H. B. Graves. 1978. Highway fences as deterrents to vehicle-deer collisions. *Transportation Research Record* 674: 53-58.

Groot Bruinderink, G. W. T. A, and E. Hazebroek. 1996. Ungulate traffic collisions in Europe. *Conservation Biology* 10:1059-1067.

Hanski, I., and M. E. Gilpin. 1997. Metapopulation biology. Academic Press, New York, New York, USA.

Iuell, B., Becker, G. J., Cuperus, R., Dufek, J., Fry, G., Hicks, C., Hlavac., V. Keller, V.B., Rosell, C., Sangwine, T., Torslov, N., Wandall, and B. le Maire. 2003. Cost 341- wildlife and traffic. A European handbook for identifying conflicts and designing solutions. Office for Official Publications of the European Communities, Luxembourg.

Clevenger, A. P. and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology* 14:47-56.

Clevenger, A. P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation* 121:453–464

Brudin, C.O. 2003. Wildlife use of existing culverts and bridges in north central Pennsylvania. ICOET 2003 Proceedings

Carbaugh, B., J. P. Vaughan, E. D. Bellis, and H. B. Graves. 1975. Distribution and activity of white-tailed deer along an interstate highway. *Journal of Wildlife Management*. 39:570-581.

Case, R.M. 1978. Interstate highway road killed animals; a data source for biologists. *Wildlife Society Bulletin* 6:8-13.

Conover M. R., W. C. Pitt, K. Kessler, T. J. DuBow, and W. A. Sanborn. 1995. Review of human injuries, illness, and economic losses caused by wildlife in the United states. *Wildlife Society Bulletin*, 23: 407-414.

Danielson, B. J. and M. W. Hubbard, 1998. Final report: a literature review for assessing the status of current methods of reducing deer-vehicle collisions. Iowa Department of Transportation, Ames, USA.

Davis, W. B. 1939. Mortality of wildlife on a Texas highway. *Journal of Wildlife Management*. 4:90-91.

Dickerson, L. M. 1939. The problem of wildlife destruction by automobile traffic. *Journal of Wildlife Management*. 3:104-116.

Dodd, N. L., J. W. Gagnon, S. Boe, and R. E. Schweinsburg. 2006. Characteristics of elk-vehicle collisions and comparison to GPS-determined highway crossing patterns. Pages 461-477 in C. L. Irwin, P. Garrett, and K.P. McDermott, technical coordinators. *Proceedings of the 2005 International Conference on Ecology and Transportation*., North Carolina Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Dodd, N. L., J. W. Gagnon, A. L. Manzo, and R. E. Schweinsburg. 2007a. Application of video surveillance to assess wildlife use of highway underpasses in Arizona. *Journal of Wildlife Management* 70:in press.

Dodd, N. L., J. W. Gagnon, S. Boe, and R. E. Schweinsburg. 2007b. Assessment of elk highway permeability using Global Positioning System telemetry. *Journal of Wildlife Management* 71:in press.

Dodd, N. L., J. W. Gagnon, S. Boe, and R. E. Schweinsburg. 2007c.Role of fencing in promoting wildlife underpass use and highway permeability. Pages xxx-xxx in *Proceedings of the 2007 International Conference on Ecology and Transportation*. North Carolina Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Epps, C. W.,P. J. Palsboll, J. D. Wehausen, G. K. Roderick, R. R. Ramry II, and D. R. McCullough. 2005.Highways block gene flow and cause rapid decline in genetic diversity od desert bighorn sheep. *Ecology Letters*. 8:1029-1038.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road ecology: science and solutions*. Island Press. Washington, DC, USA.

Foster, M. L., and S. R. Humphrey. 1995. Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin* 23:95-100.

Gagnon, J. W. 2006. Effect of traffic on elk distribution, highway crossings, and wildlife underpass use in Arizona. Thesis, Northern Arizona University, Flagstaff, Arizona, USA.

Gagnon, J. W., N. L. Dodd, R. Schweinsburg, and A.L. Manzo. 2006. Comparison of wildlife underpass usage along State Route 260 in Central Arizona. Pages 534-544 in C. L. Irwin, P. Garrett, and K.P. McDermott, technical coordinators. *Proceedings of the International Conference on Ecology and Transportation., North Carolina Center for Transportation and the Environment*, North Carolina State University, Raleigh.

Gagnon, J. W., T. C. Theimer, N. L. Dodd, R. E. Schweinsburg. 2007a. Traffic volume alters elk distribution and highway crossings in Arizona. *Journal of Wildlife Management*. 71:in press.

Gagnon, J. W., T. C. Theimer, N. L. Dodd, A. L. Manzo, and R. E. Schweinsburg. 2007b. Effects of traffic volume and type on elk use of wildlife highway underpasses in central Arizona. *Journal of Wildlife Management*. 71:in press.

Gloyne, C. G., and A. P. Clevenger. 2001. Cougar Puma concolor use of wildlife crossing structures on the Trans-Canada highway in Banff National Park, Alberta. *Wildlife Biology* 7:117-124.

Gordon, K., and S. Anderson. 2003. Mule deer use of underpasses in western and southeastern Wyoming. Pages 309-318 in C. L. Irwin, P. Garrett, and K.P. McDermott, technical coordinators. *Proceedings of the International Conference on Ecology and Transportation*, North Carolina Center for Transportation and the Environment, North Carolina State University, Raleigh.

Gunson, K. E., and A. P. Clevenger. 2003. Large animal-vehicle collisions in the central Canadian Rocky Mountains: patterns and characteristics. Pages 355-366 in C. L. Irwin, P. Garrett, and K.P. McDermott, technical coordinators. *Proceedings of the International Conference on Ecology and Transportation, North Carolina Center for Transportation and the Environment*, North Carolina State University, Raleigh, USA.

Haikonen, H., H. Summala. 2001. Deer-vehicle crashes, extensive peak at 1 hour after sunset. *American Journal of Preventive Mediceine*. 21:209-213.

Haugen, A. O. 1944. Highway mortality of wildlife in souther Michigan. *Journal of Mammology*. 25 :177-183.

Hershey, T.J., and T.A. Leege. 1976. Influences of logging on elk summer range in north-central Idaho. Pages 73-80 in Hieb, S.R. (ed.) Proceedings of the Elk-Logging-Roads Symposium. Moscow, Idaho. December 16-17, 1975. Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow. 142 pp.

Hourdequin M. 2000. Introduction special section: Ecological effects of roads. *Conservation Biology*. 14:16-17.

Lyon, L. J. 1979. Habitat effectiveness for elk as influenced by roads and cover. *Journal of Forestry* 79:658-660.

Lyon, L. J. 1983. Road density models for describing habitat effectiveness for elk. *Journal of Forestry* 81:592-595.

Lyon, L. J., and A. G. Christensen. 2002. Elk and land management. In North American elk: ecology and management, eds. D. E. Toweill and J. W. Thomas, 557-581. Washington, DC: Smithsonian Institution Press.

Manzo, A. L. 2006. An ecological analysis of environmental parameters influencing Rocky Mountain elk crossings of an Arizona highway. Thesis, Northern Arizona University, Flagstaff, USA.

Marcum, C. L., and W. D. Edge. 1991. Sexual differences in distribution of elk relative to roads and logged areas in Montana. In Proceedings Elk Vulnerability Symposium, eds. A. G. Christensen, L. J. Lyon, and T. N. Lonner, 142-148. Bozeman: Montana State University.

McCaffery, K. R. 1973. Road-kills show trends in Wisconsin deer populations. *Journal of Wildlife Management*. 37:212-216.

McCorquodale, S. M. 2003. Sex-specific movements and habitat use by elk in the Cascade Range of Washington. *Journal of Wildlife Management* 67:729-741.

Ng, S. J., J. W. Dole, R. M. Sauvajot, S. P. D. Riley, and T. J. Valone. 2004. Use of highway underpasses by wildlife in southern California. *Biological Conservation* 115:499-507.

Noss, R. F., A. Y. Cooperrider. 1994. Saving nature's legacy: Protecting and restoring biodiversity. Island Press, Washington D.C. 1994: p. 416.

Perry, C., and R. Overly. 1976. Impacts of roads on big game distributions in portions of the Blue Mountains of Washington. Pages 62-68 in Hieb, S.R. (ed.) Proceedings of the Elk-Logging-Roads Symposium. Moscow, Idaho. December 16-17, 1975. Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow. 142 pp.

Plumb, R. E., K. M. Gordon, and S. H. Anderson. 2003. Pronghorn use of a wildlife underpass. *Wildlife Society Bulletin* 31:1244-1245.

Reed, D. F., T. N. Woodard, and T. M. Pojar. 1975. Behavioral response of mule deer to a highway underpass. *Journal of Wildlife Management* 39:361-367.

Reed, D. F. 1981. Mule deer behavior at a highway underpass. *Journal of Wildlife Management* 45:542-543.

Reilly, R. E., and H. G. Green. 1974. Deer Mortality on a Michigan Interstate Highway. *Journal of Wildlife Management*, 38:16-19

Romin L. A., and J. A. Bissonette. 1996. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle Reservoir, Utah. *Great Basin Naturalist*. 56:1-11.

Rost, G. R., and J. A. Bailey. 1979. Distribution of mule deer and elk in relation to roads. *Journal of Wildlife Management* 43:634-641.

Rowland, M. M., M. J. Wisdom, B. K. Johnson, and J. G. Kie. 2000. Elk distribution and modeling in relation to roads. *Journal of Wildlife Management* 64:672-684.

Ruediger, W. C., K. Wall and R. Wall. 2006. Effects of highways on elk (Cervus elaphus) habitat in the western United States and proposed mitigation approaches. Pages 269-278 in C. L. Irwin, P. Garrett, and K.P. McDermott, technical coordinators. *Proceedings of the International Conference on Ecology and Transportation*., North Carolina Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Russel, H. N. & D. Amadon 1938: A note on highway mortality. *Wilson Bulletin* 50: 205-206.

Schwabe, K. A., and P. W. Schuhmann. 2002. Deer-vehicle collisions and deer value: an analysis of competing literatures. *Wildlife Society Bulletin* 30:609-615.

Seiler, A. 2004. Trends and spatial patterns in ungulate – vehicle collisions in Sweden. *Wildlife Biology* 10: 301-313.

Servheen, C., Shoemaker, R. and L. Lawrence. 2003. A sampling of wildlife use in relation to structure variables for bridges and culverts under I-90 between Alberton and St. Regis, Montana. Pages 331-341 in C. L. Irwin, P. Garrett, and K.P. McDermott, technical coordinators. *Proceedings of the International Conference on Ecology and Transportation*, North Carolina Center for Transportation and the Environment, North Carolina State University, Raleigh.

Singer, F. J. and J. L. Doherty. 1985. Managing mountain goats at a highway crossing. *Wildlife Society Bulletin* 13:469-477.

Sips, H. J. J., G. F. J. Smit, and G. Veenbaas. 2002. Applicability of automatic video recording near fauna passages. Road and Hydraulic Engineering Division Report No. DWW-2002-141.

Starrett, W. C. 1938. Highway casualties in Central Illinois during 1937. *Wilson Bulletin* 50 (3):193-196.

Stoner, D. 1925. The toll of the carmobile. *Science* 61 (1568): 56-57.

Stoner, D. 1936. Wildlife casualties on the highways *Wilson Bulletin* 48: 276-283.

Sawyer H., and B. Rudd. 2005. Pronghorn roadway crossings: A review of available information and potential options.

Trocme, M. S. Cahill, J. G. de Vries, H. Farrall, L. G. Folkeson, C. Hichks, and J. Peymen (Eds.) 2003. COST 341 – Habitat fragmentation due to transportation infrastructure: the European review. Office for Official Publications of the European Communities, Luxembourg.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18-30.

Ward, A.L. 1976. Elk behavior in relation to timber harvest operations and traffic on the Medicine Bow Range in south-central Wyoming. Pages 32-43, in S.R. Hieb and J.M. Peak, editors, Proceedings of the Elk-Logging-roads Symposium. Moscow, Idaho. December 16-17, 1975. Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow, USA.

Ward, A.L. 1982. Mule deer behavior in relation to fencing and underpasses on Interstate 80 in Wyoming. *Transportation Research Record* 859:8-13.

Warren, E. R. 1936: Casualties among animals on mountain roads. *Science* 83 (2140): 14.

Warren, E. R. 1936: Mountain road casualties among animals in Colorado. *Science* 84 (2187): 485.

Wisdom, M. J., N. J. Cimon, B. K. Johnson, E. O. Garton, and J. W. Thomas. 2005. Spatial Partitioning by Mule Deer and Elk in Relation to Traffic. Pages 53-66 in Wisdom, M. J., technical editor, The Starkey Project: a synthesis of long-term studies of elk and mule deer. Reprinted from the 2004 Transactions of the North American Wildlife and Natural Resources Conference, Alliance Communications Group, Lawrence, Kansas, USA.

Witmer, G. W., and deCalesta. 1985. Effect of forest roads on habitat use by Roosevelt elk. *Northwest Science*. 59:122-125.

# The Evolution of Wildlife Exclusion Systems on Highways in British Columbia

**Leonard E. Sielecki** (250-356-2255, leonard.sielecki@gov.bc.ca), British Columbia Ministry of Transportation, P.O. Box 9850, STN PROV GOVT, 4B - 940 Blanshard Street, Victoria, BC V8W 9T5, Fax: 250-387-7735 Canada

**Abstract:** Since the mid-1980's, the British Columbia Ministry of Transportation (BCMoT) has been addressing the issue of motor vehicle-related wildlife collisions on Provincial highways with engineered wildlife exclusion systems. As a result of this initiative, the British Columbia has one of the most extensive networks of wildlife exclusion systems, designed to reduce and prevent motor-vehicle-related mortality of terrestrial mammals, in North America.

Typically, wildlife exclusion systems are incorporated as an integral part of new highway development after the potential of wildlife mortality has been identified during highway planning stages. The systems are designed to protect wildlife from motor vehicles and ensure wildlife habitat connectivity. They have been constructed primarily on limited-access, high-speed highways and expressways and designed to protect specific species of wildlife, primarily large ungulates, such as deer, elk, moose and mountain sheep. The systems comprise of specialized fencing and related structures, such as one-way gates, ungulate guards, and crossing structures, designed to safely and effectively protect wildlife by recognizing species-specific behavioral, physical and anatomical characteristics. To date, BCMoT has installed over 470 km of wildlife fencing, incorporating over 100 crossing structures and hundreds of one-way gates.

While the wildlife exclusion systems have been shown to reduce the potential for motor vehicle-related wildlife mortality, BCMoT is continually reviewing the designs of the components of these systems in an ongoing effort to improve them. With each successive project, as the interactions of wildlife with these systems become better understood, BCMoT has refined its fence and crossing structure designs and standards to increase their efficiency, effectiveness and safety for wildlife. BCMoT has also focused its attention on material quality, manufacturing processes and construction techniques to offset the challenges of climate, topography, vegetation and human activity to maximize the effective functional lifespans of wildlife exclusion systems.

## Introduction

The diverse climatic, geographic and physiographic characteristics of British Columbia have produced biogeoclimatic or ecological zones that vary from dense rainforests on the west coast and deserts in the southern interior valleys to broad rolling plateaus in the central interior valleys and alpine tundra in the northern mountains (British Columbia Ministry of Forests, 1999). As a result of the exceptional range of wildlife habitats provided by these biogeoclimatic zones, British Columbia has one of the most diverse ranges of large ungulate species in North America. Large mountain ranges transect British Columbia creating numerous valleys providing critical winter habitat for many large ungulates, including deer, elk, moose, and mountain sheep, for up to six months of the year. Historically, most of the British Columbia's major highways were built in the valley bottoms, severing the winter ranges and the migratory corridors of many wild animals. For many years, the wildlife habitat/highway interface was poorly understood. Little was done to assess the impact of highways on wildlife, their migratory corridors and their use of critical ranges. As a consequence, conflicts and collisions between wildlife and motor vehicles were common and wildlife mortality was a seemingly accepted cost of developing highways in British Columbia.

This situation began to change in the mid-1980's, when the British Columbia Ministry of Transportation (BCMoT) started addressing the issue of motor vehicle-related mortality of large ungulates on Provincial highways. The British Columbia Provincial Government has made "environmental stewardship" one of the goals of its administration. In order to support the Provincial Government's environmental objectives, BCMoT has the responsibility of protecting both the motoring public and wildlife within the Province highway system that fell under its jurisdiction. To fulfill its dual obligations, BCMoT has made significant investments in its highway infrastructure to reduce the potential for motor vehicle-related wildlife mortality. Over the last three decades, a major component of these investments has been the development of engineered wildlife exclusion systems. As a result of the continuation of this initiative, the British Columbia has one of the most extensive networks of wildlife exclusion systems, designed to reduce and prevent motor-vehicle-related mortality of terrestrial mammals, in North America.

## Wildlife Exclusion Systems in British Columbia

In British Columbia, wildlife exclusion systems are typically incorporated as an integral part of new highway construction to address projected potential wildlife mortality. As part of BCMoT's comprehensive Highway Environmental Assessment Process (British Columbia Ministry of Transportation and Highways, 1997), extensive wildlife identification and monitoring programs conducted by professional biologists and wildlife experts are initiated years before highway construction begins. Particular attention is given to rare and endangered species, especially those subject to the Canadian *Species at Risk Act*. When wildlife population clusters and migration routes are identified during environmental assessments, the habitat fragmenting potential of wildlife exclusion fencing is reduced with crossing structures. In some cases, wildlife exclusion systems are retrofitted on existing highways where problematic wildlife accident locations which have developed over time are identified using BCMoT's Wildlife Accident Reporting System (WARS) (Sielecki, 2004).

## Maintaining Wildlife Habitat Connectivity

Given the vast amount of frontier land in British Columbia, highway redevelopment and expansion has occurred in areas of rich wildlife habitat. The fragmenting impact of highways on wildlife habitat is a significant issue. Highways have the potential to sever access to critical breeding, rearing and foraging areas for wildlife. For some, small, slow-moving species, highways can become an impermeable barrier to movement. Maintaining habitat connectivity has become increasingly necessary to provide continued access of wildlife to food, water and shelter for the immediate survival needs of individual animals, and continued genetic diversity necessary for the long-term survival of wildlife species as a whole. This is particularly critical in areas where the habitat of small numbers of rare or endangered species has been severed by highway development. BCMoT strives to maintain habitat connectivity by incorporating crossing structures, such as underpasses, in its wildlife exclusion systems.

To date, approximately 470 km (292 miles) of fencing and 100 crossing structures have been installed on the Coquihalla Highway (Highway 5), the Okanagan Connector Freeway (Highway 97C), Highway 97 and the Vancouver Island Highway (Highway 19). Given their size, complexity, and comprehensive design, BCMoT's wildlife exclusion systems on the Coquihalla and the Okanagan Connector were pioneering efforts for their time. The first wildlife overpass in Canada was built for the Okanagan Connector. The Vancouver Island Highway wildlife exclusion installations were state of the art initiatives at the time of their construction. With each successive project, the Ministry has refined its designs and standards, to improve the efficiency and effectiveness of its wildlife exclusion systems. Both fence and crossing structure designs have evolved over time.

BCMoT has found wildlife exclusion systems that encapsulate highway rights-of-way to be the most effective means of protecting wildlife from motor vehicles (figure 1). BCMoT's experience with regularly maintained, 2.4 m (7.9 ft) high fencing systems, which include one-way gates, ungulate guards and wildlife crossing structures, located on both sides of limited access highways, exceed 90% effectiveness in preventing highway-related wildlife mortality for large ungulates. These results are appear higher than the 80% reductions in wildlife accidents reported when wildlife exclusion fencing was installed along the Trans-Canada Highway in Banff National Park (Clevenger, Chruszez and Gunson, 2001). BCMoT has also found wildlife exclusion fencing appears to be effective when installed on only one side of a highway, if the unfenced side of the highway has pre-existing barriers to animal movement, such as a cliff face.

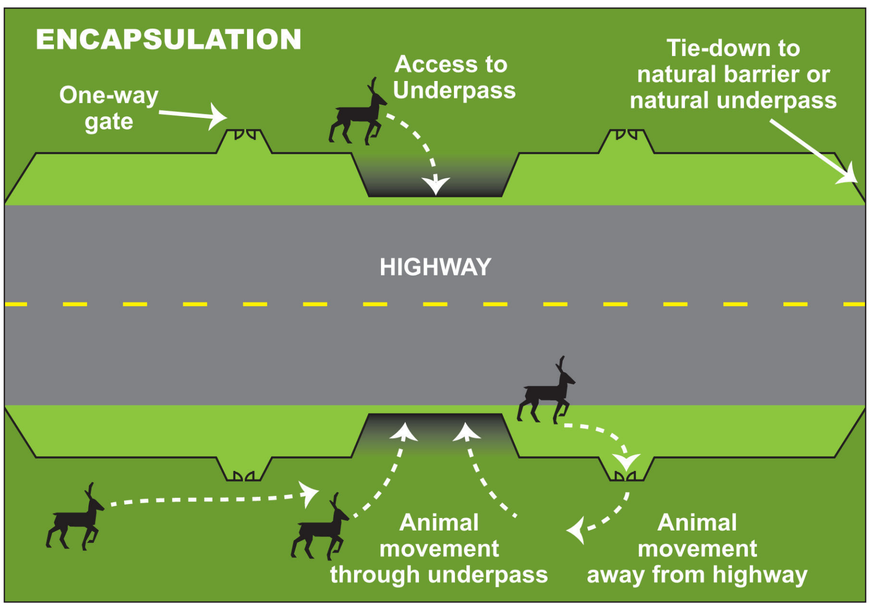



Figure 1. Highway encapsulation with wildlife exclusion system.

## Stages of Development

The development of an effective wildlife exclusion system requires detailed, comprehensive planning and evaluation. For BCMoT, there are five main stages in the development of a wildlife exclusion system:

a. historic data analysis,
b. pre-design data collection and analysis,
c. design,
d. materials selection and construction, and
e. post-construction monitoring and evaluation.

### (a) Historic Data Analysis

For almost 30 years, highway-related wildlife mortality data has been collected on a daily basis on all numbered Provincial highways that fall under the BCMoT's jurisdiction. The data is entered into the Ministry's Wildlife Accident Reporting System( WARS) database. The WARS database contains a detailed historical record of wildlife mortality and is regularly used as a tool for supporting decision-making with regards to the impacts of existing and planned highways on wildlife. For existing highways, WARS data is used to examine the magnitude and locations of highway-related wildlife mortality to focus wildlife accident mitigation efforts in the most cost-effective manner. For planned highways, WARS data is used as a surrogate data source to assist Ministry engineers and planners and private consultants in their evaluation of potential wildlife accident risks.

### (b) Pre-Design Data Collection and Analysis

Preceding the design of a wildlife exclusion system, whether as part of a new highway, or the large-scale redevelopment of an existing one, wildlife biologists are contracted by BCMoT to collect detailed wildlife population and habitat information. Aerial and ground surveys are used to supplement any existing information in an effort to quantify the numbers of wildlife and their movement patterns on lands adjacent to existing and planned highway corridors. Detailed information on the topography, vegetation and other biophysical features of the landscape is used to analyze resident and migratory wildlife movements related to critical life activities, such as breeding, rearing, and seasonal foraging. Data from the WARS database is used to identify locations where the potential for wildlife accident may be high. For new highway development and large-scale redevelopment of existing highways, these activities form an integral part of the environmental assessment process used by BCMoT. Information provided by the wildlife biologists is one of the factors BCMoT's planners and engineers consider for selecting a final highway alignment. Once the alignment has been selected, detailed plans are developed to incorporate the key components of a wildlife exclusion system as necessary to protect those species of animals identified by the wildlife biologists.

### (c) Design

Depending on the highway project involved, wildlife exclusion systems can vary greatly in scale and complexity. A wildlife exclusion system can be as simple as a fence for a single species, used to connect existing or planned structures, such as bridges and culverts; or much more complex when multi-species oriented crossing structures, such as underpasses, and wildlife habitat features, such as ponds are integrated into the design. Wildlife exclusion systems are most easily incorporated into the design and construction of new highways. In this way, the designs of major structures, such as bridges and culverts, can be modified to maximize their effectiveness for wildlife passage. Highway traffic closures are not required and significant cost savings can be realized when wildlife exclusion system construction can be integrated with highway infrastructure construction and right-of-way preparation and landscaping. In addition, issues relating to side road access and private property can also be addressed in a systematic and cost-effective manner.

Wildlife biologists provide vital information about the physical and behavioral characteristics of wildlife to BCMoT's engineers so that appropriately sized structures can be designed to meet species-specific wildlife needs and foster their use of structures, such as one-way gates, underpasses and overpasses. Wildlife exclusion systems are usually intended for specific species and their structural components are designed to accommodate and withstand the forces of the largest animals that may be affected by the systems. In British Columbia, large ungulates, such as moose and elk can weigh in excess of 700 kg (1543 lb) and stand in excess of 1.5 m (4.9 ft) in height. While efforts are made to protect the smallest animals by preventing them from accessing the highway right-of-ways, by breaching gaps in the fence, the structural size and strength requirements are designed for the largest specimens of the largest ungulates, typically bull elk or bull moose.

*Wildlife Exclusion Fencing*

Initially, BCMoT used the wildlife exclusion fencing design developed by Banff National Park (Buckingham, 2007). Over time, the fencing design used by BCMoT has evolved to meet the wildlife and environmental challenges found along highways in British Columbia. Fencing for large ungulates, such as moose and elk, requires more robust designs. This typically involves heavier metal posts or thicker wooden poles, with closer spacing, and heavier fence mesh held onto the posts with heavy clamps. Local climatic conditions can create additional demands on fencing. Heavy snow or ice loading requires heavier metal posts or thicker wooden poles, spaced closely, and heavier fence mesh held onto the posts and poles with heavy clamps. Steep and/or rocky terrain, which prevents the use of heavy equipment and makes the installation of wooden poles difficult, requires the use of metal posts placed in drilled holes. Soft and/or swampy soils require the use of longer posts and posts, and concrete to stabilize them. The spacing of posts and poles can range from 2.5 m (8.2 ft) to 3.5 m (11.5 ft).

A wildlife exclusion system that promotes long term sustainability of the wildlife it protects relies on establishing and maintaining effective habitat connectivity. If animals unexpectedly enter a highway right-of-way, they must be able to exit it as quickly and safely as possible to reach their habitat. To facilitate and expedite the movement of wildlife away from highway rights-of-way, BCMoT has focused considerable effort on the design of one-way gates to accommodate the size, shape and movement characteristics of large ungulates, in particular, deer, moose and elk.

*One-way Gates*

The original one-way gate design used by BCMoT was based on earlier designs developed in Utah by the Utah Department of Transportation (UDoT). Over time, the one-way gate design has evolved as their use by ungulates has been become better understood (figures 2 and 3).

Figure 2. One-way gate designed for moose and deer.

The original "straight" tyne was found to be an impalement hazard for large ungulates. Soon after the installation of the first one-way gates, a moose reversed its direction of movement while passing through a one-way gate and impaled itself. The moose's movement backward in the one-way gate had not been anticipated when the original "straight" tyne design was developed. The second, "improved", version of the one-way gate tyne, the "looped" tyne was also found to be hazardous as the loops became ensnarement hazards when some deer passing through the gates were found to raise their front legs and catch them in the loops. In the late 1990's, the "looped" design was replaced with the "disked" and "ball" tyne designs, which prevent impalement and ensnarement. BCMoT is monitoring the use of the "disked" and "ball" tyne designs to determine if they are operating as designed and do not create a hazard for the wildlife they were designed to protect.

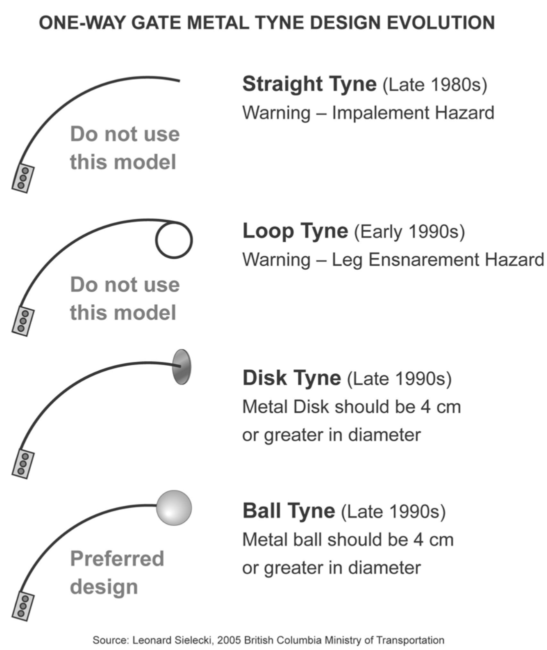



Figure 3. One-way gate metal tyne design evolution.

The BCMoT wildlife exclusion fencing specifications are typically designed to produce a fence with a 20 to 25 year lifespan. The remote and/or physically challenging locations of some wildlife exclusion fencing makes daily inspection and maintenance difficult, if not impossible. As a consequence, design, materials and construction are very important components in the development of effective and reliable wildlife exclusion fencing.

Other structures, such as earthen ramps and jumpouts, are used by other jurisdiction to enable wildlife to exit fenced highway rights-of-way (Ito, 2005). However, BCMoT does not currently use these structures. British Columbia provincial highway rights-of-way in British Columbia are accessible to the public, and although earthen ramps and jumps may be more effective than one-way gates for use by some large ungulates, unresolved safety issues, relating to the activities of mountain bikers, all terrain vehicle (ATV) users and hikers, have delayed their implementation. BCMoT continues to monitor the use of earthen ramps and jumpouts by other jurisdictions in order to ascertain their effectiveness as well as understand their operational and safety limitations and implications.

*Grade Separated Wildlife Passage Structures*

Grade-separated wildlife passage structures are key to the BCMoT's efforts to minimize habitat fragmentation. Whether these structures are used independently, or incorporated with wildlife exclusion fencing in wildlife exclusion systems, they represent the consistently, safest, and most effective method of allowing wildlife to traverse a highway corridor.

In 1987, BCMoT constructed the first wildlife overpass in Canada. The Trepanier Wildlife Overpass on the Okanagan Connector (Highway 97C) was built following the concept of the first overpass built for deer in Utah by the Utah Department of Transportation (UDoT) (figure 4). The Trepanier Wildlife Overpass was developed from the basic design of a pedestrian highway overpass at a cost of approximately CAN$1 million. Structural advancements were required to accommodate the weight of soil necessary for vegetation used to create a more "natural" environment to foster wildlife use. The decision to construct the overpass on the Okanagan Connector was supported by detailed wildlife studies. These studies also assisted in locating the structure so that it could provide essential passage for critical summer and winter deer habitat.

Figure 4. The Trepanier Wildlife Overpass on Highway 97C.

There are over 100 wildlife crossing structures located on Provincial highways in British Columbia. All, except the Trepanier Wildlife Overpass, are underpasses. They were installed on the Coquihalla Highway (Highway 5), the Okanagan Connector, Highway 97 and the Vancouver Island Highway. Terrain and geologic constraints can make locating wildlife overpasses problematic. However, BCMoT has found, that if designed properly, underpasses can be multi-purpose, meeting the needs of wildlife, adjacent land users and the highway infrastructure. The size and design of the structures has been evolving as the understanding of how wildlife interact at the wildlife habitat/highway interface grows. Underpasses are now typically taller in height , wider in width. They are more species-friendly, with carefully selected flooring materials to suit the target species.

To maximize the use of environmental enhancement funds and improve the effectiveness of passage structures, the Ministry has been focusing its attention to underpasses for multi-species use. Large multi-plate culverts can cost upwards of CAN$500,000 while concrete bridges and box culverts can cost several million dollars. Incorporating natural watercourses into the design of passage structures, enables the movement of aquatic and terrestrial species. Modifications in the design of "bottomless" culverts for the preservation of the passage envelop and trail surfacing, combined with selective riprap armouring and increasing structure clearance heights, allow underpasses to be developed to promote wildlife passage, rather than hinder it.

Underpasses are another significant component of wildlife exclusion systems that have been evolving. Early underpasses were constructed approximately 3.7 m (12.2 ft) in diameter (figure 5). Although monitoring of wildlife tracks indicated these structures were used by deer, larger structures, in excess of 5 m (16.4 ft), were constructed to increase deer use, and better accommodate the needs of elk and moose (figure 6). To make underpasses more suitable for ungulates, BCMoT has been building larger structures and incorporating features to accommodate the needs of more species, including fish, primarily salmonids (figure 7). BCMoT has been working with the United States Forest Service to develop monitoring and assessment techniques to evaluate underpasses and improve ungulate use of them.

Figure 5. Wildlife underpass designed for deer on the Okanagan Connector (early 1990's).

Figure 6. Wildlife underpass designed for elk and deer on the Vancouver Island Highway (1999).

Figure 7. Multi-species wildlife underpass on the Vancouver Island Highway (1999).

**(d) Materials Selection and Construction Techniques**

Materials and workmanship are critical components of the construction phase for wildlife exclusion systems. Attention to design details and the use of good quality materials help ensure the systems will operate as designed for a prolonged period of time. This is especially important when wildlife exclusion systems are located in remote areas where maintenance is difficult to perform.

BCMoT specifications for materials have been developed to produce fences with an expected design life of 20 to 25 years. To promote system longevity, metal components are either stainless steel or heavily galvanized. Metal fence poles, fence mesh, and high tensile wire are heavily galvanized. In areas where heavy snowfall can occur and/or aggressive large ungulates live, heavy-duty stainless steel or galvanized steel clamps are used to attach fence mesh to the poles. Wooden fence posts are typically 18 cm (7.1 in) to 22 cm (8.6 in) in diameter, and pressure treated for periods in excess of conventional construction standards.

Strict quality control and quality assurance are critical. During construction, inspections occur regularly to ensure correct materials and construction techniques are being used to produce a long, lasting, durable structure that meets design specifications. Upon completion of the projects, careful examination and thorough testing of the structures occurs before the project is accepted.

**(e) Post-Construction Monitoring and Evaluation**

In mountainous settings, severe climate conditions and aggressive vegetation can create operational problems for wildlife exclusion systems. Consequently, these systems are monitored on a regular basis to ensure they function as designed and deficiencies can be identified and addressed in a timely manner.

The most comprehensive, recent audits of BCMoT's wildlife exclusion systems were conducted for BCMoT by professional wildlife biologists in 2005 (Demarchi, 2005; Harper, 2005; Hartwig and Demarchi, 2005; and Hayward, 2005). These audits were intended to provide a detailed inventory on the fencing, one-way gates, ungulate guards and crossing structures, and to investigate the use of each component of the systems by wildlife. The audits found the wildlife exclusion systems were functioning as designed. Evidence of wildlife use of one-way gates and crossing structures was demonstrated by tracks, hair and fecal droppings. At a number of wildlife underpasses evidence of temporary human occupation was found. The effect of human presence and the remaining discarded food wrappers and packaging on the long-term use of underpasses by wildlife is unknown. However, it is believed wildlife avoid using these structures when humans are present in them.

At a number of one-way gates, the remains of dead deer were found (figure 8). From the orientation of the remains, it appeared these animals may have been using the one-way gates to exit highway rights-of-way. The causes of death could not be determined because the remains were in relatively poor condition. However, further investigation and monitoring is required to determine if the deer are dying after using the one-way gates following a collision with motor vehicles on the highway, or if the deer are being attacked by opportunistic predators when they pass through the one-way gates.

Regular maintenance is essential for ensuring that wildlife exclusion systems operate properly. In British Columbia, roadside fence maintenance is a part of the BCMoT's highway maintenance contracts maintenance specifications. As a consequence, damage done to fencing by falling trees, motor vehicles, vandals and heavy snow loads must be repaired in an expedient manner. In areas where trees are located close to wildlife exclusion fencing, the potential for a treefall on top of the fence is ever present. Where mature trees do not exist, the potential exists for new trees to grow through the fence or block one-way gates. One-way gates must be kept clear of growing trees and broken tynes must be replaced as quickly as possible. In areas subject to heavy snow accumulations, inspections and maintenance earlier in the Spring should reduce the potential for motor vehicle-related ungulate mortality.

Unlike the effects of nature, such as falling trees, ground subsidence and heavy snow, vandalism is a manmade issue that has the potential to become a serious problem. Uncontrolled human access by hunters and poachers, mountain bike enthusiasts, and all terrain vehicles (ATVs) by way of holes cut into fences or the disabling of one-way gates compromise the integrity of wildlife exclusion systems. While such activities are difficult to detect when they occur, regular monitoring and maintenance reduce the potential impact of vandalism.

Figure 8. Deer remains near one-way gate.

## Installations

BCMoT has constructed wildlife exclusion systems on both existing and new highways. From the mid-1980's until the mid-1990's, BCMoT designed and built two new, major, high speed, limited access sections of highway transecting large tracts of wildlife habitat in the southern interior of British Columbia. The highways connected the Lower Mainland with Kamloops and Kelowna. Construction occurred in three phases: Coquihalla Highway (Highway 5) Phases I and II, Okanagan Connector (Highway 97C) Phase III.

The wildlife exclusion systems developed on these highways were the first projects of their kind in British Columbia. The installation on the Coquihalla Highway is an example of a retro-fit on an existing highway, while the Okanagan Connector is an example of integrating a wildlife exclusion system as a component of a new highway.

The Coquihalla Highway and Okanagan Connector projects were followed by projects on Highway 97 and the Vancouver Island Highway. In 1999, a collective effort involving the Ministry, the Insurance Corporation of British Columbia and the Summerland Sportsmens' Association and the Peachland Sportsmen's Association, affiliated associations of the British Columbia Wildlife Federation, resulted in the construction of a wildlife exclusion system on Highway 97 near Okanagan Lake. This project was a retrofit on a long-established highway. Between 1999 and 2001, the Ministry constructed four wildlife exclusion systems as integral components of two phases of new highway construction on the Vancouver Island Highway (Highway 19). With each successive project, the Ministry has refined its designs and standards, to improve the efficiency and effectiveness of its wildlife exclusion systems. The Vancouver Island Highway installations are state-of-the art initiatives in British Columbia.

### Coquihalla Highway (Highway 5)

The Coquihalla Valley has long served as the major transportation route in British Columbia linking the Lower Mainland with the Interior (figure 9) The origins of the highway network in the valley originate with the Hope-Nicola Trail in 1876. The development of road access culminated with the construction of the Coquihalla Highway (Highway 5).

Figure 9. The Coquihalla Highway in the Coquihalla Valley.

The Coquihalla Highway is a high speed (110 km/hr (68.4 mi/hr)) toll road which extends 195 km (121.2 mi) north from Hope to Kamloops, via Merritt. It is the only toll road in British Columbia. Construction on the Coquihalla Highway between Hope and Merritt started in 1979 and was completed in 1986. Despite the challenges of severe mountainous terrain and winter conditions, the highway became operational in May, 1986, to coincide with provincial and national traffic destined for Expo 86 in Vancouver. Starting north of Hope, at an elevation of approximately 50 m (164 ft), the Coquihalla Highway climbs steadily up the western slopes of the Cascade Mountains. For the first 42 km (26.1 mi), through the Coquihalla Pass, the highway ascends to the Coquihalla Summit at an elevation of 1244 m (4081 ft). Once past the summit, the highway continues another 78 km (48.5 mi) northeast, traversing the top of the Thompson Plateau, then descending to Merritt, which has an elevation of 595 m (1592 ft).

Over its length, the Coquihalla Highway passes through a number of climatic regimes. Near Hope, the highway environment is subject to temperate climate due to warm, moist Pacific Ocean airflows (Pojar and Meidinger, 1991). Here, summers are typically dry and summer temperatures average 25oC (77 oF). Winters are typically wet and mild. Snowfalls are infrequent in low-lying areas, with accumulations melting within a few days. Further north, the Coastal Range acts as a barrier separating the moist Pacific air from the interior of the Province. As the moist ocean air is forced to rise over these mountains, heavy precipitation occurs on the western slopes, with rain at lower elevations and snow at higher ones. Rainfall in Hope can exceed 2 m (6.6 ft) each year. About 80 km (50 mi) east of Hope the interior valleys between the mountain ranges receive considerably less precipitation and experience hot summers. Further north, near Merritt, summer temperatures often exceed 30 oC (86 oF).

The steep terrain at the southern portion of the highway combined with heavy snowfalls has created a challenging environment for highway construction. The Coquihalla Highway can experience severe winter conditions. Snow accumulations of over 12 m (39.4 ft) are not uncommon, and in years of heavy snowfall, snow depths have reached 15 m (Shewchuk, 1998). In January, 2006, almost 50 cm (1.6 ft) snow fell during a 15 hour period stopping traffic (Public Safety and Emergency Preparedness Canada, 2006). A number of avalanche tracks have been identified along this portion of the highway. On average, about 100 avalanches occur per year along the Coquihalla Highway southwest of the summit. Most avalanches are small and pose no threat to motorists as they usually do not reach the highway.

At lower elevations, the Coquihalla Higwhay passes through large stands of Douglas fir and ponderosa pine. As the highway climbs to higher elevations, it passes through large stands of Engelmann spruce, lodgepole pine, and subalpine fir. Once past the Coquihalla Summit, the highway traverses the top of the Thompson Plateau and then descends through expansive rolling countryside with many small lakes. Extensive grasslands are found closer to Merritt.

Despite challenging terrain and seasonal climatic conditions, the Coquihalla Valley contains prime wildlife habitat. The primary large ungulate species found throughout the area are mule deer and smaller numbers of moose. Small concentrations of elk are found in the southern reaches of the valley. Mountain goats are widespread but restricted to rugged areas in the Coast Mountains Black bears occur throughout this area. Fewer numbers of wolves, cougars and grizzly bears are also found here. Between 1979 and 1981, prior to the construction of the Coquihalla Highway, winter wildlife studies were conducted (Kent, 2005). The studies indicated few resident deer and moose resided in the area. Limiting the studies to the winter periods resulted in a serious shortfall in information regarding migratory animals. The winter tracking studies were unable to identify the annual Spring/Summer and Fall movements of large herds of deer from the Tulamene Valley to the Coldwater Valley and down to Boston Bar across the proposed highway alignment. The lack of information became apparent just after the highway opened. In 1986, when between May and July and between October and November, unexpectedly large numbers of deer were killed during their seasonal migrations. The combination of large ungulates and high speed vehicle traffic prompted BCMoT to construct its first wildlife exclusion system to protect wildlife and motorists.

BCMoT initially installed wildlife reflectors in response to these deer-related accidents,. When it became apparent the reflectors alone would not be able to reduce the high numbers of accidents on the highway, BCMoT began the design and construction of wildlife exclusion fencing on Phase I of the highway (figure 10).

Figure 10. Wildlife exclusion fencing on the Coquihalla Highway.

By improving on the designs originally developed by Public Works Canada for Banff National Park, BCMoT was able to develop effective fencing and one-way gates (Kent, 2005). Wildlife exclusion fencing was constructed for a distance of approximately 70 km (43.5 mi) on both sides of the highway, between the toll booth and Merritt (figure 11).

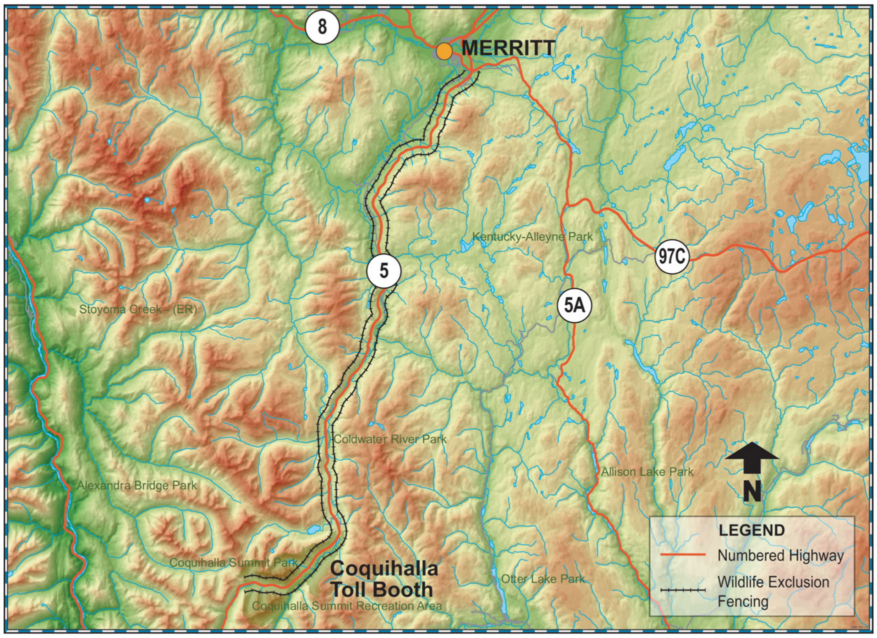



Figure 11. Location of wildlife exclusion fencing on the Coquihalla Highway.

Fencing on the Coquihalla Highway was constructed to control deer primarily because of their numbers in the area, but was designed to handle moose because of their more significant potential accident severity risk. Wildlife exclusion fencing has proven very effective in reducing wildlife accidents on the Coquihalla Highway (Highway 5) located between Hope and Merritt. On the 35 km (21.7 mi) portion of the Coquihalla Highway, between Dry Gulch Bridge and Kingsvale Bridge, wildlife exclusion fencing reduced wildlife accidents by 100%. Data from the WARS database indicates the number of wildlife accidents declined from 74, in the 1989 to 1993 period, to 0, in the 1994 to 1998 period.

**Okanagan Connector (Highway 97C)**

The Coquihalla Connector (Highway 97C) is a high speed freeway (110 km/hr (68.4 mi/hr) posted speed limit) that links the Coquihalla Highway (Highway 5) at Merrit to Highway 97 and the Okanagan communities of Kelowna and Peachland (figure 12). The highway is approximately 108 km (67.1 mi) long and provides a vital link in the Province's highway network, connecting Vancouver and the Fraser Valley to the Okanagan Valley via the Coquihalla Highway. This highway is one of the highest elevation highways in Canada. At Pennask Summit, the Okanagan Connector reaches an elevation of 1,740 m (5708.6 ft).

Figure 12. Okanagan Connector.

The Okanagan Connector lies east of the crest of the Coast and Cascade mountain ranges and west of the Columbia Mountains (Ministry of Sustainable Resource Management, 2006). This area is located in the Southern Interior Ecoprovince of British Columbia, which includes the Thompson Plateau, the Pavilion Ranges, the eastern portion of the Cascade Ranges, and the western margin of the Shuswap and Okanagan Highlands.

The leeward portion of the Coast and Cascade ranges and the drier portion of the highlands share much the same climate as the Thompson Plateau (Pojar and Meidinger, 1991). Lying in the rain shadow of the coastal mountains, this area has some of the warmest and driest areas of the Province in summer. By the time the Pacific Ocean airflows move into this area, they have already lost most of their moisture on the west facing slopes of the coastal mountains. Periodically in the summer, hot and dry air advances from the United States to the south. This produces clear skies and very warm temperatures. Since there is no effective physical barrier in the north, in the winter and early spring there are frequent outbreaks of cold, dense Arctic air. These events are less frequent in this area than on the plateaus further north. At higher elevations, the western portion of the highway is subject to cold winter temperatures and heavy snowfalls. At lower elevations, nearer Okanagan Lake, the eastern portion of the highway experiences warmer winters with considerably less snowfall.

Mule deer are the most abundant large ungulate in this area, although the white-tailed deer has been extending its range westward from the Okanagan Basin and the Okanagan and Shuswap highlands. Moose are not originally native to this area, but migrated southward from the centre of the Province as forests of the north Cariboo were opened up by farming, logging and roadbuilding activities (Shewchuk, 1998). Moose are now dispersed throughout the area and can been seen in both open grasslands and upland swamps (Shewchuk, 1998). Bighorn sheep, both native California bighorn and the introduced Rocky Mountain bighorn, occur on the rugged grasslands throughout the Thompson and Okanagan valleys and in the Clear Ranges. Smaller mammals characteristic of the area include: spotted bats, pallid bats, Nuttall's cottontails, white-tailed jack rabbits, Great Basin pocket mice, and western harvest mice.

The Okanagan Connector was opened in 1990. It is a controlled access free way with no "at grade" intersections. Prior to its construction, the seasonal ranges and movements of moose were extensively studied between 1987 and 1989. Fourteen cow moose were radio-collared and relocated a total of 1212 times during this period (Gyug and Simpson, 1989). A fixed wing aircraft and helicopter were used to estimate population numbers. The studies were able to identify migration behavior that varied from some moose remaining in one location all year round; other moose had distinct winter ranges, but combined summer fall ranges; while, yet other moose had distinct winter, summer, and fall ranges. Moose were found to pass through a 7 m ( diameter culvert. Tracking counts showed the passage rate by moose was 17%. Moose were found to migrate away from higher elevation habitats where snow depths exceeded 70 cm. Moose preferred lower elevation riparian or mixed deciduous-evergreen habitats where forage was abundant and thermal or security cover was available in nearby forests.

Underpasses for critical moose passage in winter range were determined to be 6.5 m (21.3 ft) by 7.4 m (24.3 ft) (Abrams, 1986). Deer underpasses were determined to be 4.2 m (13.8 ft) by 3.7 m (12.1 ft). The installed cost in 1989 for wildlife mitigation for the Okanagan Connector was estimated to be CAN$7 million. For this project, BCMoT spent CAN$500,000 on wildlife and mitigation studies (Stuart, 1989). Annual wildlife-vehicle collisions for the entire alignment were estimated to at 500 deer and 100 moose. A total of 40 moose collisions were estimated for the 30 km (18.6 mi) section of highway annually. There are approximately 82 km (51 mi) of wildlife exclusion fencing constructed on the Okanagan Connector on both sides of the highway. The fencing was designed to control moose, as the primary species, based on the size and weight of these animals, and deer, as the secondary species, based on their large population in the area (figure 13).


Figure 13. Location of the wildlife exclusion system between Aspen Grove and Drought Hill.

As part of the exclusion system, a wildlife overpass was constructed near Trepanier Creek. It was the first wildlife overpass constructed in Canada (figure 1). The overpass was closely modeled after the wildlife overpass built in Utah, the first wildlife overpass built in North America. Since the wildlife exclusion system was constructed on the Coquihalla Connector Freeway (Highway 97C) in 1990 to 1998, no wildlife accidents were recorded in either the westbound or eastbound lanes of the highway which are protected by wildlife exclusion fencing.

**Highway 97**

Extending almost 3,200 km, Highway 97 is one of the longest north-south highways in North America. It connects the City of Weed, in northern California to the Town of Watson Lake and the Alaska Highway, in the southeastern Yukon. From the late-1900's, in southern British Columbia, Highway 97 evolved on the terraces and benches above the western shores of Okanagan Lake.

The section of Highway 97 located between Peachland and Summerland is located in the Southern Interior Ecoprovince of British Columbia, the only ecoprovince in the Province that is part of the Dry and Semi-arid Steppe Highland ecodivisions. The southern end of the Okanagan Valley in British Columbia represents the northernmost extension of the Western Great Basin of North America. The area is located between the leeward ranges of the Coast Mountains, and the western side of the Okanagan and Shuswap highlands. Winters are cold and the summers are often very hot. This is one of the warmest and driest areas of the Province in summer. The Coast Mountains act as a barrier to the moist westerly air flow (Tourism British Columbia, 2006). Periodically, there are hot, dry air arrives from the United States, to the south, in the summer. This produces clear skies and very warm temperatures. The southern portions of the Interior Plateau, including the Okanagan, Similkameen, and Thompson River Valleys, experience the Province's hottest summers, with temperatures often in the 30oC (86 oF), occasionally rising above 40°C (104°F). In the winter and early spring, outbreaks of cold, dense Arctic air are common because there is no effective physical barrier in the north.

The area is very arid as it receives an average of 25 cm (8.9 in) to 40 cm (15.7 in) of precipitation and 2,000 hours of sunshine annually. (British Columbia Ministry of Environment, 2007). Low annual rates of precipitation, hot summers, and very mild winters create a number of different of semi-arid habitats. The dry grasslands and open pine forests in this area provide a vital landscape corridor between the shrub-steppe habitats of the Columbia Basin in Washington State in the south and the grasslands of the Thompson and Nicola valleys to the north and west.

The South Okanagan and Lower Similkameen has long been recognized as a providing a variety of habitats for unique species, many of which are found nowhere else in British Columbia or in the rest of Canada (British Columbia Ministry of Environment, 2007a, 2007b, 2007c, 2007d). The Okanagan Valley also has more species of plants and animals living here than in most areas of both British Columbia and Canada. The dry shrub grasslands of this area support a great variety of wildlife, including many of British Columbia's most rare and endangered species. There area is primarily habitat for mule deer but includes white-tailed deer, moose and mountain goats (Hope et. al., 1991). While mule deer are the most abundant large ungulate, the white-tailed deer has been extending its range westward from the Okanagan Basin and the Okanagan and Shuswap highlands. Bighorn sheep, both native California bighorn and the introduced Rocky Mountain bighorn, occur on the rugged grasslands throughout the Okanagan Valley and in the Clear Ranges. Spotted bats, pallid bats, Nuttall's cottontails, white-tailed jack rabbits, Great Basin pocket mice, and western harvest mice are characteristic small mammals.

From the late 1980's to the mid-1990's, the number of deer-related motor vehicles accidents occurring between Summerland and Peachland began increasing. In 1999, BCMoT partnered with the Insurance Corporation of British Columbia (ICBC) and Summerland Sportsmens' Association and the Peachland Sportsmen's Association, affiliated associations of the British Columbia Wildlife Federation, to construct a wildlife exclusion fence on the west side of Highway 97 between Bentley Road and Deep Creek. While BCMoT supplied fencing materials, ICBC contributed CAN$128,000 and the sportsmen's associations provided construction labour and on-going maintenance. Most Ministry wildlife exclusion installations involve the construction of fencing on both sides of a highway. However, due to the topography of this area, with steep banks on the east side of the highway, a decision was made to construct fencing on only the west side of the highway (figure 14).

Figure 14. Highway 97 between Peachland and Summerland.

The fence along this section of Highway 97 is only 15 km (9.3 mi) long and represents the BCMoT's shortest wildlife exclusion installation (figure 15). However, the installation has proven to be very effective, dramatically reducing the incidence of deer-related motor vehicle accidents. The installation also demonstrates how a fence installed on one side of a highway can be successful, if suitable physical landscape features can be incorporated into the design.


Figure 15. Location of the wildlife exclusion system between Peachland and Summerland.

**Vancouver Island Highway (Highway 19)**

The Vancouver Island Highway (Highway 19) runs for most of the length of the eastern coast of Vancouver Island. From Victoria to Port Hardy, the highway extends over 500 km (310 mi). Between 1989 and 2002, after extensive planning and preliminary, functional and detailed design stages, major upgrades to the highway were made. The longest section of the Vancouver Island Highway Project (VIHP), the Inland Island Highway, stretches from Parksville to Campbell River through an environmentally-sensitive area. The route includes new freeway and expressway alignments with numerous connectors and interchanges. The longest bridge on Vancouver Island, the Tsable River Bridge, was built on this section. The Inland Island Highway included the construction of 150 km (93 mi) of new 4-lane, limited access, divided highway between Victoria and Campbell River.

The Inland Island Highway is located on the leeward side of the Vancouver Island Ranges. After passing eastward over the Vancouver Island Mountains, Pacific Ocean surface air flow descends producing clearer and drier conditions than those found on the west side of the island. As a consequence, this area has the greatest annual amounts of sunshine in British Columbia (Pojar, Klinka and Demarchi, 1991a, 1991b). The moderating influence of the waters of the Strait of Georgia also produces local temperatures among the mildest in Canada. The climate on the East coast of the island is characterized by mild winters and warm summers. Precipitation ranges from 0.8 m (2.6 ft) to 2.5 m (8.2 ft) per year and rainfall is greatest between October and March. Large accumulations of snow on the Vancouver Island Mountains produce some of the lowest treelines in the British Columbia. However, at sea level, while winters are usually wet, snow is not common every year. Typically, summers tend to be dry, especially between June and August. Summer droughts often last 5 to 6 weeks.

The temperate coniferous forests of Vancouver Island provide among the richest habitats in North America for mammals, amphibians and birds. Mule deer ("black-tailed") are the predominant ungulate. From wild and rural areas to urban golf courses and suburban developments, they are ubiquitous. Although relatively few in number in comparison to mule deer, a number of growing herds of Roosevelt elk are found at scattered locations. Although there have been sporadic reports of Grizzly bear, the primary large carnivores on the island are cougar and black bear. Smaller carnivores include river otters, mink and raccoons. These animals tend to be found near water, either along ocean shorelines and in estuaries, or along lake shores and river banks. Small mammals in the area include the Virginia opossum, marsh shrew, Trowbridge's shrew, shrew-mole, Townsend's mole, coast mole, Douglas' squirrel, and creeping vole. The highest diversity of birds in British Columbia are also found in this area. Of all species known in the Province, approximately 90% occur on Vancouver Island. Reptiles found in the area include the sharptail snake while the ensatina and Pacific giant salamander are the predominant amphibians. A number of alien species are also found here. These include the western pond turtle, eastern cottontail rabbit, bullfrog and green frog.

In 1999, the Mud Bay-Courtenay section of the Inland Island Highway was completed. Two years later, the highway was extended to Campbell River. Finally, in 2001, Highway 19 was extended from Courtenay along the last section of the new inland highway to the Campbell River Bypass. The new sections of the Inland Island Highway were constructed through or near, one of the world's most diverse ecosystems, ranging from rainforests, marshes, meadows, beaches, mountains, oceans, rivers and lakes creating habitats for many wildlife species. Special care was taken to ensure the footprint of the new sections of highway were as small as possible and measures were implemented to compensate for lost wildlife habitat. Extensive efforts were also made to protect the Roosevelt elk. At four locations along the Inland Island Highway, where alignment transected elk habitat, wildlife exclusion systems were constructed. Wildlife exclusion fencing and associated structures were installed on both sides of three sections of highway and on one side of one section (figure 16). A total of 148 km (92 mi) of fencing was installed over 84 km (52 mi) of highway (figure 17).

Figure 16. Wildlife exclusion fencing on Vancouver Island Highway (Highway 19).


Figure 17. Location of wildlife exclusion systems on the Vancouver Island Highway.

## Ongoing Advancements

It is becoming evident that approaching the issue of wild accident mitigation from a single species perspective does not provide the maximum benefit for wildlife. For BCMoT, integrated wildlife accident management is becoming a greater component of new construction and rehabilitation projects. While, for over 20 years, BCMoT projects have largely focused on highway-related mortality involving larger ungulates, such deer, elk and moose, new projects are increasingly becoming more responsive to the needs of smaller mammals, such as badgers, and amphibians, such as salamanders.

Wildlife exclusion systems are being designed and integrated with larger scale structures and alignment drainage schemes to protect an increasing number of animal species. The construction of larger underpasses, such as bridges and culverts, and the retention of natural watercourses, vegetation and landforms under these structures, increases their effectiveness for wildlife and fish passage. High quality wildlife habitat ponds are developed along highway alignments to lessen the impact of highways on wildlife habitat. On the Vancouver Island Highway Project, wildlife crossing structures and wildlife habitat ponds were carefully integrated with natural topography and drainage systems, to reduce the potential for highway-related wildlife mortality and limit the wildlife habitat fragmenting effects of highways (figure 18).

Figure 18. Man-made wildlife habitat pond adjacent to the Vancouver Island Highway.

## Summary

BCMoT has found its wildlife exclusion systems to be very effective in reducing motor vehicle-related mortality on high speed highways for ungulates, in particular deer, elk and moose. Whether these systems are incorporated into the designs of new highways or retrofitted into existing ones, they are becoming an increasingly integral component on BCMoT's approach to reducing the potential for wildlife mortality on British Columbia highways.

Wildlife exclusion systems are most easily incorporated into new highways during the early planning and design stages. This allows major structures, such as bridges and culverts, to be designed to maximize their effectiveness for wildlife passage. Exclusion systems have been found to be the most effective means of keeping wildlife off highway rights-of-way when installed in conjunction with well-designed, well-located, wildlife crossing structures. Clevenger and Waltho (2000) found underpasses increase the success of exclusion fencing by increasing the permeability and habitat connectivity across highways.

BCMoT's experience with wildlife exclusion systems properly designed for specific species, that are well maintained, and strategically located, and that incorporate 2.4 m (7.9 ft) high fencing on both sides of rights-of-way and components, such as one-way gates, ungulate guards, underpasses and overpasses, can be more than 90% effective in preventing highway-related wildlife mortality. Improvements in the effectiveness of wildlife exclusion systems have been the result of system design evolution as the dynamics of the highway/wildlife habitat interface and the behavioral, physical and anatomical characteristics of specific species of wildlife have become better known.

**Biographical Sketch:** Leonard Sielecki is a registered professional biologist and a registered professional land use planner working under the Chief Engineer of the British Columbia Ministry of Transportation (BCMoT). Since the mid-1990's, Leonard has been the Government of British Columbia's expert on wildlife collision monitoring and mitigation. He manages BCMoT's Wildlife Accident Reporting System (WARS) and is actively involved in both the operational and research aspects of Provincial wildlife collision mitigation initiatives. He supervises and directs the work of wildlife consultants for BCMoT and is responsible for the design and development of the Ministry's wildlife exclusion systems. Leonard is involved in wildlife-related policy development and acts as the Ministry's liaison with Canadian federal and provincial agencies on wildlife-related transportation issues. He provides consulting services to Transport Canada and expert advice to BCMoT staff and consultants involved in major transportation projects in British Columbia. In 2005, the United States National Academies of Science appointed Leonard to the Transportation Research Board (TRB) expert panel overseeing the ongoing National Cooperative Highway Research Program (NCHRP) study on animal collisions in North America. Leonard has a B.Sc. in Biology and Geography, a Masters in Geography, and is currently completing a Ph.D. on natural hazard risk management at the University of Victoria.

## References

Abrams, A.,1986, British Columbia Ministry of Transportation and Highways Communication to D.G. Johnson, Senior Design Engineer, Special Project, British Columbia Ministry of Transportation and Highways.

British Columbia Ministry of Environment, 2007a, Grassland Ecosystems, http://wlapwww.gov.bc.ca/sir/fwh/wld/atlas/ecosystems/ecosystems_index.html, accessed April 6, 2006

British Columbia Ministry of Environment, 2007b, Forest Ecosystems, http://wlapwww.gov.bc.ca/sir/fwh/wld/atlas/ecosystems/ecosystems_index.html, accessed April 20, 2007

British Columbia Ministry of Environment, 2007c, Riparian and Wetland Ecosystems, http://wlapwww.gov.bc.ca/sir/fwh/wld/atlas/ecosystems/ecosystems_index.html, accessed April 20, 2007

British Columbia Ministry of Environment, 2007d, Rugged Terrain Ecosystems, http://wlapwww.gov.bc.ca/sir/fwh/wld/atlas/ecosystems/ecosystems_index.html, accessed April 20, 2007

British Columbia Ministry of Forests, 1999, Biogeographic Zones of British Columbia Map, Research Branch, Victoria, British Columbia, Canada

British Columbia Ministry of Sustainable Resource Management, 2007, Ecoregions of British Columbia Home, http://srmwww.gov.bc.ca/ecology/ecoregions/index.html, Accessed April 20, 2007

British Columbia Ministry of Transportation, 2004, Quick Facts Book, October 2004, Victoria, B.C. 32 pp.

Buckingham, A.F., 2007, British Columbia Ministry of Transportation Communication to L.E. Sielecki, Environmental Issues Analyst, British Columbia Ministry of Transportation

Clevenger, A.P., Chruszez B. and Gunson, K.E., 2001, Highway mitigation fencing reduces wildlife-vehicle collisions, *Wildlife Society Bulletin*, 29(2): 646-653.

Demarchi, M., 2005, Wildlife Exclusion Fencing Audit: Coquihalla Highway (No. 5): Dry Gulch to Inks Lake Interchange, LGL Limited, Sidney, BC. 17pp.

Gyug, L. and Simpson K., 1989, Okanagan Connector Ungulate Telemetry and Inventory Progress Report, Seasonal Ranges and Movements of Moose, Keystone Bioresearch, Surrey, B.C. 32 pp.

Harper, W.L., 2005, Wildlife Exclusion Fencing on the Okanagan Connector Freeway (Highway 97C) Audit and Evaluation of Structures and Materials and Recommendations for Maintenance, Osiris Wildlife Consulting, Victoria, B.C., 48pp.

Hope, G.D., W.R. Mitchell, D.A. Lloyd, W.R. Erickson, W.L. Harper, and B.M. Wikeem, 1991, Interior Douglas-fir Zone, Chapter 3 in in Meidinger, D. and J. Pojar (Eds.), Ecosystems of British Columbia, British Columbia Ministry of Forests, pp. 153-166.

Ito, T., 2005, Wildlife-oriented measures against road kill accidents in Japan and their evaluation on Shari Eco-Road, IX International Mammalogical Congress, Proceedings of the Symposium on Wild animals and traffic accidents: Monitoring, analysis, prevention measures, and measure evaluation, Sapporo, August 2, 2005, pp.111-121

Hartwig C.L. and Demarchi R.A., 2005, Wildlife Exclusion Fencing Audit: Vancouver Island Highway No.19., Ecodomain Consulting, Duncan, B.C., 19pp.

Hayward, D., 2005, Highway 97 Wildlife Exclusion Fence Audit, Summit Environmental Consultants Ltd., Vernon, B.C., 33pp.

Hope, G.D., W.R. Mitchell, D.A. Lloyd, W.R. Erickson, W.L. Harper and B.M. Wikeem, Interior Douglas Fir Zone, Chapter 10 in Meidinger, D. and J. Pojar (Eds.), Ecosystems of British Columbia, British Columbia Ministry of Forests, pp. 153-166.

Kent, M., 2005, British Columbia Ministry of Transportation Communication to L.E. Sielecki, Environmental Issues Analyst, British Columbia Ministry of Transportation

Nuszdorfer, F.C., K. Klinka and D.A. Demarchi, 1991a, Coastal Douglas-fir Zone, Chapter 5 in Meidinger, D. and J. Pojar (Eds.), Ecosystems of British Columbia, British Columbia Ministry of Forests, pp. 81-93

Nuszdorfer, F.C., K. Klinka and D.A. Demarchi, 1991b, Coastal Western Hemlock Zone, Chapter 6 in Meidinger, D. and J. Pojar (Eds.), Ecosystems of British Columbia, British Columbia Ministry of Forests, pp. 95-111

Pojar, J. and D. Meidinger, 1991, British Columbia: The Environmental Setting, Chapter 3, in Meidinger, D. and J. Pojar (Eds.), Ecosystems of British Columbia, British Columbia Ministry of Forests, pp. 39-67

Public Safety and Emergency Preparedness Canada, 2007, Keeping Canadians Safe, http://www.psepc.gc.ca/dob/dob06-021-en.asp, Accessed April 20, 2007

Sielecki, L.E., 2004, WARS 1983 – 2002: Wildlife Accident Reporting and Mitigation in British Columbia: Special Annual Report, British Columbia Ministry of Transportation, Environmental Management Section, British Columbia, Canada, 222pp.

Stuart, K., 1989, British Columbia Ministry of Environment, Communication to Mike Kent, Senior Environmental Coordinator, British Columbia Ministry of Transportation and Highways

Shewchuk, M., 1998, Coquihalla Country, Sonotek Publishing, Merritt, British Columbia, 224 pp.

Tourism British Columbia, 2007, Climate and Weather, http://www.hellobc.com/en-CA/AboutBC/ClimateWeather/BritishColumbia.htm, accessed April 20, 2007

# Role of Fencing in Promoting Wildlife Underpass Use and Highway Permeability

**Norris L. Dodd** (928-367-5675, doddnbenda@cybertrails.com), **Jeffrey W. Gagnon**, **Susan Boe**, and **Raymond E. Schweinsburg**, Arizona Game and Fish Department, Research Branch, 2221 West Greenway Road, Phoenix, AZ 85023 USA

**Abstract:** Ungulate-proof fencing has been used successfully to mitigate the incidence of wildlife-vehicle collisions on highways throughout North America. And while fencing is often regarded as an integral component of effective wildlife passage structures, limited information or guidelines exist for the application of fencing in conjunction with wildlife passages. Fencing itself may limit wildlife permeability across highways and exacerbate the barrier effect of highways on wildlife populations. An 8-km section of highway reconstructed from a two- to four-lane divided highway in central Arizona was opened to traffic six months before ungulate-proof fencing was erected linking four wildlife underpasses (UP) and three bridges. To assess the role of strategically placed fencing along 49% of the section, we compared before and after fencing Rocky Mountain elk (*Cervus elaphus nelsoni*)-vehicle collision incidence, wildlife use of UP, and elk highway permeability. From 2002–2006, we documented 110 elk-vehicle collisions. The incidence of collisions increased over three fold after highway reconstruction was completed but before fencing was erected. After fencing, the incidence of elk collisions declined 87%. We employed video camera surveillance systems at two UP to compare wildlife use for nine months before and 11 months after fencing was erected. Before fencing, we recorded 500 elk and deer (*Odocoileus* spp.) at the UP, of which only 12% successfully passed through the UP; 81% of animals continued to cross the highway at grade. After fencing, of 595 elk and deer recorded, 56% crossed successfully and no animals crossed the highway at grade. The probability of an approaching animal crossing through an UP increased from 0.09 to 0.56 with fencing, and the combined odds of a crossing through the UP after fencing was 13.6:1 compared to before fencing. We used Global Positioning System (GPS) telemetry to assess highway permeability and crossing patterns. We instrumented 22 elk (16 female, 6 male) with GPS receiver collars April 2004–October 2005, during which time our collars accrued 87,745 GPS fixes. The elk highway passage rate, our measure of permeability, after the highway was opened to traffic but before fencing was erected (0.54 crossings/approach) was 32% lower than the level determined from a previous study for the section during reconstruction (0.79 crossings/approach). Once fencing was erected, the passage rate increased 52% to 0.82 crossings/approach. The proportion of elk crossings that occurred along fenced highway stretches declined 50% while the proportion of crossings along unfenced highway increased 40%. Fencing plays an important role in reducing the incidence of wildlife-vehicle collisions and increasing the effectiveness of wildlife passage structures. Furthermore, fencing in combination with a relatively high density of passages (1 structure/1.1 km) promoted elk highway permeability by funneling animals toward the UP where resistance to crossing was lower than that associated with crossings at grade.

## Introduction

The awareness and understanding of highway impacts to wildlife populations in North America have increased dramatically in the past decade (Forman et al. 2003), with highways considered one of the most significant forces altering natural ecosystems (Noss and Cooperrider 1994, Trombulak and Frissell 2000, Farrell et al. 2002). Forman and Alexander (1998) estimated that highways have affected >20% of the land area within the U.S. through habitat loss and degradation. In addition to direct habitat loss (Forman 2000), mortality from vehicle collisions has been recognized as posing a serious and growing problem for wildlife, motorist safety, and property loss (Reed et al. 1982, Farrell et al. 2002). Estimates of annual vehicle collisions involving deer (Odocoileus spp.) alone in the U.S. have ranged as high as 1.5 million (Conover 1997). Wildlife-vehicle collisions cause human injuries, deaths, and tremendous property loss (Reed et al. 1982, Schwabe and Schuhmann 2002).

An even more pervasive impact of highways on wildlife is indirect barrier and fragmentation effects resulting in diminished habitat connectivity and permeability (Noss and Cooperrider 1994, Forman and Alexander 1998, Forman 2000, Forman et al. 2003). Highways act as barriers to free movement of wildlife, fragmenting and isolating habitats, limiting juvenile dispersal (Beier 1995), and reducing genetic interchange (Epps et al. 2005). Long-term fragmentation and isolation increases population susceptibility to stochastic events (Swihart and Slade 1984, Forman and Alexander 1998, Trombulak and Frissell 2003).

Just as our understanding of highway impacts has increased in the past decade, so have comprehensive efforts to mitigate and address these impacts in conjunction with highway construction and maintenance projects. Structures designed to promote wildlife passage across highways are increasingly being implemented and shown to be effective throughout North America, particularly large bridges (e.g., underpasses or overpasses) designed specifically for large animal passage (Foster and Humphrey 1995, Clevenger and Waltho 2003, Gordon and Anderson, 2003, Dodd et al. 2007a). Transportation agencies are increasingly receptive to integrating passage structures into highways to address both safety and ecological needs (Farrell et al. 2002) and there is increasing expectation that such structures will yield benefit to multiple species and enhance connectivity (Clevenger and Waltho 2000).

Ungulate-proof fencing ranging in height from 2.0–2.4 m has been demonstrated as effective in reducing the incidence of wildlife-vehicle collisions (WVC), especially when used in conjunction with passage structures (Romin and Bissonette 1996, Forman et al. 2003). Ward (1982) reported >90% reduction in mule deer (O. heminous) collisions with vehicles where underpasses and fencing were applied in Wyoming, though modifications to the original fencing were needed to achieve this reduction in WVC. Woods (1990) reported 94–97% reductions in WVC involving several species in Alberta with passages and fencing, while Clevenger et al. (2001) reported an 80% reduction in the same area. Similar reductions in moose (Alces alces)-vehicle collisions in Sweden were attained with fencing (Lavsund and Sandegren 1991).

Though fencing is generally regarded as effective in reducing WCV, mixed results nonetheless have been reported (Falk et al. 1978), especially where animals cross at the ends of fencing resulting in zones of increased incidence of WVC

(Feldhammer et al. 1986, Woods 1990, Clevenger et al. 2001). Furthermore, fencing is costly and requires substantial maintenance (Forman et al. 2003), potentially contributing to reluctance on the part of transportation managers to fencing extensive stretches of highways. And while fencing is often regarded as an integral component of effective passage structures (Romin and Bissonette 1996, Forman et al. 2003), limited information or guidelines exist for the application of fencing in conjunction with wildlife passages. Inasmuch as fences themselves constitute effective barriers to ungulate passage across highways (Falk et al. 1978), fencing may potentially exacerbate the reduction in wildlife permeability associated with highways alone (Dodd et al. 2007b), particularly where effective measures to accommodate animal passage are lacking.

Since 2000, the Arizona Department of Transportation (ADOT) has been reconstructing a 30-km stretch of State Route 260 (SR 260) in central Arizona, with plans to ultimately construct 11 sets of wildlife underpass (UP) and six sets of bridges. ADOT's general model for integrating 2.4-m ungulate-proof fencing with UP was to erect limited (<100 m) wing fences outward from each UP and most bridge abutments to funnel animals toward the structures. An adaptive management approach to reconstruction has been embraced by ADOT where data from our research has been used to make modifications to UP design (Dodd et al. 2007a) and the strategic placement of fencing to intercept crossing wildlife as determined from Global Positioning System (GPS) telemetry (Dodd et al. 2007b).

On our study section of SR 260, the highway was opened to traffic six months before ungulate-proof fencing was erected along approximately half of the section. This provided us an opportunity to assess and compare wildlife response and use of the highway corridor and UP, as well as WVC patterns before and after fencing was erected. The majority of UP construction was completed approximately 14 months before the section was opened to traffic, providing time for animals to habituate to the seven passage structures prior to our study, consistent with ungulate habituation reported by Clevenger and Waltho (2003) and Dodd et al. (2007a).

During the period that this section was under reconstruction, Dodd et al. (2007b) conducted a GPS telemetry assessment of Rocky Mountain elk (Cervus elaphus nelsoni) movement and crossing patterns and permeability across the highway corridor. They found that the elk passage rate on the lone completed section opened to traffic (0.43 crossings/approach +/- 0.15 SE, *n* = 15 elk) was lower than the mean rate for two control sections (0.88 crossings/approach +/- 0.16, *n* = 15) and two sections under reconstruction (0.84 crossings/approach +/- 0.12, *n* = 22) including that associated with this study (0.79 crossings/approach +/- 0.09, *n* = 14). Thus, we were further presented the opportunity to compare permeability before (Dodd et al. 2007b) and after the study section was opened to traffic following construction, as well as before and after fencing was erected to limit elk crossings at grade and to funnel animals toward UP. Numerous studies have alluded to highway barrier effects on wildlife (e.g., see Forman et al. 2003, Dodd et al. 2007b), but none have yielded quantitative data relative to animal highway passage rates in an experimental (e.g., before and after reconstruction) context.

The objectives of our study were to take an integrated approach to assess and compare: 1) elk highway crossing patterns and permeability before and after the highway section was opened to traffic before fencing was erected, 2) elk highway crossing patterns and permeability before and after fencing was erected once the highway section was opened to traffic, 3) wildlife use of UP before and after fencing was erected, focusing on elk, mule deer and white-tailed deer (*O. virginianus couesii*), and 4) WVC patterns before and after fencing was erected. We attempted to determine to what degree fencing is necessary to achieve wildlife use of UP, and to develop recommendations on the use of fencing in conjunction with wildlife UP to maximize their effectiveness in reducing WVC and maintaining wildlife permeability.

## Study Area

Our study was conducted as part of the reconstruction of a 30-km stretch of SR 260, beginning 15 km east of Payson and extending to the base of the Mogollon Rim in central Arizona (lat 34o15'–34o18'N, long 110o15'–111o13'W; fig. 1). The existing two-lane highway is in the process of being reconstructed to a four-lane divided highway; in places, the footprint of the upgraded highway exceeds 0.5 km in width. Reconstruction of three of five sections has been completed, with seven of 11 planned UP and all six bridges completed (fig. 1). (Note: all figures are presented at end of paper.) The first section, Preacher Canyon, was completed and all lanes opened to traffic in November 2001, with two wildlife UP in addition to a large bridge over Preacher Canyon (fig. 1). The Kohl's Ranch section was the most recently reconstructed section, completed in March 2006; this section includes one UP and 2 bridges. Highway reconstruction of the last two sections, Little Green Valley and Doubtful Canyon will not occur before 2007.

We conducted this aspect of our study along the 8-km Christopher Creek (CC) section at which reconstruction was begun in early 2002. This reconstruction incorporated four wildlife UP and three bridges (fig. 1, table 1). On average, a passage structure was located every 1.1 km along the section. The majority of heavy reconstruction, including bridge and UP construction was completed by May 2003, at which time wildlife could pass through them. Vehicular traffic was confined to a single set of lanes until early-July 2004, when all four lanes were opened to traffic. Erection of ungulate-proof fencing was not completed until mid-December 2004. Original construction designs incorporated 2.4-m metal pipe, T-post, and mesh wire fencing adjacent to 1.8 km of the CC section (22%). This extent of fencing was increased to 3.9 km (49%; fig. 2) by raising the existing 1.1-m right-of-way (ROW) fence to 2.3 m through the adaptive management process to address peak elk highway crossing zones determined by GPS telemetry. The added fencing was projected to intercept 45% of elk crossings, for a total of 58% crossing interception by all fencing (Dodd et al. 2007b). During the extension of the ROW-fence, a 0.2-km gap was left in the fence midway along a 1.4-km stretch of fenced highway due to complexities associated with integrating fencing at a lateral access road into the community of Christopher Creek (fig. 2). Also, steep (4:1) fill slopes atop which ROW fence and guard rail were placed and tied into fencing with large boulder "elk rock" rip-rap (fig. 3) adjacent to 0.9 km of the highway was evaluated as an alternative treatment to deter at-grade wildlife crossings. This treatment was projected to intercept 27% if the GPS-identified elk crossings (Dodd et al. 2007b).

Our study area lies within the ponderosa pine (*Pinus ponderosa*) association of the montane coniferous forest community (Brown 1994a). Elevations range from 1,680-1,900 m. The Mogollon Rim escarpment to the north is the dominant land-form, rising precipitously to 2,400 m (fig. 1). Numerous riparian and wet meadow habitats occur at several locations along the highway corridor (fig. 1), with some meadows >25 ha in size. Several perennial streams flow adjacent to portions of the highway (fig. 1). Climatic conditions within the study area are mild, with a mean maximum monthly temperature (July) for Payson of 32.4oC, and mean minimum monthly temperature (January) of -6.9oC. Annual precipitation averages 52.6 cm, with a mean of 54.1 cm of snowfall in winter; precipitation has averaged two-thirds of normal since 2002.

Average annual daily traffic (AADT) volume on this portion of SR 260 (ADOT Control Road traffic monitoring station) doubled in 10 years from 3,100 in 1994 to nearly 6,300 in 2002, and increased to 8,700 (+38%) in 2003 (ADOT Data Management Section). Over the same period, annual wildlife-vehicle collisions involving ungulates and large carnivores on this stretch of SR 260 increased from 28 to 44, with a mean of 35.9 (+/-2.5 SE; Dodd et al. 2006).

Table 1: Physical characteristics associated with wildlife underpasses (UP) and bridges on the Christopher Creek section of State Route 260, Arizona, USA

| Passage structure | Span m (ft) | Rise m (ft) | Length m (ft)[a] | Atrium m (ft)[b] |
|---|---|---|---|---|
| Wildlife 1 UP | 103.0 (338) | 15.0 (49) | 110.0 (361) | 24.0 (79) |
| Christopher Creek bridge | 158.5 (520) | 17.7 (58) | 91.4 (300) | 20.0 (66) |
| Pedestrian/wildlife UP | 34.2 (112) | 6.8 (22) | 128.0 (420) | 47.9 (157) |
| Hunter Creek access UP | 38.1 (125) | 6.5 (21) | 112.8 (370) | 53.3 (175) |
| Wildlife 2 UP | 39.9 (131) | 10.0 (33) | 118.8 (390) | 31.9 (105) |
| Sharp Creek bridge | | | | |
| Eastbound lanes | 174.0 (571) | 17.5 (57) | 175.0 (574) | 125.0 (410) |
| Westbound lanes | 39.9 (131) | 6.6 (22) | | |
| Wildlife 3 UP | 37.7 (124) | 5.1 (17) | 63.9 (210) | None |

[a]Length = distance for animals to fully negotiate passage structure, from mouth to mouth including fill material
[b]Atrium = width of opening between eastbound and westbound bridge spans

Rocky Mountain elk (*Cervus elaphus nelsoni*) were a focus of our research for several reasons. First, elk accounted for >80% of all collisions between vehicles and wildlife (Dodd et al. 2006) and the vast majority of property loss and human injuries associated with collisions with vehicles. Elk are large animals that can readily support our GPS telemetry collars, yielding substantial data on movements in relation to the highway corridor, and were relatively easy to trap. Both resident and migratory elk herds occurred within our study area. Resident elk were common, especially in proximity to meadow and riparian habitats. Elk migrate off the Mogollon Rim with the first snowfall >30 cm, typically in late October (Brown 1990, 1994b). Elk return to summer range with forage green up at higher elevations (Brown 1990). The Arizona Game and Fish Department estimated the resident elk population in game management units encompassing our study area at 1,500-1,600 (Arizona Game and Fish Department, Game Management Branch, unpublished data), though not all elk resided in proximity to SR 260. Whitetail deer (*Odocoileus virginianus cousei*) were frequently seen in our study area, while mule deer (*O. hemionus*) were less common and more localized on the CC section.

## Methods

To address our study objectives, we used data collected during a previous phase of research conducted when the CC section was under reconstruction, yielding data on elk crossing patterns and passage rates determined from GPS telemetry (Dodd et al. 2007b) and WVC collision patterns (Dodd et al. 2006). We used these baseline data to make comparisons among the following three highway reconstruction treatment classes: 1) under reconstruction, 2) post reconstruction-before fencing (henceforth before fencing), and 3) post reconstruction-after fencing (henceforth after fencing). The availability of under reconstruction treatment data allowed us to make comparisons among all three treatment classes for our elk permeability and WVC patterns data. Our comparisons of UP wildlife use however were limited to before and after fencing, as the video camera surveillance systems we employed to assess wildlife use were not installed until after reconstruction was completed. Statistical tests were performed using the program STATISTICA® (Statsoft, Inc. 1994). Results were considered significant at $P \leq 0.05$. Mean values were reported with +/- one SE.

### Comparison of Elk Crossing Patterns and Permeability

We captured and handled elk at six trap sites spaced an average of 1.1 km apart along the CC section and one site each on the Kohl's Ranch and Doubtful Canyon sections, similar to Dodd et al. (2007b). We trapped elk in net-covered Clover traps (Clover 1954) baited with salt and alfalfa hay, with all traps located within 300 m of the highway corridor. We timed trapping to target resident elk to maximize yearlong acquisition of GPS fixes near the highway. We used model TGW-3600 "store-on-board" GPS receiver collars (Telonics, Inc., Mesa, Arizona, USA) programmed to receive a fix every 1.5 hours from 1700–900 hours (12 fixes) and one at 1200; operational battery life was 22 months.

We employed ArcGIS® Version 8.3 software (ESRI, Redlands, California, USA) and Animal Movement ArcView Extension Version 1.1 software (Hooge and Eichenlaub 1997) to analyze GPS data similar to Dodd et al. (2007b). We divided the length of the CC section into 50 sequentially numbered 0.16-km segments (fig. 4) to quantify highway approaches and crossings. To infer highway crossings, we drew lines connecting all consecutive GPS fixes; crossings were identified where lines between fixes crossed the highway through a segment (fig. 4). We compiled crossings by individual animal by highway segment. We calculated crossing rates for individual elk by dividing the crossings by the days a collar was worn.

We calculated elk passage rates as per Dodd et al. (2007b); passage rates were considered our best relative measure of highway permeability (e.g., compared to crossing rates; Dodd et al. 2007b). An approach was considered to have occurred when an elk traveled (determined by successive GPS fixes) to within 0.25 km of SR 260 (fig. 4); successive fixes within 0.25 km of SR 260 were treated as a single approach. Our approach zone corresponded to the road-effect zone where elk were affected by traffic-related disturbance (Rost and Bailey 1979, Forman et al. 2003) and the zone adjacent to highways avoided by elk (Witmer and deCalesta 1985). We calculated passage rates for each elk as the proportion of highway crossings to approaches during the same period. We calculated and compared different rates for the periods before and after ungulate-proof fencing was erected. We also compared the elk passage rates determined by Dodd et al. (2007b) when the CC section was under reconstruction to those after reconstruction was completed (before and after fencing). Values were derived for individual elk and pooled for each comparison class.

We employed ANOVA to test the null hypothesis that no differences in elk passage rates existed among treatment classes. Where significant ANOVA results were obtained among classes, we conducted post hoc pairwise comparisons using a Tukey test for unequal sample sizes (Statsoft Inc. 1999, Dodd et al 2007b). We made similar comparisons for elk highway crossing rates among treatment classes.

To assess how fencing affected the elk crossing distribution patterns after reconstruction was completed, we compared the change in the proportions of crossings before and after fencing that occurred along the CC section for three crossing deterrent treatments: 1) fenced, 2) steep slopes-elk rock, and 3) not fenced (fig. 2). We compared the mean change in proportions of elk crossings that occurred along highway stretches between passage structures among the treatments. We made these comparisons with ANOVA, and where significant results were obtained, post hoc pairwise comparisons were done using a Tukey test for unequal sample sizes.

### Comparison of Elk-Vehicle Collision Patterns

To document WVC along SR 260, we used consolidated records from multiple sources as described by Dodd et al. (2006). Our primary source was a long-term statewide accident database maintained by the ADOT Data Management Section (ADOT, unpublished data), including WVC. Records in this database included the date, time, and location of the WVC, and wildlife species (genus only in the case of deer) involved. From this database, we were also able to determine the proportion of total accidents through 2005 that involved collisions with wildlife. Further, at the onset of our project in late-2000, we developed a standardized WVC tracking form for use by agencies and research project personnel to document all WVC, including roadkills. This database reflected concerted efforts to regularly search for and document WVC, especially by research project personnel Our database included the same information as the ADOT database, including species of deer. All WVC were recorded to the nearest 0.16 km.

We compared the incidence of WVC involving elk only among treatments as ungulate-proof fencing, especially the modified ROW fence was permeable to deer and other species. We compared elk-vehicle collisions among treatments documented from 2002 (when reconstruction was begun) through 2006. We compiled elk-vehicle collision data by season (January–March, April–June, July–September, October–December) and highway treatment class. Season influenced elk UP (Dodd et al. 2006) and highway crossing patterns (Gagnon 2006), with the fall (October–December) migratory period accounting for the highest incidence of elk-vehicle collisions (Dodd et al. 2006). We used ANOVA to compare mean elk-vehicle collisions among seasons and highway treatments. Where significant results were obtained in our ANCOVA, post hoc pairwise comparisons were done using a Tukey test for unequal sample sizes.

### Wildlife Underpass Use Comparison

We used triggered four-camera video surveillance systems described by Dodd et al. (2007a) and Gagnon et al. (2006) to examine the number of elk and deer that used UP on the CC section. These systems included two cameras that recorded animals approaching the UP from one side of the UP (approximately 40–50 m from the mouth of the UP) and the other two cameras recording animals as they passed through UP. Though video camera systems were installed at four UP on the CC Section, only two systems were installed prior to erection of fencing, limiting our before and after fencing comparison of UP wildlife use to the Pedestrian/Wildlife and Wildlife 2 UP (table 1, fig. 2) located 2.4 km apart. Both UP at which we compared wildlife use had separate east- and west-bound bridges with open atria between bridges (32–48 m; table 1).

We assessed and compared wildlife use at the two UP for nine months (April–December 2004) prior to fencing and 11 months (January–December 2005) after the erection of fencing to funnel animals to UP. We focused on elk, mule deer, and white-tailed deer since they comprised a majority of animals recorded by camera systems; fencing was permeable to smaller species. We used individual elk and deer as our sampling unit even though these ungulate species exhibit a herding nature, as individual animals within groups often exhibited different responses to approaching and crossing the two UP.

We considered an UP approach to occur when animals crossed over the 1.1-m ROW fence approximately 40–50 m from the mouth of the UP. We compared mean daily and monthly usage and overall probability of usage before and after erection of fencing. We assessed the number of animals that approached the UP and assigned them to two approach categories based on their subsequent behavior recorded by our cameras:

- *Attempted to cross* – animals that approached the highway corridor in the vicinity of the UP and attempted to cross the highway either via the UP or over the highway.
- *No attempt to cross* – animals that were recorded by cameras at the UP but appeared to have had no intention of crossing the highway.

Once we identified an animal as attempting to cross the highway, we assigned them to one of three crossing behavior categories and examined the proportion of crossings that fell within the categories:

- *Avoid UP altogether* – animals crossed up and over both sets of highway lanes at grade.
- *Partial crossing* – animals passed through one bridge below grade but entered the median between bridges via atria and crossed the other two lanes at grade.
- *Successful crossing* – animals crossed through both bridges and all lanes of traffic below grade.

We tested the overall hypothesis that probability of use and daily and monthly wildlife of the UP use did not differ before and after the erection of fencing. To test the hypothesis that probability of use was independent of fencing we examined the number of observed successful elk and deer crossings and compared them to expected using a chi-square contingency table. We used fencing as the treatment and successful crossing (yes/no) as our bivariate response variable. We also estimated the odds ratio and associated 95% confidence interval (CI) of an elk or deer using the UP, both combined and individually with and without fencing with a general linear model with a logit link (Agresti 1996). To test the hypothesis that mean daily and monthly use did not differ after fencing, we compared elk and deer use of the two UP for an equivalent 9-month period before and after fencing was erected. As these data were not normally distributed, we used a Mann-Whitney U-test to compare mean daily and monthly UP use by wildlife.

## Results

### Comparison of Elk Crossing Patterns and Permeability

We instrumented a total of 32 elk (25 female, 7 male) with GPS receiver collars between April 2004 and October 2005. Of these elk, 22 (16 female, 6 male) were relocated along the CC section and used in this analysis. All collars were recovered and data downloaded by June 2006. GPS collars were affixed to elk an average of 370.0 days (+/- 36.6; range = 84–662 days). Elk wore our collars more days after fencing was erected (5,175; $n$ = 22 elk) than before (2,693; $n$ = 16) due to various collar-related problems; 14 elk wore collars across both treatments. We accrued 87,745 GPS fixes, representing an 85.6% fix success (range = 31.9–100.0). We obtained a mean of 4,172.8 fixes/elk (+/- 484.2; range = 926–8,648); 64.2% (range = 52.2–75.4) of our fixes were 3-dimensional fixes. Of the GPS fixes our collars recorded, 42,542 (48.5%) occurred within 1.0 km of SR 260. On average, we obtained 5.1 fixes/day/elk (+/- 0.5) ≤1.0 km from the highway. Elk occurred within 0.25 km of the highway (approach distance) on 12,563 occasions with a mean of 571.0 fixes/elk (+/-107.3).

Our collared elk crossed the CC section 2,692 times, with a mean of 122.4 crossings/elk (+/- 25.3) that ranged from 14–402 crossings; 986 crossings occurred before and 1,706 crossings occurred after fencing was erected. The number of different elk crossing at each 0.16 km highway segment ranged from 1–13 and averaged 6.4 (+/- 0.5). Overall, elk crossed the highway 0.38 times/day compared to 0.28 crossings/day when the highway was under reconstruction (Dodd et al. 2007b: table 2). Post reconstruction, our elk crossed the highway an average of 0.38 times/day before and 0.35 times/day after fencing was erected on the CC section (table 2). Among the three treatments, there was no difference in highway crossing rates (ANOVA $P$ = 0.618; table 2).

Compared to our mean elk passage rate of 0.79 while the CC section was under reconstruction (Dodd et al. 2007b; table 2), permeability was 31.6% lower, or 0.54 crossings/approach following reconstruction but before fencing was erected (table 2). Once fencing was erected, our passage rate rebounded 51.8% to 0.82 crossings/approach (table 2). Our ANOVA found differences among the treatment classes ($F_{2,44}$ = 3.33, P = 0.045). Both our mean passage rates for elk during reconstruction (*P* = 0.042) and after fencing was erected (*P* = 0.014) were higher than the rate after reconstruction but before fencing was erected (table 2).

We found differences in the proportions of elk crossings before and after fencing along highway stretches between passage structures among the three passage deterrent treatments (ANOVA $F_{2,5}$ = 7.27, *P* = 0.033; table 3). The mean proportion of elk crossings on the fenced stretches declined 50.0% after fencing was erected, from 0.20 to 0.10 (mean change = -0.10), which was lower (*P* = 0.045) than the mean change for unfenced stretches (table 3). On unfenced stretches the mean proportion of elk crossings increased 39.7% from 0.07 to 0.10 (mean change = 0.03; table 3) once fencing was erected; the proportion of crossings increased 106.2%, from 0.03 to 0.07 at the 0.2-km gap in the fence at the CC access road. On steep slopes with elk rock, the proportion of crossings increased 60.8% after fencing from 0.12 to 0.19, though the change in proportion of crossings here did not differ from fenced or unfenced stretches (table 3).

Table 2: Mean elk crossings/day and passage rate (crossings/approach) for elk fitted with Global Positioning System (GPS) telemetry collars by highway reconstruction treatment, Christopher Creek section, State Route 260, Arizona, USA. GPS telemetry conducted 2002–2004 for during reconstruction (Dodd et al. 2007b) and 2004–2006 for the post construction treatments. Letters denote significant differences for Tukey test pairwise construction class comparisons for significant ANOVA among classes

| Highway reconstruction class | Elk *n* | Crossings/day ( SE) | Passage rate[a] ( SE) |
|---|---|---|---|
| During reconstruction | 14 | 0.28 (0.07)<br>A | 0.79 (0.09)<br>A |
| Post reconstruction – before fencing | 15 | 0.38 (0.08)<br>A | 0.54 (0.06)<br>B[b] |
| Post reconstruction – after fencing | 21 | 0.35 (0.08)<br>A | 0.82 (0.09)<br>A |

[a] Passage rates differed among highway reconstruction classes (ANOVA $F_{2,44}$ = 3.33, P = 0.045)
[b] Passage rate for post reconstruction - before fencing class was less than the rate for during reconstruction (*P* = 0.042) and post reconstruction - after fencing (*P* = 0.014) classes

**Comparison of Elk-Vehicle Collision Patterns**

From 2002–2006, we documented 139 WVC that occurred along the CC section, 110 involving elk (79.1%) and 29 vehicle collisions with deer (20.9%). In both 2002 and 2003, 19 elk-vehicle collisions were recorded, with a large increase in 2004 to 52 collisions, of which 41 (78.8%) occurred in the 6 months after the section was opened to traffic but not fenced (fig. 5). Elk-vehicle collisions dropped to 12 in 2005 and 8 in 2006 after fencing. During 2002–2005, the proportion of total accidents that involved wildlife averaged 0.52 +/- 0.06); the proportion (0.76) increased 78.4% in the year after reconstruction was completed but before fencing was erected (2004), and then declined 30.3% in the year (2005) after fencing was erected to 0.55.

We found that differences in elk-vehicle collisions/season occurred among treatments ($F_{2,17}$ = 31.4, P < 0.001; table 4). The number of collisions during the period after the highway reconstruction was completed but before fencing (20.5 collisions/season) was higher than the mean number of collisions both during reconstruction (4.9 collisions/season) and after fencing (2.7 collisions/season; table 4). Of the elk-vehicle collisions that occurred in 2005 (12) and 2006 (8) since the CC section was fenced, 16 (80.0%) occurred where fencing was not erected, five (25%) occurred along the steep slope/elk rock treatment, and four (20%) where fencing was in place. Of the collisions that occurred along unfenced portions of the section, eight (50.0%) occurred in association with the 0.2-mi gap in the fence by the CC access road.

Table 3: Mean proportion of elk highway crossings along the Christopher Creek section, State Route 260, USA, before and after ungulate-proof fencing was erected and the mean proportion of change (Δ) with fencing. Letters denote significant differences for Tukey test pairwise passage deterrent class comparisons for significant ANOVA among classes

| Highway passage deterrent class (*n* = no. of stretches) | Mean proportion of elk crossings | | Mean in proportion of elk crossings[a] ( SE) |
|---|---|---|---|
| | Before fencing | After fencing | |
| Ungulate-proof fencing (*n* = 3) | 0.20 | 0.10 | -0.10 (0.02)<br>A |
| Steep slopes-"elk rock" ( *n* = 1) | 0.12 | 0.19 | +0.07 -<br>B |
| None (*n* = 4) | 0.07 | 0.10 | +0.03 (0.02)<br>A,B |

**Wildlife Underpass Use Comparison**

We recorded 500 elk and deer that approached the two UP from the camera side of the UP during the nine-month period prior to the erection of fencing. Of the 352 elk and deer that we categorized as attempting to cross the highway, a large proportion (0.60) avoided entering the UP altogether and crossed at grade over both sets of highway lanes in the vicinity of the UP. Another 74 elk and deer (0.21) were recorded making partial crossings under the first bridge at the UP and then crossing into the median and over one set of lanes. Overall, only 12% of the elk and deer successfully crossed below grade entirely through the UP prior to fencing. During the 11-month period after fencing was erected, we recorded 595 elk and deer that we determined were approaching the 2 UP, of which 331 successfully crossed (55.6%). We did not document any highway crossings at grade in the vicinity of the UP after fencing was erected.

The mean frequency of daily successful UP crossings by deer and elk increased 345.4% between the equivalent 9-month periods before ($\bar{x}$ = 0.66 +/- 0.06) and after ($\bar{x}$ = 2.94 +/- 0.20) fencing was erected on the CC Section (Mann-Whitney U-Test Us = 12.8, df =1, P < 0.001). Mean monthly successful elk and deer UP crossings increased over six fold between the nine-month period before ($\bar{x}$ = 11.5 ?0.08) and after ($\bar{x}$ = 65.4 +/- 3.87) fencing was erected ($U_s$ = 12.8, df =1, P < 0.001).

The combined probability of an animal approaching either UP and successfully crossing was dependent on treatment, with an increase in probability from 0.09 to 0.56 following the erection of fencing ($X^2$ = 268.02, df = 1, P < 0.001, $G^2$ = 297.1, df =1, P < 0.001). The odds of and elk or deer successfully using the UP after fencing was 13.6:1 (95% CI: 9.6, 19.6) of that before fencing was erected. Considering the two UP separately, the probability of successful use of the Pedestrian/Wildlife UP by deer and elk increased from 0.19 to 0.67 following installation fencing ($X^2$ = 87.4, df = 1, P < 0.001, $G^2$ =92.6, df =1, P < 0.001), while the odds of them successfully using it after versus before fencing were 8.8:1 (95% CI: 5.5, 14.5). At the Wildlife 2 UP, the probability of successful wildlife use increased from 0.19 to 0.67 following fencing ($X^2$ = 177.5, df = 1, P < 0.001, $G^2$ =204.07, df =1, P < 0.001), and the odds of elk and deer successfully using this UP during the period after fencing versus before were 23.6:1 (95% CI: 13.6, 44.7).

Table 4. Mean collisions/season (2002–2006) by season and highway reconstruction class along the Christopher Creek section, State Route 260, Arizona, USA. Letters denote significant differences for Tukey test pairwise construction class comparisons for significant ANOVA among classes.

| Season | Collisions per season ( SE) | Highway reconstruction class (*n* = seasons) | Collisions per season[a] ( SE) |
|---|---|---|---|
| Spring (Apr-Jun) | 4.8 (0.9) A | During reconstruction (10) | 4.9 (0.8) A |
| Summer (Jul-Sep) | 6.7 (2.6) A | Post reconstruction - before fencing (2) | 20.5 (5.5) B[b] |
| Fall (Oct-Dec) | 9.8 (4.4) A | Post reconstruction - after fencing (8) | 2.7 (1.2) A |
| Winter (Jan-Mar) | 3.2 (0.7) A | | |

## <u>Discussion</u>

We documented a benefit from ungulate-proof in reducing WVC comparable to that reported by Ward (1982) and Clevenger et al. (2001), with an 86.8% reduction in elk-vehicle collisions after fencing was erected. Further, our study points to the importance of fencing in funneling crossing wildlife toward and successfully through passage structures to maximize their effectiveness in promoting improved highway safety. Most surprisingly however, was the role that fencing played in promoting wildlife permeability in concert with increased use of UP and bridges along SR 260, heretofore undocumented by previous studies.

Prior GPS telemetry by Dodd et al. (2007b) provided an unprecedented opportunity to assess the degree to which highway reconstruction impacts wildlife permeability. The diminished passage rate reported for the CC Section, from 0.79 to 0.54 crossings/approach was consistent with the differential passage rates among highway reconstruction classes reported by Dodd et al. (2007b). They found that the rate for control sections averaged 0.88 compared to 0.43 on the section where reconstruction was complete; however, Dodd et al. (2007b) did not compare passage rates along the same section of highway in an experimental context as we did in this study. Dodd et al. (2007b) attributed the difference in passage rates among reconstruction classes to the combined influence of the increased highway footprint and presence of traffic on all lanes, effectively creating a large versus small road with high traffic volume, as described by Jaeger et al. (2005).

Numerous studies have alluded to the benefit of passage structures in maintaining or enhancing wildlife connectivity and permeability (e.g., Romin and Bissonette 1996, Clevenger and Waltho 2000, Forman et al. 2003). Our study provides some of most conclusive evidence to date to support the use of passage structures in restoring pre reconstruction levels of elk permeability. Our findings further point to the important dual role that fencing plays in not only achieving desired UP use by wildlife but in promoting permeability; in our case, both components were integral to fully mitigating the impact of highway reconstruction and reducing the incidence of WVC. We attribute the recovery in elk passage rate to pre reconstruction levels following fencing to the funneling of animals toward UP and bridges where they were presented below-grade opportunities for crossing that apparently ameliorated the road avoidance resistance to crossing a large roadway at grade (Jaeger et al. 2005) and traffic-associated impact reported by Gagnon (2006). Though Gagnon (2006) and Gagnon et al. (2007a) found that traffic volume affected elk distribution and crossing patterns at grade along SR 260, traffic volume had minimal affect on elk below-grade crossings through five wildlife UP along SR 260 (Gagnon 2006, Gagnon et al. 2007b), as illustrated in figure 6 from (Gagnon et al. 2007c).

We suspect that the success in promoting elk permeability with UP and fencing is partly attributable to the relatively high density of suitable passage structures along the CC section, though the degree to which spacing of structures contributed to permeability is uncertain. Bissonette (2006) applied allometric scaling principles to theorize on the spacing distance between passage structures to promote wildlife permeability. He reported that highest permeability would be attained where passage structure spacing is based on the species' linear home range distance; in the case of elk spacing was estimated at 3.5 km. On the CC section, our passage structures were spaced considerably closer with an average of 1.1 km between UP and bridges. Elsewhere on SR 260, ungulate-proof fencing was erected in late 2006 along 5 km of the Preacher Canyon (PC) section. Here the average passage structure spacing is 2.4 km, intermediate between that recommended by Bissonette (2006) and the spacing associated with our study. Permeability on the unfenced PC section averaged 0.43 crossings/approach (Dodd et al. 2007b), and post fencing elk GPS telemetry monitoring is ongoing to evaluate the change in permeability with fencing, and will yield considerable insights into the role of spacing distance between passage structures.

Our data underscore the important role that fencing plays in promoting wildlife use of passage structures, particularly those that are considered suboptimal. Gagnon et al. (2006) reported differential elk passage rates for the Pedestrian/wildlife (59%) and Wildlife 2 (27%) UP on the CC section, and hypothesized that the differential use was at least partly attributable to the degree of offset of bridges associated with each UP. At the Pedestrian/wildlife UP, the two bridges were constructed in line such that wildlife can see through the entire UP from any approaching angle. The Wildlife 2 UP was constructed with an offset along an existing drainage that ran diagonally to the highway, severely limiting visibility through the UP structure. With the erection of fencing, we noted a substantially greater benefit (e.g., >2.5× higher odds of successful crossings after fencing) achieved in "forcing" animals to use the Wildlife 2 versus the Pedestrian/wildlife UP. Such an approach to promoting wildlife passage through suboptimal passage structures or structures not specifically designed to accommodate wildlife passage has been reported by Singer and Doherty (1985) and Ng (2004). This may also be important where structures are not situated in proximity to preferred foraging areas or established travel corridors (Beier and Loe 1992, Bruinderink and Hazebroek 1996, Dodd et al 2007a). Though animals continually habituated to UP during the course of our study, we do not believe that this accounted for the dramatic increase in wildlife use of the two UP before and after fencing. As our UP were constructed and useable by wildlife well in advance (12 months) of the installation of our video camera systems, we believe that substantial wildlife exposure the UP had occurred in advance of our study, especially by elk which readily adapt to new UP (Clevenger and Waltho 2003, Dodd et al. 2007a).

Strategic fencing of peak elk crossing areas based on GPS telemetry (Dodd 2007b) accounting for only 49% of the CC section effectively mitigated the over three-fold increase in elk-vehicle collisions that occurred after the section was opened to traffic but before fencing was erected. Compared to the two years before the section was opened to traffic (2002-2003), the elk-vehicle collision rate for 2005-2006 declined 44.9%. However, once the 0.2-km gap at the entrance to Christopher Creek is fenced to eliminate elk crossings that account for half the collisions along the CC section, we expect the overall reduction in elk-vehicle collisions from before reconstruction levels to exceed 70%. Our application of steep slopes as an alternative to fencing did not prove effective in limiting at-grade elk crossings of SR 260.

**Biographical Sketches:** Norris Dodd has worked for the department for 28 years, the past 12 as a wildlife research biologist and project leader working on forest restoration and wildlife-highway relationships research projects. He received his B.S. and M.S. degrees from Arizona State University. He lives in Pinetop-Lakeside with his wife, Rebecca and two teenage daughters.

Jeff Gagnon is a wildlife research biologist and has worked for the department for 8 years. He received his B.S. and M.S. degrees from Northern Arizona University. He resides in Flagstaff with his wife, Amanda.

Susan Boe has been a research GIS spatial analyst for the department for 14 years. She earned B.S. and M.S. degrees from the University of Minnesota-Duluth.

Ray Schweinsburg has been a research program supervisor with the department for 14 years. He received his Ph.D from the University of Arizona. He has done extensive wildlife research in the Canadian arctic, including studies on polar bears.

## References


Agresti, A. 1996. An introduction to categorical data analysis. John Wiley and Sons, Inc., New York, New York, USA.

Beier, P. 1995. Dispersal of juvenile cougars in fragmented habitat. *Journal of Wildlife Management* 59:228-237.

Beier, P. and S. Loe. 1992. A checklist for evaluating impacts to wildlife movement corridors. *Wildlife Society Bulletin* 20:434-440.

Bissonette, J. A. 2006. Evaluation of the use and effectiveness of wildlife crossings. Interim report for Project NCHRP 25-27 FY04, National Cooperative Research program, *Transportation Research Board*, Washington, DC, USA.

Brown, D. E., editor. 1994a. Biotic communities: southwestern United States and northwestern Mexico. University of Utah Press, Salt Lake City, Utah, USA.

Brown, R. L. 1990. Elk seasonal ranges and migration. Arizona Game and Fish Department Technical Report 1, Phoenix, Arizona, USA.

Brown, R. L. 1994b. Elk seasonal ranges and migration. Arizona Game and Fish Department Technical Report 15, Phoenix, Arizona, USA.

Bruinderink, G., and E. Hazebroek. 1996. Ungulate traffic collisions in Europe. *Conservation Biology* 10:1059-1067.

Clevenger, A. P. and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology* 14:47-56.

Clevenger, A. P., and N. Waltho. 2003. Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies. Pages 293-302 in C. L. Irwin, P. Garrett, and K. P. McDermott, editors. 2003 *Proceedings of the International Conference on Ecology and Transportation*. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Clevenger A. P., B. Chruszcz, and K. Gunson. 2001. Highway mitigation fencing reduces wildlife-vehicle collisions. *Wildlife Society Bulletin* 29:646-653.

Clover, M. R. 1954. A portable deer trap and catch-net. *California Fish and Game* 40:367-373.

Conover, M. R. 1997. Monetary and intangible valuation of deer in the United States. *Wildlife Society Bulletin* 25:298-305.

Dodd, N. L., J. W. Gagnon, S. Boe, and R. E. Schweinsburg. 2006. Characteristics of elk-vehicle collisions and comparison to GPS-determined highway crossing patterns. Pages 461-477 in C. L. Irwin, P. Garrett, and K. P. McDermott, editors. *2005 Proceedings of the International Conference on Ecology and Transportation*. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Dodd, N. L., J. W. Gagnon, A. L. Manzo, and R. E. Schweinsburg. 2007a. Application of video surveillance to assess wildlife use of highway underpasses in Arizona. *Journal of Wildlife Management* 71(4; In press).

Dodd, N. L., J. W. Gagnon, S. Boe, and R. E. Schweinsburg. 2007b. Assessment of elk highway permeability using Global Positioning Satellite telemetry. *Journal of Wildlife Management* 71(7; In press).

Epps, C. W., P. J. Palsboll, J. D. Wehausen, G. K. Roderick, R. R. Ramey II, and D. R. McCullough. 2005. Highways block gene flow and cause rapid decline in genetic diversity of desert bighorn sheep. Ecology Letters 8: 1029-1038.

Falk, N. W., H. B. Graves, and E. D. Bellis. 1978. Highway right-of-way fences as deer deterrents. *Journal of Wildlife Management* 42:646-650.

Farrell, J. E., L. R. Irby, and P. T. McGowen. 2002. Strategies for ungulate-vehicle collision mitigation. *Intermountain Journal of Sciences* 8:1-18.

Feldhammer, G. A., J. E. Gates, D. M. Harman, A. L. Loranger, and K. R. Dixon. 1986. Effects of interstate highway fencing on white-tailed deer activity. *Journal of Wildlife Management* 50:497-503.

Forman, R. T. T. 2000. Estimate of area affected ecologically by the road system in the United States. *Conservation Biology* 14:31-35.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematic* 29:207-231.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road ecology: science and solutions*. Island Press, Washington, D.C., USA.

Foster, M. L., and S. R. Humphrey. 995. Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin* 23:95-100.

Gagnon, J. W. 2006. Effect of traffic on elk distribution, highway crossings, and wildlife underpass use in Arizona. Thesis, Northern Arizona University, Flagstaff, USA.

Gagnon, J. W., N. L. Dodd, A. L. Manzo, and R. E. Schweinsburg. 2006. Use of video surveillance to assess wildlife behavior and use of wildlife underpasses in Arizona. Pages 534-544 in C. L. Irwin, P. Garrett, and K. P. McDermott, editors. *2005 Proceedings of the International Conference on Ecology and Transportation*. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Gagnon, J. W., T. C. Theimer, N. L. Dodd, and R. E. Schweinsburg. 2007a. Traffic volume alters elk distribution and highway crossings in Arizona. *Journal of Wildlife Management* 71(7; In press ).

Gagnon, J. W., T. C. Theimer, N. L. Dodd, A. Manazo, and R. E. Schweinsburg. 2007b. Effects of traffic volume and type on elk use of wildlife highway underpasses in central Arizona. *Journal of Wildlife Management* 71(In press).

Gagnon, J. W., N. L. Dodd, and R. E. Schweinsburg. 2007c. Effects of roadway traffic on wild ungulates: a review of the literature and a case study of elk on Arizona. Pages XXX-XXX (In press). *2007 Proceedings of the International Conference on Ecology and Transportation*. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Gordon, K. M., and S. H. Anderson. 2003. Mule deer use of underpasses in western and southeastern Wyoming. Pages 309-318 in C. L. Irwin, P. Garrett, and K. P. McDermott, editors. *2003 Proceedings of the International Conference on Ecology and Transportation*. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Hooge, P. N., and B. Eichenlaub. 1997. Animal movement extension to ArcView version 1.1. Alaska Biological Science Center, U.S. Geological Survey, Anchorage, Alaska, USA.

Jaeger, J. A. G., J. Bowman, J. Brennan, L. Fahrig, D. Bert, J. Bouchard, N. Charbonneau, K. Frank, B. Gruber, K. T. von Toschanowitz. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. *Ecological Modelling* 185:329-348.

Lavsund, S., and F. Sandegren. 1991. Moose-vehicle relations in Sweden: a review. *Alces* 27:118-126.

Ng, S. J., J. W. Dole, R. M. Sauvajot, S. P. D. Riley, and T. J. Valone. 2004. Use of highway underpasses by wildlife in southern California. *Biological Conservation* 115:499-507.

Noss, R. F., and A. Y. Cooperrider. 1994. Saving nature's legacy. Island Press, Washington, D.C., USA.

Reed, D. F., T. D. Beck, and T. N. Woodward. 1982. Methods of reducing deer-vehicle accidents: benefit-cost analysis. *Wildlife Society Bulletin* 10:349-354.

Romin, L. A., and J. A. Bissonette. 1996. Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. *Wildlife Society Bulletin* 24:276-283.

Rost, G. R., and J. A. Bailey. 1979. Distribution of mule deer and elk in relation to roads. *Journal of Wildlife Management* 43: 634-641.

Schwabe, K. A., and P. W. Schuhmann. 2002. Deer-vehicle collisions and deer value: an analysis of competing literatures. *Wildlife Society Bulletin* 30:609-615.

Singer, F. J. and J. L. Doherty. 1985. Managing mountain goats at a highway crossing. *Wildlife Society Bulletin* 13:469-477.

Statsoft, Inc. 1994. STATISTICA user's manual. Statsoft, Inc. Tulsa, Oklahoma, USA.

Swihart, R. K., and N. A. Slade. 1984. Road crossing in Sigmodon hispidus and Microtus ochrogaster. *Journal of Mammalogy* 65:357-360.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18-30.

Witmer, G. W., and D. S. deCalesta. 1985. Effect of forest roads on habitat use by Roosevelt elk. *Northwest Science* 59: 122-125.

Woods, J. G. 1990. Effectiveness of fences and underpasses on the Trans-Canada Highway and their impact on ungulate populations project. Report to Banff National Park, Environment Canada Parks Service, Banff, Alberta, Canada.

Ward, A. L 1982. Mule deer behavior in relation to fencing and underpasses on Interstante 80 in Wyoming. *Transportation Research Record* 859:8-13. Ng, S. J., J. W. Dole, R. M. Sauvajot, S. P. D. Riley, and T. J. Valone. 2004. Use of highway underpasses by wildlife in southern California. *Biological Conservation* 115:499-507.

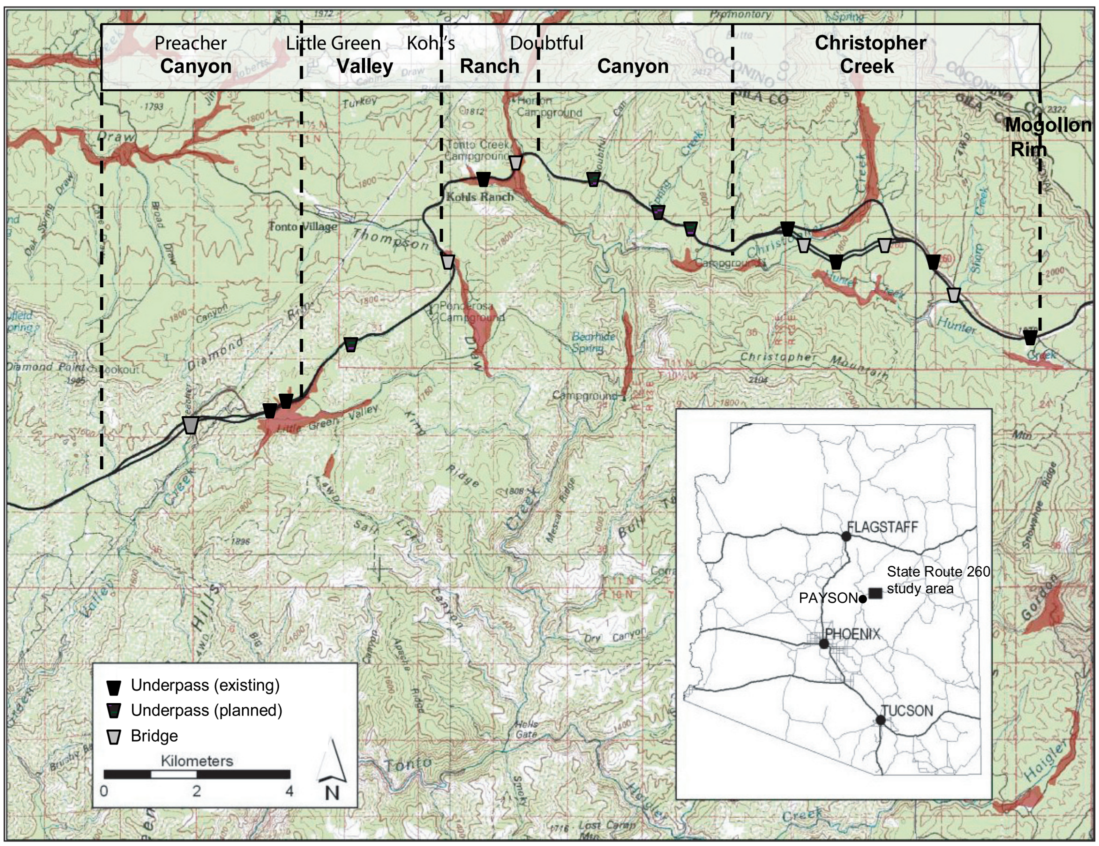



Figure 1. Location of our State Route 260 study area and the five highway sections along which phased highway reconstruction has been ongoing since 2000, and the location of wildlife UP and bridges. The shaded areas correspond to riparian-meadow habitats located adjacent to the highway. Topographic relief reveals the study area's proximity to the Mogollon Rim escarpment, the dominant physiographic feature within the study area.

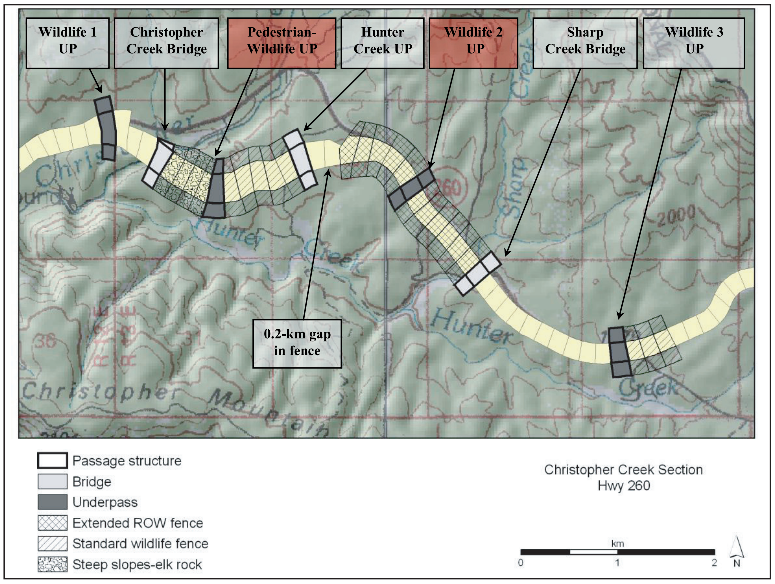



Figure 2. Location of wildlife underpasses (UP) and bridges along the Christopher Creek section of State Route 260, Arizona, USA, and delineation of different treatments to deter wildlife passage onto the highway and funnel animals toward passage structures. Also identified is the 0.2-km gap in the fence at the east entrance into Christopher Creek and the 2 UP where before and after fencing video surveillance was conducted (shaded red).

Figure 3. Alternatives to fencing to deter at-grade wildlife crossings along the Christopher Creek section of State Route 260, Arizona, USA. The steep 4:1 fill slopes below guard rails (left), boulder rip-rap ("elk-rock") and steep cut slopes (right) were evaluated as alternative treatments to fencing.

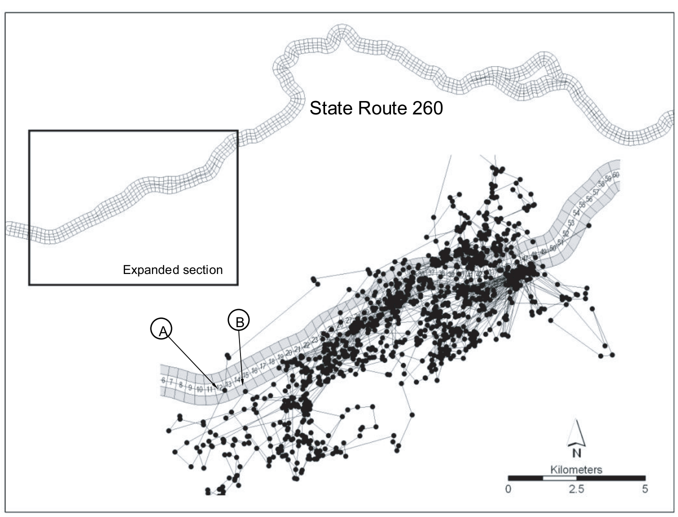



Figure 4. Highway segments (0.16 km) delineated along State Route 260, Arizona, USA, used to compile highway crossings by elk, and the 0.25-km distance buffer in which approaches to the highway were determined. The expanded section shows GPS locations for cow elk no. 2, and lines between successive fixes to determine approaches to the highway (shaded band) and crossings. Example A denotes an approach and subsequent highway crossing, while B denotes an approach without a crossing.

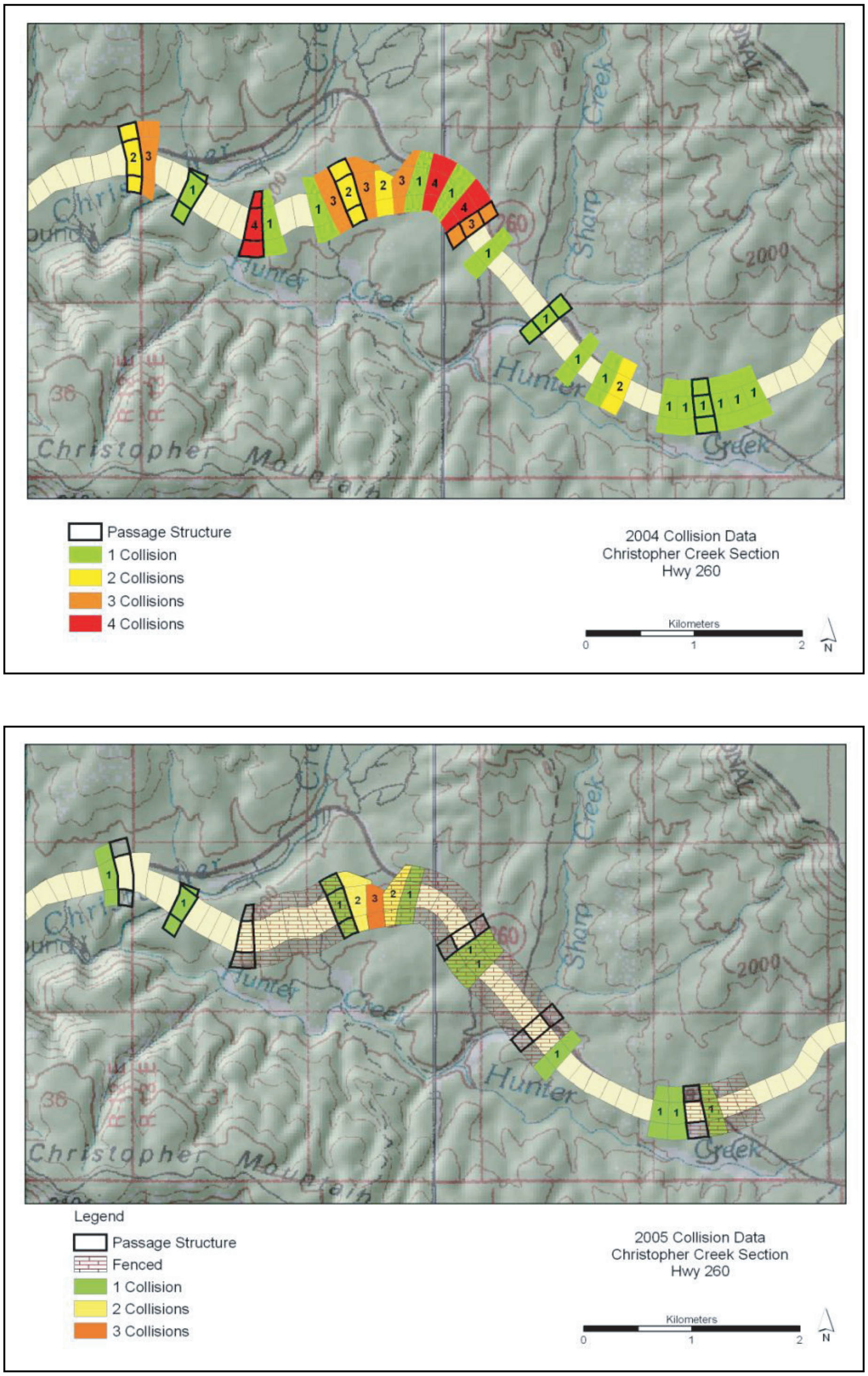



Figure 5. Number of elk-vehicle collisions recorded along the Christopher Creek section of State Route 260, Arizona, USA in 2004 (top; 51 collisions) before ungulate-proof fencing was erected and 2005 (bottom; 12 collisions) after fencing was erected. Note the concentration of collisions in 2005 at the 0.2-km gap in the fence near the entrance to Christopher Creek.

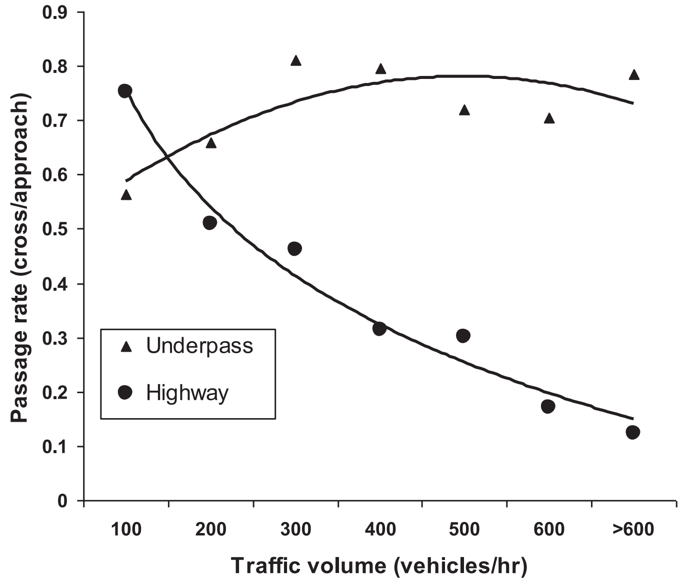



Figure 6. At-grade and below-grade (through 6 wildlife underpass) elk passage rates at varying traffic volume levels along State Route 260, Arizona, USA (figure from Gagnon et al. 2007c). At-grade passage rates determined from GPS telemetry tracking of 44 elk from 2003-2006 (Gagnon et al. 2007a) and below-grade underpass passage rates determined from video surveillance of wildlife use of underpasses from 2002-2006 (Gagnon et al. 2007b).

# Transportation Corridors in Arizona and Mexico and Pronghorn: Case Studies

**Richard A. Ockenfels** (602-789-3379, rockenfels@azgfd.gov), Wildlife Program Supervisor;
**James C. deVos Jr.**, Research Branch (Retired); and
**John J. Hervert**, Yuma Region; Arizona Game and Fish Department, 2221 W. Greenway Road, Phoenix, AZ 85023, Fax: 602-789-3918 USA

**Abstract**

We reviewed 13 case studies from Arizona and Sonora, Mexico, on the effects of transportation corridors on pronghorn (Antiocapra americana). What do we know and what can we do about it? Since the mid-1900s, naturalists/biologists have known that transportation corridors such as highway and railroad rights-of-way can affect pronghorn populations. Beginning in 1983, we have radiomarked ~250 adult pronghorn across Arizona and northern Sonora, Mexico to assess the effects of transportation corridors on various populations. During this over 20-year period, we conducted 3 studies, 1 in Sonora, Mexico, on the endangered Sonoran pronghorn (A. a. sonoriensis) and 10 studies in central and northern Arizona on other subspecies. With >34,000 radio locations, we report on the documented effects of transportation corridors from these 13 case studies. Transportation corridor effects varied by type of corridor (number of lanes, fenced vs. unfenced, and presumably by traffic volume). Pronghorn readily crossed paved, unfenced roadways with low traffic volume, occasionally crossed paved, fenced 2-lane highways, but only in certain situations, but did not cross high-volume highways or divided interstates. Railroad rights--of-way also isolated pronghorn herds and fragmented habitat. Six mitigation ideas are presented and discussed that could improve the likelihood of pronghorn crossings. The current "wildlife missing linkages" project in Arizona is attempting to identify fragmentation of habitat across the state due to transportation corridors and plan for remedies to lessen the impact of transportation on many species of wildlife, including pronghorn. We conclude that additional research on mitigation features is warranted.

# Using Site-Level Factors to Model Areas at High Risk of Deer-Vehicle Collisions on Arkansas Highways

**Philip A. Tappe** (870-460-1352, tappe@uamont.edu) and
**Donald I.M. Enderle** (770-270-7678, denderle@photoscience.com), Arkansas Forest Resources Center and School of Forest Resources, University of Arkansas, Monticello, AR 71656 USA

**Abstract:** Deer-vehicle collisions (DVCs) are increasing across the United States, including Arkansas. These collisions involve risk of human injury and fatality, property damage, and loss of wildlife. The annual number of DVCs in Arkansas may be as great as 18,000 (13.6% of the reported legal deer harvest in 2005) with an estimated property damage of $35 million. Numerous studies have examined the impacts and causes of DVCs; however, few studies have utilized a state-wide approach to increase understanding of the factors involved.

We evaluated the influence of site-level factors on the number of DVCs reported during 1998-2001 along all state and federal highways in Arkansas. Site-level factors included landcover patterns, landcover characteristics, and number of stream/highway intersections within 400, 800, and 1200 m of collision sites; landcover crossing types and maximum topographic relief within 100 m of collision sites; and distances to nearest forest and to nearest water. A total of 3,170 DVC locations were compared with an equal number of randomly-chosen highway locations based upon proportions of DVCs within each physiographic region of Arkansas. Logistic regression analysis was used to develop and test a state-wide model and six physiographic region models to identify high risk areas along highways. Akaike information criterion values were used to select the best model for the entire state and for each physiographic region. We randomly selected 25% of the DVC sites and randomly-located highway sites to exclude from model development in order to test the predictive ability of each model.

Over 1,000 variables were considered prior to model development. However, exclusion of intercorrelated variables and variables that did not differ between collision and random sites reduced the variable set to 31. These 31 variables revealed a variety of differences between known DVC locations and randomly-selected locations. Twenty-six variables were more associated with known DVC locations than with random locations. Five variables were more associated with randomly selected highway locations than with known DVC locations. The state-wide model had an overall correct classification rate of 62%. Most models developed for individual physiographic regions performed as well or better than the state-wide model: Arkansas River Valley (62%), Boston Mountains (69%), Gulf Coastal Plain (59%), Mississippi River Delta (70%), Ouachita Mountains (67%), and Ozark Mountains (60%). Almost all variables included in the state model were also included in at least one physiographic region model, and most variables of each physiographic region model were also found in the state model. Five groups of factors that were strongly correlated with DVC locations were apparent in all models: (1) the presence and amount of water in terms of distance to the nearest source, number of streams intersecting within 400 m, and amount of water within 1200 m; (2) the presence of a diverse association of land cover types in close proximity to a highway; (3) the amount and size of urban area within 1200 m; (4) forested area (deciduous and/or coniferous) in close proximity to a highway, particularly in terms of higher density of coniferous forest and greater size and irregularity of deciduous forest patches; and (5) the density of pasture and crop patches, and the density of pasture edge in particular, within 1200 m of a highway.

These results and models may be used to produce maps indicating potential segments of highways at high risk for the occurrence of DVCs. Additionally, they may aid in planning and road construction. Finally, these results provide a foundation for future research in examining more specific deer-vehicle interactions, and can aid in the evaluation of appropriateness and effectiveness of proposed methods to reduce DVCs in Arkansas.

## Introduction

Deer-vehicle collisions (DVCs) are of increasing safety and economic concern. The consequences of deer-vehicle collisions include risk of human injury or fatality, property damage, and loss of wildlife, with associated costs estimated at over $1 billion dollars in the United States (Conover et al. 1995). The annual number of DVCs in Arkansas may be as great as 18,000 (13.6% of the reported legal deer harvest in 2005) with an estimated property damage of $35 million (Tappe 2005).

Several studies have focused on investigating factors that may influence the probability of occurrence of a DVC at a specific location or along a segment of roadway (e.g., Bashore et al. 1985, Finder et al. 1999, Hubbard et al. 2000). However, few studies have utilized a state-wide approach to increase understanding of the factors involved. Additionally, relatively few of these investigations have occurred in the Southeastern region of the United States, with most being conducted in the Midwestern or Northeastern regions. Results and conclusions have been mixed regarding which specific factors play important roles in DVC occurrences and locations; though, most studies have indicated that the proximity of forested areas to a roadway is influential. Given variation in geographic, biotic, and climatic factors, it is important to understand the nature and/or circumstances of DVCs in different regions. Identification of factors contributing to DVCs can provide information on the interactions of deer populations with habitat, road, and human influences; aid in the identification of areas at high risk for DVCs; and help efficiently target available resources for addressing the problem. Thus, our objectives were (1) to identify and evaluate site-level factors relating to DVCs along state and federal highways in Arkansas, and (2) to develop and validate regional models based upon site-level characteristics to predict occurrence of DVCs in Arkansas.

## Methods

### Study Area

This study was conducted using land cover within 1200 m of the state and federal highways in the state of Arkansas. Arkansas is composed of 6 physiographic regions: Arkansas River Valley, Boston Mountains, Gulf Coastal Plain, Mississippi River Alluvial Floodplain, Ouachita Mountains, and Ozark Mountains (figure 1). These regions were used as a basis for the comparison of deer-vehicle collision locations with randomly selected locations along state and federal highways.

### Data

We obtained hard-copy motor vehicle/animal accident reports from the Arkansas State Police Department Headquarters in Little Rock, AR. These reports represented the most extensive and accessible source of information available on DVCs in Arkansas (Tappe 2005). However, the reports included only accidents that occured on state and federal highways, not on county or municipality maintained roads, and that were serious enough to involve the state police. Locations (road section and log mile) of DVCs from the years 1998 to 2001 were selected and entered in a database. Of the 5,858 reports, 2,444 lacked sufficient information (section and log mile) to be geo-referenced. We sent location data from the remaining 3,414 reports to the Arkansas Highway and Transportation Department (AHTD) for geo-referencing by means of an in-house parsing program and transformation into an ArcView® shape file for incorporation into ArcView® GIS software ([ESRI] 2000). Of these locations, 244 failed to be geo-referenced due to incorrect section and/or log mile information. Thus, 3,170 collisions were successfully geo-referenced and were available for further analyses.

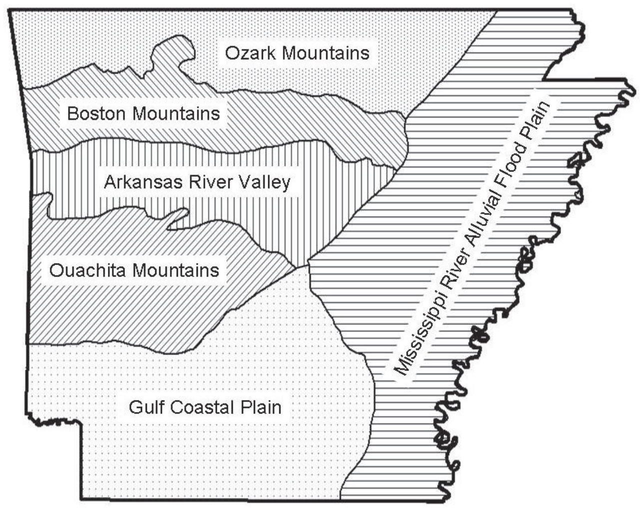



Figure 1. Physiographic regions of Arkansas.

Other data used in this study included roads, streams, land use/land cover, and elevation (table 1) for the entire state of Arkansas. The two raster data sets, land use/land cover and elevation, were each resampled and aligned to an identical cell size resolution of 30 m. This resampling was performed to facilitate combination with the other data sets while maintaining a degree of uniformity by ensuring that the cells in each raster data set would align correctly for data analysis. All spatial analyses were performed in ArcView® version 3.2a GIS software. The ArcView® Spatial Analyst Extension and ArcView® Geoprocessing Wizard Extension were utilized within ArcView® to perform many of the spatial analyses.

In order to compare characteristics of DVC locations, we selected a proportional number of randomly selected locations along highways by physiographic region. In order to accomplish this, state and federal highways were converted to points spaced 30 m apart. We randomly selected 25% of the random and collision locations in each physiographic region to be excluded from model development in order to test and validate resulting models.

In order to simplify the use of land cover data, we reclassified the 50 land cover classes of the Arkansas land cover data set into the following 10 classes: urban, water, coniferous forest, deciduous forest, mixed forest, pasture, crops, old field, and barren. We chose these classes based on their general use and significance as found in other DVC studies and to remove classification bias by consolidating multiple land cover types into broad classes.

Table 1: Primary datasets utilized for modeling deer-vehicle collision locations in Arkansas

| Data Set | Source |
|---|---|
| Deer-vehicle collision locations | Hard-copy motor vehicle – animal accident reports (1998 – 2001), Arkansas State Police headquarters, Little Rock, Arkansas |
| State and federal highways | County mapping files (2000), Arkansas Highway and Transportation Department |
| Landuse/landcover | 1998 and 1999 multi-temporal LANDSAT V and VII Thematic Mapper satellite imagery, Center for Advanced Spatial Technologies, University of Arkansas |
| Streams and rivers | USGS 1:100,000 Digital Line Graph data, 1989 |
| Elevation | USGS National Elevation Dataset, 1999 |

We evaluated the influence of land cover characteristics within varying distances of collision and random locations by using three buffer distances in determining land cover characteristics: 400, 800, and 1200 m. We used FRAGSTATS software (McGarigal and Marks 1995) in batch mode to compute several categories of class and landscape metrics (table 2). These calculated metrics were then linked to each collision and random location for statistical analysis and model development.

We reclassified the land cover data into forest and non-forest to determine distance to nearest forest from each DVC and random location. Likewise, we reclassified the land cover data into water and non-water to determine distance to nearest water from each DVC and random location. We determined the numbers of stream/highway intersections (i.e., bridges) within 400, 800, and 1200 m buffer distances from each collision and random location. Additionaly, we computed differences in right-of-way topography between collision and random locations by calculating maximum relief within a 100 m buffer of each point.

In order to determine crossing types (defined as dominant vegetation or land cover types on opposite sides of the road) at each point, we reclassified land cover data into the following 6 classes: urban, water, forest, field, crop, and barren. As this variable involved dominant land cover classes adjacent to a highway, we used a 100 m buffer distance to identify crossing type classes.

Table 2: Summary of FRAGSTATS metrics used to describe land cover characteristics of collision and random locations at 400, 800, and 1200 m buffer distances

| Category | Metric | Scale |
|---|---|---|
| Area/Density/Edge | Percent of Landscape | Class/Landscape |
| | Patch Density | Class/Landscape |
| | Edge Density | Class/Landscape |
| | Patch Area Distribution[1] | Class/Landscape |
| Shape | Shape Index Distribution[1] | Class/Landscape |
| Nearest Neighbor | Euclidean Nearest Neighbor Distance Distribution[1] | Class/Landscape |
| Edge Contrast | Contrast-Weighted Edge Density | Class/Landscape |
| | Total Edge Contrast Index | Class/Landscape |
| | Edge Contrast Index Distribution[1] | Class/Landscape |
| Contagion/Interspersion | Clumpiness Index | Class |
| | Aggregation Index | Class/Landscape |
| | Interspersion and Juxtaposition Index | Class/Landscape |
| Diversity | Patch Richness Density | Landscape |
| | Relative Patch Richness | Landscape |
| | Shannon's Diversity Index | Landscape |
| | Simpson's Diversity Index | Landscape |
| | Shannon's Evenness Index | Landscape |
| | Simpson's Evenness Index | Landscape |

[1]This metric involved the calculation of mean, area-weighted mean, median, range, standard deviation, and coefficient of variation.

### Statistical Analyses

We evaluated all variables for normality and used Mann-Whitney U-tests to determine whether variables differed between collision and random locations. A significance level of 0.05 was used as a cutoff value to exclude statistically non-significant variables from further consideration. We computed Pearson correlation coefficients between all variables and eliminated variables from further consideration if they were strongly correlated ($|r| \geq 0.600$) with other variables. We selected one variable from each group of intercorrelated variables to represent that group in further analyses based upon three criteria: interpretability, biological significance, and greatest (or one of the greatest) Mann-Whitney U-test statistic. Thus, the resulting list of variables to be considered for inclusion in logistic regression analyses included 31 variables that were statistically different between collision and random locations, were not correlated ($|r| \leq 0.60$) with other selected variables, and were both interpretable and biologically significant (Table 3).

Table 3: Variables selected for development of models to predict deer-vehicle collision locations on state and federal highways in Arkansas

| Variable | Abbreviation |
|---|---|
| At least one side forest - 100 m | CT03_ONE |
| Water both sides - 100 m | CT02_02 |
| Forest across from urban - 100 m | CT03_01 |
| Forest across from field - 100 m | CT03_04 |
| Forest across from crop - 100 m | CT03_05 |
| Field across from urban - 100 m | CT04_01 |
| Distance to nearest water (m) | D2NW |
| Number of stream/highway intersections - 400 m | NSHI04 |
| Mean nearest neighbor distance of similar patch types for the entire landscape (m) - 400 m | L_N_MN04 |
| Range of nearest neighbor distance of similar patch types for the entire landscape (m) - 400 m | L_N_RA04 |
| Shannon's Diversity Index of all patches in the landscape - 400 m | L_SHDI04 |
| Mean nearest neighbor distance of similar patch types for the entire landscape (m) - 800 m | L_N_MN08 |
| Area-weighted mean nearest neighbor of similar patch types for the entire landscape (m) - 800 m | L_N_AM08 |
| Edge contrast index range of all patches in the landscape - 800 m | L_E_RA08 |
| Median shape index of all patches in the landscape - 1200 m | L_S_MD12 |
| Area-weighted mean nearest neighbor of similar patch types for the entire landscape (m) - 1200 m | L_N_AM12 |
| Urban percent of landscape (%) - 1200 m | C01PLA12 |
| Urban patch density (no./100 ha) - 1200 m | C01PD12 |
| Water percent of landscape (%) - 1200 m | C02PLA12 |
| Water patch density (no./100 ha) - 1200 m | C02PD12 |
| Coniferous forest patch density (no./100 ha) - 400 m | C04PD04 |
| Mean area of deciduous forest patches (ha) - 400 m | C05AMN04 |
| Mean shape index of deciduous forest patches - 400 m | C05SMN04 |
| Mean area of deciduous forest patches (ha) - 1200 m | C05AMN12 |
| Mean shape index of deciduous forest patches - 1200 m | C05SMN12 |
| Pasture patch density (no./100 ha) - 1200 m | C07PD12 |
| Pasture edge density (m/ha) - 1200 m | C07ED12 |
| Crop patch density (no./100 ha) - 1200 m | C08PD12 |
| Barren patch density (no./100 ha) - 800 m | C10PD08 |
| Mean area of barren patches (ha) - 1200 m | C10AMN12 |
| Area-weighted mean shape index of barren patches - 1200 m | C10SAM12 |

We used logistic regression analysis to develop and test a state-wide model and six physiographic region models to identify high risk areas along highways. We evaluated models composed of all possible combinations of variables that were selected through a stepwise process that used $P = 0.05$ to enter the model, $P = 0.10$ to be removed from the model, 20 iterations, and a classification cutoff of 0.50. We then used Akaike information criterion values to select the best models.

After we selected the best models, we used the randomly selected collision and random locations that were not included in model development (25% of all locations) to test each models' validity. A location was classified as a DVC location if its predicted probability was ≥ 0.50 and as a non-collision location if its predicted probability was < 0.50. The predicted values were examined to determine each model's classification rate.

## Results

### State-Wide Model

The analyses resulted in five competing models that performed better than all others considered table 4). Due to intercorrelations between interactions and main-effects variables, none of the interactions entered into the stepwise procedure significantly added to the models when included with the main effects.

Table 4: Comparison of the five best statewide models predicting likelihood of a location being a known deer/vehicle collision site.

| | | | Overall Model Test | | | Overall classification | |
|---|---|---|---|---|---|---|---|
| Model | -2LL | AIC | $X^2$ | *df* | *P* | Model data | Test data |
| 1[1] | 6196.88 | 6228.88 | 396.34 | 15 | <0.001 | 61.9% | 62.0% |
| 2 | 6201.05 | 6231.05 | 392.17 | 14 | <0.001 | 62.2% | 62.1% |
| 3 | 6213.21 | 6237.21 | 380.01 | 11 | <0.001 | 61.5% | 62.4% |
| 4 | 6218.77 | 6240.77 | 374.45 | 10 | <0.001 | 61.4% | 62.2% |
| 5 | 6222.26 | 6242.26 | 370.96 | 9 | <0.001 | 61.3% | 62.4% |

[1]Model 1 was selected as the final statewide model.

We selected a final state model that was composed of 15 parameters, including occurrence/nonoccurrence within the Arkansas River Valley or Mississippi River Alluvial Floodplain physiographic regions (table 5). Based on both the Wald Chi-squared test statistics and the standardized estimates for the parameters, the six most important predictors were C07ED12, ECONEW(2), C01PD12, NSHI04, C05AMN04, and D2NW.

The model discriminated well between known DVC locations and random highway locations. Sixty-three percent of the known collision locations (n = 2,378) had a probability of ≥ 0.50 of being a known deer-vehicle collision location. Sixty-one percent of the random highway locations (n = 2,378) had a probability of < 0.50 of being a known deer-vehicle collision location. From the 1584 test locations (50% from known collision locations and 50% from random highway locations), the final state model correctly predicted 498 (63%) known collision locations (n = 792) and 484 (61%) random highway locations (n = 792).

### Physiographic Region Models

Our analyses of models for each of the physiographic regions resulted competing models that performed better than all others considered (table 6). Due to intercorrelations between interactions and main-effects variables, none of the interactions entered into the stepwise procedure significantly added to the models when included with the main effects.

We selected final models that were composed of 6 – 10 parameters (tables 7 – 12). Almost all variables included in the state model were also included in at least one physiographic region model, and most variables of each physiographic region model were also found in the state model. Most models developed for individual physiographic regions performed as well or better than the state-wide model (62%): Arkansas River Valley (62%), Boston Mountains (69%), Gulf Coastal Plain (59%), Mississippi River Delta (70%), Ouachita Mountains (67%), and Ozark Mountains (60%).

Table 5: Parameter estimates for the final statewide logistic regression model predicting the likelihood of a location being a known deer/vehicle collision site

| | | | Wald $X^2$ Test | | | |
|---|---|---|---|---|---|---|
| Parameter | Estimate (B) | SE | Statistic | *P* | Standardized estimate (?) | Odds ratio (exp(B)) |
| CT02_02 | -2.3539 | 1.0935 | 4.6335 | 0.0314 | -0.0558 | 0.0950 |
| D2NW | -0.0002 | 0.0001 | 13.2699 | 0.0003 | -1.0741 | 0.9998 |
| NSHI04 | 0.2243 | 0.0437 | 26.3272 | <0.0001 | 0.0888 | 1.2514 |
| L_SHDI04 | 0.2291 | 0.0991 | 5.3436 | 0.0208 | 0.0567 | 1.2575 |
| C01PLA12 | -0.0054 | 0.0024 | 5.2356 | 0.0221 | -0.0505 | 0.9946 |
| C01PD12 | 0.3978 | 0.0774 | 26.4414 | <0.0001 | 0.1066 | 1.4885 |
| C02PLA12 | 0.0143 | 0.0071 | 4.0215 | 0.0449 | 0.0391 | 1.0144 |
| C04PD04 | 0.0123 | 0.0042 | 8.4024 | 0.0037 | 0.0633 | 1.0124 |
| C05AMN04 | 0.0303 | 0.0068 | 19.8549 | <0.0001 | 0.0922 | 1.0308 |
| C05SMN12 | 0.3668 | 0.1215 | 9.1115 | 0.0025 | 0.0573 | 1.4432 |
| C07PD12 | 0.1053 | 0.0496 | 4.5170 | 0.0336 | 0.0510 | 1.1111 |
| C07ED12 | 0.0151 | 0.0021 | 53.2714 | <0.0001 | 0.1839 | 1.0152 |
| C08PD12 | 0.1459 | 0.0722 | 4.0806 | 0.0434 | 0.0426 | 1.1571 |
| ECONEW[1] | --- | --- | 62.9830 | <0.0001 | --- | --- |
| ECONEW(1)[2] | -0.1920 | 0.0813 | 5.5723 | 0.0182 | -0.0830 | 0.8253 |
| ECONEW(2)[3] | 0.7593 | 0.1147 | 43.8419 | <0.0001 | 0.3282 | 2.1368 |
| INTERCEPT | -1.7677 | 0.2088 | 71.7008 | <0.0001 | --- | 0.1707 |

Table 6: Comparison of the best physiographic region models predicting the likelihoods of locations being known deer/vehicle collision sites

| Physiographic Region | Model | -2LL | AIC | Overall Model Test $\chi^2$ | *df* | *P* | Overall Classification Model data | Test data |
|---|---|---|---|---|---|---|---|---|
| Arkansas River Valley | AV1 | 1535.02 | 1557.02 | 125.76 | 10 | <0.001 | 63.1% | 61.5% |
| | AV2 | 1540.17 | 1560.17 | 120.61 | 9 | <0.001 | 62.6% | 62.3% |
| Boston Mountains | B1 | 511.97 | 525.97 | 67.50 | 6 | <0.001 | 67.2% | 69.3% |
| | B2 | 516.15 | 528.15 | 63.32 | 5 | <0.001 | 68.2% | 67.9% |
| Gulf Coastal Plain | GC1 | 1090.78 | 1104.78 | 70.94 | 6 | <0.001 | 61.8% | 58.6% |
| | GC2 | 1095.33 | 1107.33 | 66.38 | 5 | <0.001 | 61.2% | 57.2% |
| Mississippi River Alluvial Flood | MR1 | 1065.87 | 1081.87 | 195.66 | 7 | <0.001 | 69.2% | 69.7% |
| Plain | MR2 | 1070.34 | 1084.34 | 191.19 | 6 | <0.001 | 69.8% | 70.4% |
| Ouachita Mountains | OU1 | 734.53 | 748.53 | 86.16 | 6 | <0.001 | 66.4% | 67.3% |
| | OU2 | 741.94 | 753.94 | 78.75 | 5 | <0.001 | 66.2% | 66.3% |
| Ozark Mountains | OZ1 | 1069.86 | 1083.86 | 39.18 | 6 | <0.001 | 61.0% | 60.2% |
| | OZ2 | 1073.91 | 1085.91 | 35.13 | 5 | <0.001 | 58.0% | 56.4% |

Table 7: Parameter estimates for the final Arkansas River Valley physiographic region model predicting the likelihood of a location being a known deer/vehicle collision site

| Parameter | Estimate (B) | S.E. | Wald $\chi^2$ Test Statistic | *P* | Standardized estimate (β) | Odds ratio (exp(B)) |
|---|---|---|---|---|---|---|
| D2NW | -0.0005 | 0.0002 | 6.0768 | 0.0137 | -0.0890 | 0.9995 |
| NSHI04 | 0.3217 | 0.0784 | 16.8244 | <0.0001 | 0.1462 | 1.3795 |
| C01PLA12 | -0.0094 | 0.0034 | 7.8439 | 0.0051 | -0.1146 | 0.9906 |
| C01PD12 | 0.4267 | 0.1373 | 9.6617 | 0.0019 | 0.1251 | 1.5322 |
| C04PD04 | 0.0194 | 0.0077 | 6.3206 | 0.0119 | 0.0946 | 1.0196 |
| C05AMN12 | 0.1288 | 0.0376 | 11.7306 | 0.0006 | 0.1588 | 1.1374 |
| C07PD12 | 0.1935 | 0.0814 | 5.6456 | 0.0175 | 0.0890 | 1.2135 |
| C08PD12 | 0.2627 | 0.1018 | 6.6593 | 0.0099 | 0.1034 | 1.3004 |
| C10PD08 | -0.1217 | 0.0538 | 5.1154 | 0.0237 | -0.0917 | 0.8854 |
| C10SAM12 | 0.3773 | 0.1231 | 9.3912 | 0.0022 | 0.1227 | 1.4584 |
| INTERCEPT | -1.0124 | 0.2031 | 24.8533 | <0.0001 | --- | 0.3633 |

Table 8: Parameter estimates for the final Boston Mountains physiographic region model predicting the likelihood of a location being a known deer/vehicle collision site

| Parameter | Estimate (B) | S.E. | Wald $\chi^2$ Test Statistic | *P* | Standardized estimate (β) | Odds ratio (exp(B)) |
|---|---|---|---|---|---|---|
| CT03_ONE | -0.5050 | 0.2474 | 4.1664 | 0.0412 | -0.1392 | 0.6035 |
| L_SHDI04 | 1.2499 | 0.4456 | 7.8675 | 0.0050 | 0.2315 | 3.4898 |
| L_N_MN08 | -0.0102 | 0.0049 | 4.2794 | 0.0386 | -0.1649 | 0.9898 |
| C01PD12 | 0.7436 | 0.2797 | 7.0669 | 0.0079 | 0.2127 | 2.1036 |
| C05AMN12 | 0.0549 | 0.0213 | 6.6307 | 0.0100 | 0.1741 | 1.0565 |
| C07ED12 | 0.0215 | 0.0074 | 8.3429 | 0.0039 | 0.2178 | 1.0217 |
| INTERCEPT | -1.3016 | 0.8243 | 2.4934 | 0.1143 | --- | 0.2721 |

Table 9: Parameter estimates for the final Gulf Coastal Plain physiographic region model predicting the likelihood of a location being a known deer/vehicle collision site

| Parameter | Estimate (B) | S.E. | Wald $X^2$ Test: Statistic | Wald $X^2$ Test: *P* | Standardized estimate (β) | Odds ratio (exp(B)) |
|---|---|---|---|---|---|---|
| L_SHDI04 | 0.4641 | 0.2192 | 4.4825 | 0.0342 | 0.0891 | 1.5906 |
| C01PD12 | 0.4797 | 0.1832 | 6.8592 | 0.0088 | 0.1174 | 1.6157 |
| C05AMN04 | 0.0768 | 0.0262 | 8.5644 | 0.0034 | 0.1617 | 1.0798 |
| C07ED12 | 0.0214 | 0.0053 | 16.3595 | 0.0001 | 0.1771 | 1.0216 |
| C08PD12 | -0.9839 | 0.3131 | 9.8770 | 0.0017 | -0.1531 | 0.3738 |
| C10SAM12 | 0.5851 | 0.1618 | 13.0725 | 0.0003 | 0.1561 | 1.7951 |
| INTERCEPT | -1.6909 | 0.3245 | 27.1599 | <0.0001 | --- | 0.1844 |

Table 10: Parameter estimates for the final Mississippi River Alluvial Plain physiographic region model predicting the likelihood of a location being a known deer/vehicle collision site

| Parameter | Estimate (B) | S.E. | Wald $^2$ Test: Statistic | Wald $^2$ Test: *P*-value | Standardized estimate (β) | Odds ratio (exp(B)) |
|---|---|---|---|---|---|---|
| CT03_ONE(1) | 0.5191 | 0.2237 | 5.3835 | 0.0203 | 0.1113 | 1.6806 |
| NSHI04 | 0.3338 | 0.1208 | 7.6299 | 0.0057 | 0.1224 | 1.3962 |
| C01PLA12 | -0.0118 | 0.0058 | 4.1526 | 0.0416 | -0.0887 | 0.9883 |
| C02PD12 | 0.2014 | 0.0821 | 6.0228 | 0.0141 | 0.1109 | 1.2231 |
| C05SMN04 | 0.3256 | 0.1283 | 6.4426 | 0.0111 | 0.1302 | 1.3849 |
| C05SMN12 | 0.4780 | 0.2009 | 5.6583 | 0.0174 | 0.1140 | 1.6128 |
| C07ED12 | 0.0303 | 0.0044 | 46.8902 | <0.0001 | 0.3606 | 1.0308 |

Table 11: Parameter estimates for the final Ouachita Mountains physiographic region model predicting the likelihood of a location being a known deer/vehicle collision site

| Parameter | Estimate (B) | S.E. | Wald $X^2$ Test: Statistic | Wald $X^2$ Test: *P*-value | Standardized estimate (β) | Odds ratio (exp(B)) |
|---|---|---|---|---|---|---|
| CT03_01 | 2.1951 | 1.0577 | 4.3071 | 0.0380 | 0.1900 | 8.9813 |
| NSHI04 | 0.2503 | 0.1191 | 4.4197 | 0.0355 | 0.1045 | 1.2844 |
| C04PD04 | 0.0465 | 0.0103 | 20.3642 | <0.0001 | 0.2292 | 1.0476 |
| C07PD12 | 0.4639 | 0.1368 | 11.4965 | 0.0007 | 0.2008 | 1.5903 |
| C07ED12 | 0.0116 | 0.0053 | 4.8232 | 0.0281 | 0.1251 | 1.0116 |
| C10AMN12 | 0.6226 | 0.2778 | 5.0231 | 0.0250 | 0.1960 | 1.8637 |
| INTERCEPT | -2.1856 | 0.2903 | 56.6796 | <0.0001 | --- | 0.1124 |

Table 12: Parameter estimates for the final Ozark Mountains physiographic region model predicting the likelihood of a location being a known deer/vehicle collision site

| Parameter | Estimate (B) | S.E. | Wald $X^2$ Test: Statistic | Wald $X^2$ Test: *P*-value | Standardized estimate (β) | Odds ratio (exp(B)) |
|---|---|---|---|---|---|---|
| C01PD12 | 0.3297 | 0.1301 | 6.4220 | 0.0113 | 0.1050 | 1.3906 |
| C02PD12 | 0.3355 | 0.1291 | 6.7516 | 0.0094 | 0.1165 | 1.3986 |
| C04PD04 | 0.0318 | 0.0160 | 3.9412 | 0.0471 | 0.0822 | 1.0324 |
| C05AMN04 | 0.0391 | 0.0113 | 11.9665 | 0.0005 | 0.1786 | 1.0399 |
| C07ED12 | 0.0101 | 0.0043 | 5.3601 | 0.0206 | 0.0990 | 1.0101 |
| C10AMN12 | -0.8355 | 0.3191 | 6.8555 | 0.0088 | -0.1389 | 0.4337 |
| INTERCEPT | -0.8506 | 0.2481 | 11.7586 | 0.0006 | --- | 0.4271 |

## Discussion

Logistic regression analysis on the statewide level produced a fifteen-variable model to predict occurrence of DVCs on state and federal highways in Arkansas. Four of these variables, CT02_02, D2NW, C01PLA12, and ECONEW(1), tended to decrease the odds of a location being a collision site. The remaining eleven variables, NSHI04, L_SHDI04, C01PD12, C02PLA12, C04PD04, C05AMN04, C05SMN12, C07PD12, C07ED12, C08PD12, and ECONEW(2), tended to increase the odds of a location being a collision site.

The most important site-level factor found to predict the probability of DVCs was the density of pasture edge within 1200 m of a location. The positive contribution of pasture edge density supports the idea that edge, particularly edge between woods and fields, represents the close proximity of food and cover requirements for deer (Halls 1984, Sealander and Heidt 1990,Gerlach et al. 1994, Hiller 1996). This edge effect is considered the result of three primary factors. First, grasses and broad-leaved herbs (commonly referred to as forbs) are among the food preferred by deer and are commonly available in fields and pastures (Sealander and Heidt 1990). Second, other foods preferred by deer, such as leaves, twigs and shoots (commonly referred to as browse) often occur along the edge between woods and fields (Sealander and Heidt 1990). Third, the woods provide cover for deer, particularly when bedding down during the day (Whitaker and Hamilton 1998).

An abundance of edge, particularly edge between woods and fields or pasture, provides an ideal situation providing both food and cover for deer in a relatively small area (Hiller 1996). Thus, a high density of pasture edge over a constant area (1200 m buffer) suggests three things: a large number of pasture patches, a small mean patch size, and potentially more irregularly shaped patches of pasture, all of which denote more edge between pasture and other land cover types. Edge allows deer greater access to food and cover in a smaller area by minimizing the travel requirements between them, which can lead to smaller home ranges and potentially higher densities of deer.

Occurrence of a given location within the Mississippi River Alluvial Floodplain physiographic region increased the probability of that location being a collision site. Of all the physiographic regions, the Mississippi River Alluvial Floodplain had the smallest proportions of randomly selected locations within 800 and 2400 m of known collision locations (9% and 24%, respectively). If the characteristics of known collision locations are truly different from the characteristics of random highway locations, then having few random locations in close proximity to known collision locations could enhance a model's discrimination ability. In contrast, having a majority of random locations in close proximity to known collision locations could potentially reduce a model's discrimination ability. Thus, by virtue of the spatial separation of known collision locations and random locations, the Mississippi River Alluvial Floodplain physiographic region increased the state model's discrimination ability.

The density of urban patches within a 1200 m buffer was also positively related to the probability of a given location being a collision site. In other words, the likelihood that a given location was a known collision location increased as the amount of urban patches within a 1200 m buffer increased. A high urban patch density implies a large number of urban patches and a small mean urban patch size. This variable describes not deer habitat, but characteristics influencing traffic levels and human population densities. Thus, an increased density of urban areas suggests the presence of human residences and/or proximity to urban areas, where local traffic levels are likely to be greater and increase the risk of collisions with deer, especially if this density of urban patches occurs in conjunction with good deer habitat.

The number of stream/highway intersections within a 400 m buffer was positively related to the probability of a given location being a collision site. There are three potential explanations for this relationship. First, intersections of streams and highways often indicate potential travel corridors for deer moving within their home ranges or dispersing (Hubbard et al. 2000). Second, these intersections indicate the presence of water in the proximate area, which is another requirement for deer, particularly during late summer and early fall (Hiller 1996). Third, in areas with intensively managed timberland or heavily utilized agricultural lands, streams are likely less disturbed, providing additional habitat and edge for deer.

The mean area of deciduous forest patches within a 400 m buffer also was positively related to the probability of a given location being a collision site. In other words, as the mean area of deciduous forest within 400 m of the road increased, the probability of that location being a collision site also increased. There are two potential reasons for this relationship. The first reason is food, particularly hard mast such as acorns that is available in deciduous forests and along their edges (Whitaker and Hamilton 1998). With a larger mean area of deciduous forest patches, there is a greater likelihood that older trees (mast producers) are present to provide this preferred deer food during the fall season. The second reason is that the woods in these patches provide cover to deer.

The distance to the nearest water body was negatively related to the probability of a given location being a collision site. In other words, locations where water was close to the road were more often associated with collision sites than locations where water was further from the road. Proximity to water is an important component of deer habitat (Hiller 1996). Thus, when water sources are close to the highway it is more likely that deer will utilize the area, especially when other important components of deer habitat are also present. Likewise, as the nearest water source is further away from the highway (even if the local area has other characteristics of deer habitat) those deer that may utilize the habitat near the highway would have to travel further for water, decreasing the likelihood that deer would heavily use this habitat.

The mean shape index of deciduous forest patches within a 1200 m buffer was positively related to the probability of a given location being a collision site. In other words, as the mean shape of deciduous forest patches became more irregular within 1200 m of a given location, the likelihood of that location being a collision site increased. There are two potential explanations of this relationship. First, the greater irregularity of shape of deciduous forest patches would imply a greater amount of forest edge, which would potentially allow more favorable browse/forage along the edge of these deciduous forest patches (Hiller 1996). This increase in edge would thereby enhance the habitat for deer. A second possible explanation is that irregularly shaped forest patches are less likely being intensively managed for timber and thus are more likely to contain older, mast-producing trees.

The density of coniferous forest patches within a 400 m buffer was positively related to the probability of a given location being a collision site. Coniferous forest patches, when in close proximity to deer feeding sites, often provide necessary cover for deer during times of relative inactivity, such as during the day (Gerlach et al. 1994). A greater density of coniferous forest patches over a constant amount of area would suggest not only more patches, but also smaller mean patch sizes. This would imply that the area within 400 m of the highway is relatively open and the coniferous forest patches are dispersed among other patch types. The distances from cover provided by these coniferous forest patches to food found along the forest edges and/or in nearby pastures, crops, or deciduous forest, are therefore shorter than otherwise, leading to potentially smaller home ranges and greater deer densities. Another result of a large density of coniferous forest patches is a greater amount of edge habitat.

Occurrence of a given location within the Arkansas River Valley physiographic region was negatively related to the probability of a location being a collision site. The reasons may be similar to those of the variable for occurrence of a location within the Mississippi River Delta ecoregion, although with the opposite outcome. Whereas the Mississippi River Alluvial Floodplain physiographic region had the lowest number of reported collisions weighted by area (about 7 collisions per 100 km of highway), the Arkansas River Valley physiographic region had the greatest number of reported collisions weighted by area (about 19 collisions per 100 km of highway). One result of this greater "density" of collisions in the Arkansas River Valley is that a large proportion of randomly selected highway locations were within 800 and 2400 m of known collision locations, 28% and 62% respectively. This high proportion of random locations in close proximity to known collision locations could create a blurring of any distinctions between collision and random locations. If the characteristics of known collision locations are truly different from the characteristics of random highway locations, then a set of collision and random locations having a majority of random locations in close proximity to known collision locations may be less distinguishable.

The Shannon's Diversity Index for all patches within a 400 m buffer was positively related to the probability of a location being a known collision location. Shannon's Diversity Index takes into account the richness of patch types in an area and the evenness of the distribution of area among the patch types (McGarigal and Marks 1995). This index tends to be more sensitive to richness than evenness, meaning that rare patch types have an influence on diversity that is not proportional to the area of such patch types (McGarigal and Marks 1995). Therefore, a large diversity index reflects a large number of patch types and/or an increase in the proportional distribution of area among these patch types.

In terms of deer habitat, an area with more types of patches and/or a more even distribution of area of such patch types (especially in an area within 400 m of the highway) suggests the probability that the local area around the highway has a combination of land cover providing a proper distribution of food, cover, and water for deer. With such a high diversity of land cover within a 400 m buffer, the distances between any given pair of patch types would be shorter. Thus, the home ranges of deer in this area could be much smaller than other areas and thereby allow for a greater density of deer supported in the area if the habitat is suitable (Hiller 1996).

The percent of urban land cover within a 1200 m buffer was negatively related to the probability of a location being a collision site. The loss of deer habitat to competing urban land uses is reflected in this negative relationship (Gerlach et al. 1994). A greater proportion of land put to urban uses would imply that a location is closer to or within a town, city, or metropolitan area. Furthermore, more land used for urban purposes potentially means a smaller amount of area available as food or cover for deer. Another possible reason for this negative relationship is that urban centers and greater traffic flow could act as a barrier to deer desiring to cross a highway (Bellis and Graves 1978).

The presence of water across from water within a 100 m buffer also decreased the probability of a given location being a collision site. This finding makes sense because a dominance of water within 100 m on either side of a highway suggests that the location is on a bridge crossing a large body of water where deer are perhaps least likely to occur. As bridges have little if any form of vegetation on them, either in terms of potential food or cover, it is less likely for deer to move onto them during their daily or seasonal movements. Also, the magnitudes of both the coefficient and the odds ratio of this variable suggest that the presence of this factor may override the influence of other factors in determining whether or not a location is a probable collision site.

The density of pasture patches within a 1200 m buffer was positively related to the probability of a given location being a collision site. Pasture land and fields can provide food for deer, particularly during the spring, when grasses and forbs are most palatable to deer (Rue 1989, Whitaker and Hamilton 1998). A greater density of pasture patches suggests more pasture bordering with other patch types, with this increased edge having a high probability of containing plant species favorable for deer browse.

The density of crop patches within a 1200 m buffer was also positively related to the probability of a given location being a collision site. There are several potential reasons for this relationship. A high crop density implies more crop patches and smaller mean patch sizes of crops, which suggests that the area is not under intensive agriculture where large blocks of land are managed. Additionally, a greater crop density suggests a greater diversity of land cover types and more edge habitat available to deer. Finally, several of the crops grown on these lands are potential food for deer, and smaller field sizes would increase the availability of this food to deer.

Finally, the percentage of water within a 1200 m buffer was positively related to the probability of a given location being a collision site. This result may seem to contradict the finding of this study that the presence of water across from water within 100 m decreases the probability of being a known collision location. However, the reason for this seeming difference appears to be a matter of scale. Within the smaller 100 m buffer, a greater amount of water (being the dominant type) suggests the highway is crossing a river or other body of water, where deer are not as likely to be found. Within the larger 1200 m buffer, a greater amount of water (though not greater than 68% at any of the studied locations) suggests more water available within the locality, which, if combined with the presence of other food and cover-related factors, would suggest greater suitability for the presence of deer in that locality.

Logistic regression analysis on the physiographic region level resulted in six models which each included from 6 – 10 variables to predict occurrence of DVCs on state and federal highways in Arkansas. These six physiographic region models could be considered as subsets of the final state model. At least half of the variables in each physiographic region model could also be found in the state model with a similar influence on the probability of a location being a collision site. Additionally, all but four (two of which being the categorical variables describing physiographic region) of the fifteen variables in the state model could be found in at least one of the six physiographic region models. Furthermore, five general groups of factors appear in most, if not all, of the six physiographic region models.

The first group of factors involves the effect of water on the occurrence of DVCs. Two physiographic region models, the Boston Mountains and Gulf Coastal Plains, did not have a variable related to water, which could be explained by the fact that these two had the smallest proportions of water (< 1%) of all six physiographic regions. The remaining four physiographic regions, each with greater proportions of water, had at least one water-related variable. Of further interest, the two physiographic regions with the greatest proportions of water (exceeding that of the state average) each had two water-related variables in their models.

The second group of factors involves the effect of a diverse land cover association in proximity to a highway on the occurrence of DVCs. This factor is embodied in the state model as the variable describing the Shannon's Diversity Index of all land cover patches within a 400 m buffer. This same variable was found in the Boston Mountains and Gulf Coastal Plains physiographic region models, suggesting a strong influence of diverse land cover types on DVCs in these regions. The influence of this factor on the other physiographic regions appears to be more indirect, with variables such as those involving density of land cover patches suggesting an indirect measure of some diversity in the landscape.

The third group of factors involves the effect of urban area on the occurrence of DVCs. All six physiographic region models had at least one variable describing urban area. The Arkansas River Alluvial Floodplain physiographic region model had two urban-related variables, both of which were found, with similar influences, in the state model. This finding should not be surprising, as the Arkansas River Valley is comprised of the greatest proportion of urban area in the state.

The fourth group of factors involves the effect of forested area on the occurrence of DVCs, particularly the influence of deciduous and/or coniferous forests. The density of coniferous forest patches within a 400 m buffer was included in three of the six physiographic region models: Arkansas River Valley, Ouachita Mountains, and Ozark Mountains. The first two physiographic regions mentioned had fairly large proportions of coniferous forest, with the Ouachita Mountains having the largest proportion, which would suggest a strong influence of coniferous forests on collisions in this physiographic region. However, the inclusion of coniferous forest patch density in the Ozark Mountains physiographic region is surprising, considering the proportion of coniferous forests in this region is not more than 1.2%, and is not included in the Gulf Coastal Plains physiographic region model, which has a large proportion of coniferous forest (23%). One possible explanation may be that the presence of coniferous forests in the Ozark Mountains, though scarce, is an important source of cover for deer, particularly during the winter months, which are more likely to be severe than in other portions of the state, such as the Gulf Coastal Plains. Variables describing the size or shape of deciduous forest patches were found in all but one of the physiographic region models: the Ouachita Mountains, which has already been described as predominately coniferous forest. These findings suggest the strong influence of deciduous forests on DVCs in the state, as brought out in the state model.

Finally, the fifth group of factors involves the effect of pasture and cropland on deer-vehicle collisions. The pasture edge density within a 1200 m buffer, found to be the most influential variable in the state model, was also found in all but one physiographic region, the Arkansas River Valley. A similar variable, pasture patch density within a 1200 m buffer, was found in the Arkansas River Valley physiographic region as well as in the Ouachita Mountains physiographic region. Thus, the distribution and edge of pastureland appears to be a strong influence in the state as a whole as well as within each physiographic region. The other part of this general factor, cropland, was found not in the physiographic region model of the Mississippi River Alluvial Floodplain, which has the majority of Arkansas's cropland, but in the physiographic region models of the Arkansas River Valley and Gulf Coastal Plains. Of interest are the opposite influences of crop patch density on DVCs in these two physiographic regions. In the Arkansas River Alluvial Floodplain, with 3.5%

cropland, density of crop patches within a 1200 m buffer was positively related to the likelihood of a location being a collision site, suggesting the potential use of these lands by deer. On the other hand, in the Gulf Coastal Plains, with 0.5% cropland, density of crop patches within a 1200 m buffer was negatively related to the likelihood of a location being a collision site.

## Conclusions

We considered and evaluated 1,100 variables for comparisons between known collision locations and random highway locations. Although about 700 variables examined in this study had significant differences between known collision locations and random locations, a relatively small number were selected for consideration in logistic regression analysis based on intercorrelations among these variables. Hence, a variety of different variables could have been selected from such a large starting base. The variables selected and used in the logistic regression analyses should thus be viewed as representing and reflecting several classes of variables.

Five general conclusions arise from our study. First, the presence and amount of water accessible to deer, in terms of distance to the nearest source, number of streams intersecting within 400 m, and amount within 1200 m, are strongly related to the occurrence of DVCs. Second, the presence of a diverse association of land cover types in close proximity to the highway is also strongly related to the occurrence of DVCs. Third, the amount and size of urban area within 1200 m of a location has a strong relation to occurrence of DVCs. Fourth, forested area (deciduous and/or coniferous) in close proximity to the highway, particularly in terms of higher density of coniferous forest and greater size and irregularity of deciduous forest patches, is also strongly related to occurrence of DVCs. Finally, the density of pasture and crop patches, and the density of pasture edge in particular, within 1200 m of the highway are strongly related to DVCs.

Our results and models may be used to produce maps indicating potential segments of highways at high risk for the occurrence of DVCs. Additionally, they may aid in planning and road construction. Finally, these results provide a foundation for future research in examining more specific deer-vehicle interactions, and can aid in the evaluation of appropriateness and effectiveness of proposed methods to reduce DVCs in Arkansas.

**Acknowledgements:** We would like to thank the Arkansas Highway and Transportation Department and the Arkansas State Police for providing data. We appreciate M.C. Farrell and S. Enderle for their assistance with data collection and compilation. Funding was provided by the Arkansas Forest Resources Center.

**Biographical Sketches:** Philip A. Tappe is a professor of wildlife ecology and management, Associate Director of the Arkansas Forest Resources Center, University of Arkansas Division of Agriculture; and Associate Dean of the School of Forest Resources, University of Arkansas at Monticello. He received his B.S. and M.S. from Stephen F. Austin State University, and his Ph.D. from Clemson University.

Donald I.M. Enderle is currently a GIS Analyst with Photo Science, Inc., Tucker, GA 30084. He received his B.S. from Auburn University and his M.S. from the University of Arkansas at Monticello.

## References

Bashore, T. L., W. M. Tzilkowski, and E. D. Bellis. 1985. Analysis of deer-vehicle collision sites in Pennsylvania. *Journal of Wildlife Management* 49:769-74.

Bellis ED, Graves HB. 1971. Deer mortality on a Pennsylvania Interstate highway. *J Wildl Manage* 35(2):232-7.

Conover M. R., W. C. Pitt, K. K. Kessler, T. J. DuBow, and W. A. Sanborn. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. *Wildlife Society Bulletin* 23:407-14.

Finder, R. A., J. L. Roseberry, and A. Woolf. 1999. Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. *Landscape and Urban Planning* 44:77-85.

Gerlach, D., S. Atwater, and J. Schnell. (editors) 1994. Deer. Mechanicsburg (PA): Stakepole Books. 384p.

Halls, L. K. (editor). 1984. White-tailed deer ecology and management. Harrisburg (PA): Stackpole Books. 870p.

Hiller, I. 1996. The white-tailed deer. College Station (TX): Texas A&M University Press. 115p.

Hubbard, M. W., B. J. DaNeilsen, and R. A. Schmitz. 2000. Factors influencing the location of deer-vehicle accidents in Iowa. *Journal of Wildlife Management* 64:707-13.

McGarigal, K., and B.J. Marks. 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. USDA Forest Service General Technical Report PNW-351.

Rue, L. L., III. 1989. The deer of North America. 2nd edition. Danbury (CT): *Outdoor Life*. 544p.

Sealander J. A., and G. A. Heidt. 1990. Arkansas mammals, their natural history, classification, and distribution. Fayetteville (AR): University of Arkansas Press. 308p.

Tappe, P. A. 2005. Deer-vehicle collisions in Arkansas. *Journal of the Arkansas Academy of Science* 59:218-221.

Whitaker, J. O., Jr., and W. J. Hamilton. 1998. Mammals of the eastern United States. Third edition. Ithaca (NY): Cornell University Press. 583p.

# Wildlife Mitigation and Human Safety for Sterling Highway MP 58-79, Kenai Peninsula, Alaska

**Richard Ernst** (907-262-7021, rick_ernst@fws.gov), Wildlife Biologist/Pilot, U.S. Fish and Wildlife Service, Kenai National Wildlife Refuge, P.O. Box 2139, Soldotna, AK 99669 USA

**Jeff Selinger** (907) 260-2905, jeff_selinger@fishgame.state.ak.us), Area Wildlife Biologist, Alaska Department of Fish and Game, 43961 Kalifornsky Beach Road, Soldotna, AK 99669 USA

**Jim Childers** (907) 269-0544, jim_childers@dot.state.ak.us), Project Manager, Alaska Department of Transportation and Public Facilities, P.O. Box 196900, 4111 Aviation Avenue, Anchorage, AK 99519 USA

**Dale Lewis** (907-586-7429, dale.j.lewis@fhwa.dot.gov), Central Region Liaison Engineer, Federal Highway Administration, Alaska Division, P.O. Box 21648, Juneau, AK 99802 USA

**Gary Olson** (907) 336-6673, golson@growmoremoose.org), President, Alaska Moose Federation, 11701 Brayton Drive, Anchorage, AK 99516 USA

**Lt. Steve Bear** (907-262-4453, steve_bear@dps.state.ak.us), Detachment Commander, Alaska Department of Public Safety, Wildlife Troopers, 44009 Kalifornsky Beach Road, Soldotna, AK 99669 USA

**Abstract:** The Sterling Highway is a paved two-lane road which links Alaska's western Kenai Peninsula, to the Seward Highway and Anchorage, the state's largest city. The Kenai National Wildlife Refuge is bisected by the Sterling Highway, which has one of the highest moose (*Alces alces*) vehicle collision rates for a rural highway in the state. The Alaska Department of Transportation and Public Facilities is planning to reconstruct a section of the Sterling Highway between MPs 58 and 79, occurring mostly within the Refuge. A working group was formed in 2005 to collect data on moose movements and review wildlife-vehicle collisions (WVC). The group consists of representatives from the Federal Highway Administration; the Alaska Departments of Transportation and Public Facilities, Fish and Game, and Public Safety; the Alaska Moose Federation (non-profit); and the U.S. Fish and Wildlife Service. The purpose of this cooperative effort is to reduce wildlife-vehicle collisions along the Sterling Highway corridor through the Kenai National Wildlife Refuge while maintaining permeability and enhancing habitat connectivity. In this paper, we describe our study design and provide interim results from 2005-06.

## Introduction

Vehicle collisions with moose are a major problem on the Sterling Highway within the Kenai National Wildlife Refuge (State of Alaska, 1994). The Sterling Highway is part of the National Highway System and is the only highway connecting the western Kenai Peninsula with Anchorage, the state's largest city (Figure 1). Milepost (MP) 58 begins at the junction of the east entrance to Skilak Lake Road (the original Sterling Highway) in the upper Kenai River valley. The highway exits the Kenai Mountains around MP 63 and descends onto the Kenai lowlands - a broad expanse of wetlands, bogs, lakes and boreal forest. Black (*Picea mariana*) and white spruce (*Picea glauca*), mixed with aspen (*Populus tremuloides*), white birch (*Betula papyrifera*) and willow (*Salix* spp.) line the highway except where bogs and muskeg are intersected. The highway crosses the East Fork of the Moose River, an anadromous stream, at MP 71.3. The boundary of the Kenai Refuge is at MP 76 and the project ends at MP 79 near Sterling where the existing four-lane divided highway begins. Elevations range from 91m (300ft) to 191m (625ft). Much of the area surrounding this section of highway was burned in 1947 when the highway was originally constructed. Following the 1947 burn moose numbers reached a peak density of 3.6/km$^2$ (Bishop and Rausch 1974) in 1971 (Loranger et al. 1991). Densities dropped off quickly after that time.

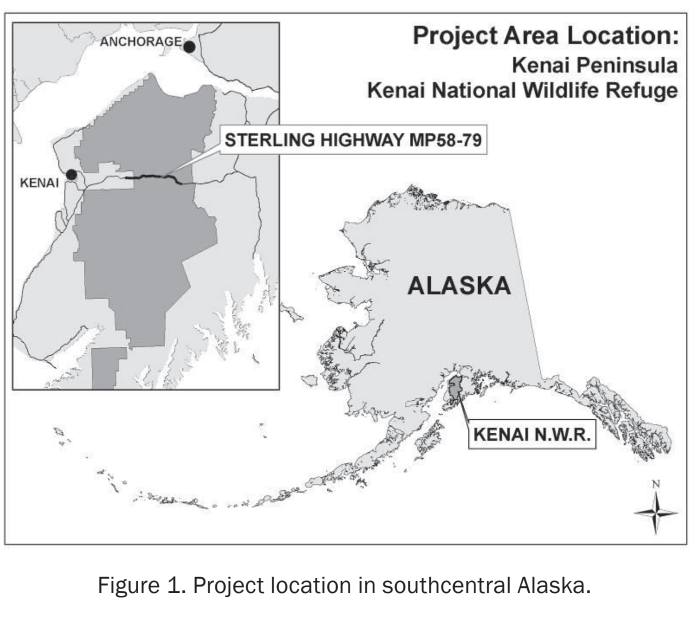



Figure 1. Project location in southcentral Alaska.

Planned improvements to the highway infrastructure include passing lanes, wider shoulders and smoother surface which may result in increased speeds. Increased speeds in conjunction with expected increases in traffic volume may exacerbate the wildlife-vehicle collision problem. Local moose populations may also increase due to recent wildfires and prescribed burns adding to the problem; however, currently moose numbers are low. This highway bisects the Kenai National Wildlife Refuge, further fragmenting the refuge since its creation as the Kenai National Moose Range in December 1941 (U.S. Fish & Wildlife Service 1985). The Moose Range was renamed to the Kenai National Wildlife Refuge and its purposes broadened with the passage of the Alaska National Interest Lands Conservation Act of 1980.

The Kenai Refuge in cooperation with the Alaska Department of Fish and Game submitted a proposal to the Alaska Department of Transportation and Public Facilities and the Federal Highway Administration to look at ways of mitigating impacts to wildlife and provide for improved safety for motorists. The study proposal was submitted in December 2003 and called for the formation of an interagency working group to oversee the study. This group includes members from the Alaska Departments of Transportation and Public Facilities, Fish and Game, Public Safety; the Alaska Moose Federation (non-profit), the Federal Highway Administration, and the U.S. Fish and Wildlife Service. The study proposal was originally designed to collect and analyze wildlife-vehicle collision data and collar up to 35 cow moose for two successive winters to identify crossing areas. Later a third data source was added: getting motorists to call in wildlife sightings as they drive through the area.

## Funding Sources

The study is designed in two phases, pre- and post-construction. Presently only the pre-construction phase has been funded. The 2-phase design should determine the success of any wildlife crossing structures and other means of reducing wildlife-vehicle collisions while maintaining habitat connectivity. Funding for the pre-construction phase of the study was provided by a grant from the Alaska Department of Transportation and Public Facilities ($290,000) and from the U.S. Fish and Wildlife Service ($25,000).

## Methods

Three sources of data are being collected for analysis: (1) monitoring collared moose and caribou to determine highway crossing paths, (2) WVC data from Alaska State Trooper and Alaska Department of Transportation and Public Facilities records, and (3) call-in reports to a wildlife hotline from motorists driving the highway.

### Global Positioning Satellite Collars

Alaska Department of Transportation and Public Facilities data on moose-vehicle collisions demonstrated a higher occurrence during winter months. Therefore we decided to program global positioning satellite (GPS) collars (manufactured by Telonics, Inc. of Mesa, Arizona) to record a fix every 30 minutes from October through March, then every two hours until release on June 30. The goal was to get detailed information on where and when moose crossed the road during the winter months while enabling the transmitters to function well past the release date to allow time for retrieval.

Thirty-one adult cow moose were captured and collared in late October and early November of 2005. By July all but one of the collars was retrieved, information was downloaded and the collars were refurbished. In late October and early November of 2006 we captured and deployed collars on 32 cow moose and 5 cow caribou (*Rangifer tarandus*). Collars are still active and will be retrieved in July 2007.

### Wildlife-Vehicle Collisions

Data were combined on wildlife-vehicle collisions from two data sources: Alaska Department of Transportation and Public Facilities and the Alaska State Trooper radio logs (compiled by Alaska Department of Fish and Game). Most records were duplicated by each source however there were unique incidents that were only found in one of the two sources.

These data included road kills, accidents where animals were hit but walked off or were not found, and where animals were found dead but not reported by the motorist involved. These data were collected according to some feature of the roadway, usually MP marker, stream crossing, pullout, or junction with another road. Data are now required to be collected with GPS units in latitude and longitude. Half-mile markers were installed along the highway to help improve the accuracy of WVC locations.

### Wildlife Hotline

The third data set consists of motorists' observations of wildlife on or near the highway. To aid motorists (especially those not familiar with the area) in establishing their location, we installed half MP markers along the entire 18 miles of the study area within the Kenai Refuge. A large reflective sign warning motorists they are entering a high wildlife crossing area is posted at both east and west ends of the study area. The signs include the "wildlife hotline" phone number.

Numerous local newspaper stories, posters displayed in stores, post offices, visitor centers; printed brochures, and public seminars have been used to inform the local public of our efforts and to encourage calls to the hotline from motorists. We also installed a local AM radio transmitter at MP 62.3 to broadcast a request to motorists to report wildlife sightings and include the following information: what species, how many, between what half MP markers, the date, and time.

## Summary of Findings

We collected over 247,000 fixes from 29 GPS collared moose between October 2005 and October 2006. The release mechanism on two collars failed and the moose carried them until October 2006. One collar was not retrieved and deemed lost. Four collared moose never crossed the highway. Of the 25 moose that did cross the highway there were 337 crossings and 1199 locations within the 300ft highway right-of-way. The highest number of crossings was between MP 73 and 74 (figure 2). Almost 2 of 3 collared moose crossed the highway at this location, probably because it is the most direct path between two recent fires that are currently the best winter moose habitat. The next highest crossing occurred between MP 70 and 70.5. While 48 crossings occurred at this half mile segment, they involved only four collared moose.

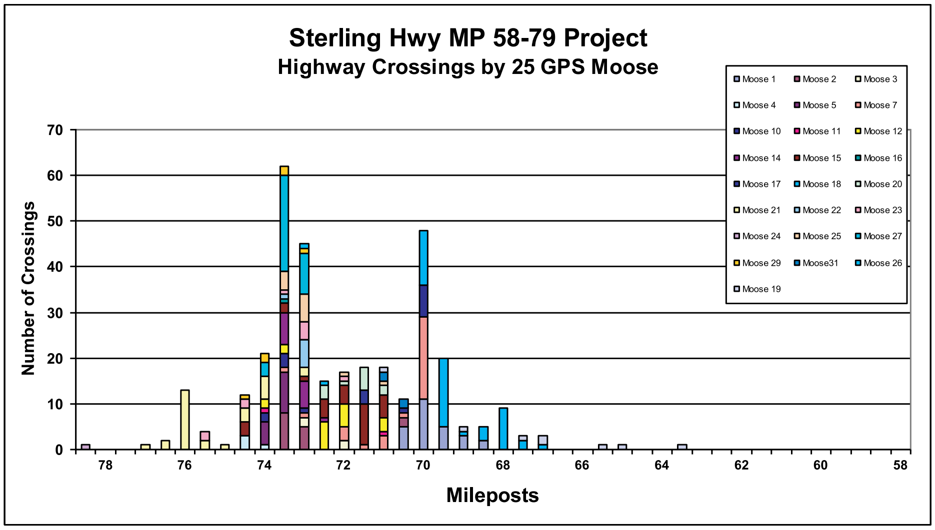



Figure 2. Sterling Highway crossings by GPS collared moose (n=337).

Most of the GPS moose crossings occurred during the months of January and February, typically the darkest months of the year, with bad weather and road conditions (figure 3).

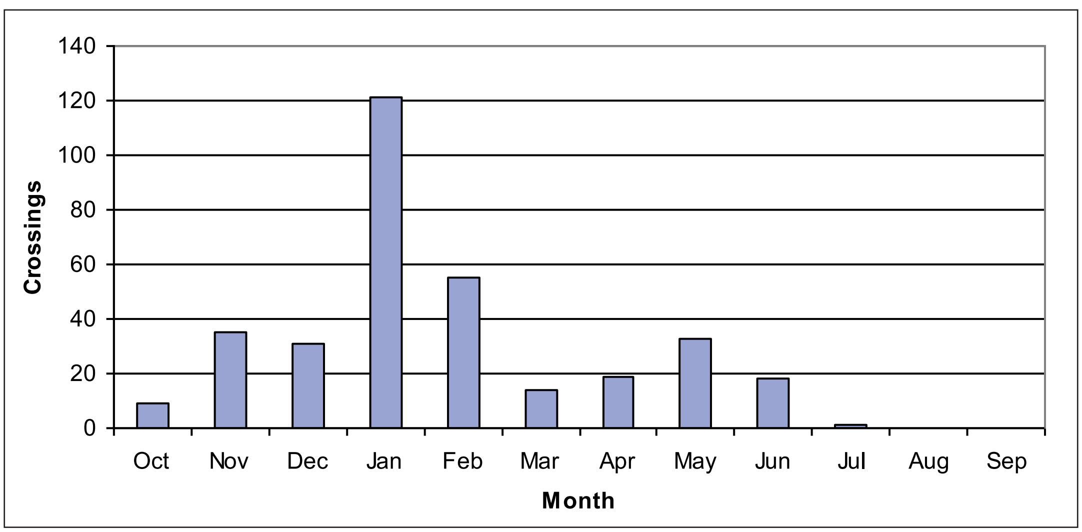



Figure 3. Moose crossings of the Sterling Highway, October 2005 through September 2006 (n=337).

Moose crossings during the hour of the day exhibit a typical dusk to dawn activity. Crossings were least during mid-day (figure 4).

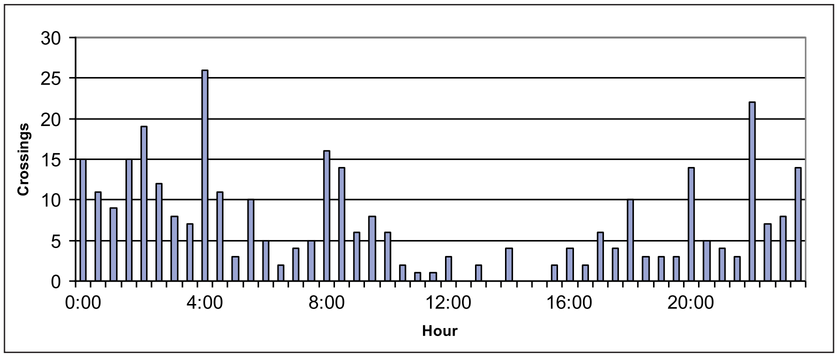



Figure 4. Moose crossings of the Sterling Highway by time of day, Alaska Standard Time (n=337).

The WVC data were compiled from 2000-06 from a combination of Alaska Department of Transportation and Public Facilities as well as from Alaska State Trooper radio logs. There were 134 WVC, an average of 19.1 per year for this section of highway. This collision rate is almost certainly higher as there are unreported accidents. Bangs et al. (1989) suggested the unreported rate was between 75-100% of those reported on the Kenai Peninsula. Tagged moose were killed by vehicles at twice the rate confirmed by troopers. During winters of heavy snowfall, the number of collisions reported in Alaska may triple the number in an average snowfall season (Franzmann and Schwartz 1997).

An interesting note is that while in past years moose made up the vast majority of all WVC, in 2006 bears and caribou made up 35%, a significant increase. Over the past seven years moose make up 84% of the WVC (figure 5).

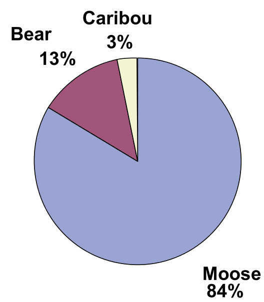



Figure 5. Composition of the wildlife vehicle collisions from 2000 to 2006 (n=134).

The combination of WVC, Wildlife Hotline sightings and GPS moose crossings help to identify some "hot spots" along the 21 miles of the Sterling Highway being studied (figure 6). These data are preliminary and retrieval of the currently deployed GPS collars in July 2007 may alter these locations. We also hope that our wildlife hotline database will also grow over the next year.

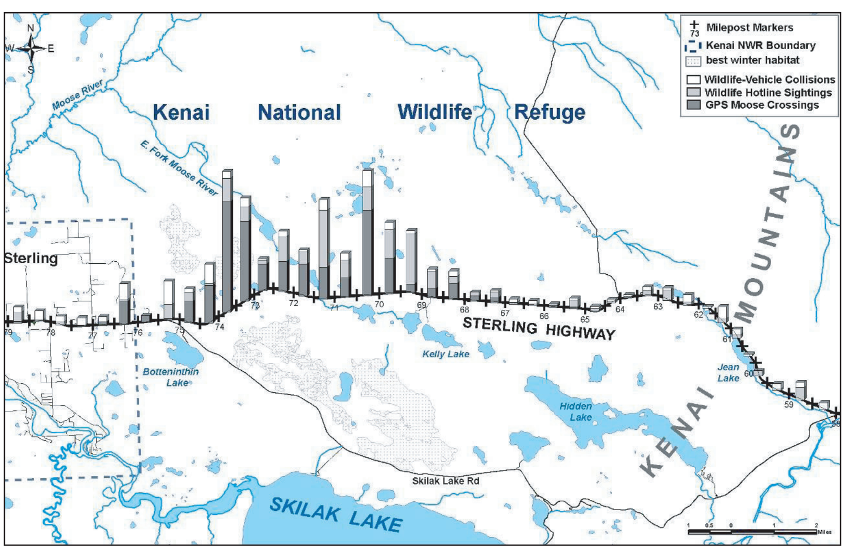



Figure 6. Hot Spots along the Sterling Highway between MPs 58-79. Includes WVC data from 2000 to 2006 (n=134), Wildlife Hotline sightings (n=119), and GPS moose crossings (n=337).

## Future Research

This July we will retrieve the currently active GPS collars and add the stored data to the first years GPS crossings. We will continue to summarize WVC data set and Wildlife Hotline calls. Our interagency working group will meet with the Alaska Department of Transportation and Public Facilities to discuss the design, placement and types of wildlife crossing structures and/or other techniques that may help reduce WVC while maintaining the permeability of the highway for wildlife on the Kenai National Wildlife Refuge.

A post-construction study plan will be developed to help document use of any structures as well as wildlife movements. Video cameras to document use of structures and also track counts will be utilized. It is important that long term monitoring of any structures takes place since wildlife require time to adjust and learn to use them.

**Biographical Sketch:** Richard Ernst is a wildlife biologist/pilot for the U.S. Fish and Wildlife Service at the Kenai National Wildlife Refuge in Soldotna, AK. The Kenai Refuge encompasses almost 2 million acres of which two-thirds is wilderness. Rick has been working on improving the safety and mitigating the Sterling Highway which cuts through the refuge for the past four years. He chairs the interagency working group to redesign and reconstruct a more "wildlife friendly" highway. Rick received his B.S. and M.S. from Utah State University.

## References


Bangs, E.E., T.N. Bailey and M.F. Portner. 1989. Survival rates of adult female moose on the Kenai Peninsula, Alaska. *J. Wildl. Manage.* 53(3):557-563.

Bishop, R.H. and R.A.Rausch. 1974. Moose population fluctuations in Alaska, 19501972. Nat. Can. (Que.) 101:559593.

DelFrate, G.G. and T.H. Spraker. 1992. Moose vehicle interactions and an associated public awareness program on the Kenai Peninsula, Alaska. *Alces* 27:1-7.

Franzmann, A.W. and C.C. Schwartz. Eds. 1997. Ecology and management of the North American Moose. *Wildlife Management Institute.* Washington, DC.

Loranger, A.J., T.N. Bailey and W.L. Larned. 1991. Effects of Forest Succession after fire in moose wintering habitats on the Kenai Peninsula, Alaska. *Alces* 27:100-109.

U.S. Fish and Wildlife Service. 1985. Kenai National Wildlife Refuge Final Comprehensive Conservation Plan. Soldotna, Alaska.

## Citizen Monitoring Along Interstate 90 at Snoqualmie Pass

**Jen Watkins** (206-675-9747, jwatkins@conservationnw.org), Outreach Director, I-90 Wildlife Bridges Coalition, 3414 1/2 Fremont Avenue North, Seattle, WA 98103, Fax: 206-675-1007 USA
**Dave Moskowitz** (425-788-1301), Project Manager, Cascade Wildlife Monitoring Project, Wilderness Awareness School, P.O. Box 5000, PMB 137, Duvall, WA 98019 USA

**Abstract:** Interstate 90 over the Cascades is significant barrier to over 250 species of wildlife, including cougar, elk, deer, mustelids (otters, fishers, badgers, etc.), amphibians and reptiles. In the vicinity of Snoqualmie Pass, urban development to the west and agriculture and resort development on the east has shrunk the forest connecting north and south Cascades to less than 64.6 kilometers wide.

The Washington State Department of Transportation (WSDOT) is proposing to expand a 24.15-kilometer stretch of Interstate 90 just east of Snoqualmie Pass through a particularly critical zone for north-south wildlife corridors. These corridors have been identified through numerous studies, and the state has made ecological connectivity a project goal, along with increasing capacity, straightening curves, and repaving. A preferred alternative design for this project was chosen in summer 2006 that includes numerous high quality crossing structures, and was endorsed by the I-90 Wildlife Bridges Coalition.

The I-90 Wildlife Bridges Coalition is made up of over 40 local and national conservation organizations and has been working with WSDOT, other public officials, transportation interests, and the public to promote high quality wildlife crossing structures in this project while educating the public in our state about transportation and ecology issues. An additional role beyond advocacy and education that the coalition has engaged in during 2006 is citizen wildlife monitoring at the proposed crossing structure locations.

Good data is available to inform where to build crossing structures. WSDOT and the US Forest Service collaborated on a study entitled I-90 Snoqualmie Pass Wildlife Habitat Linkage Assessment (Singleton and Lehmkuhl, 2000) that used tracking and and road-kill counts to map existing crossing activity. Additional relevant information comes from analysis leading to the Snoqualmie Pass Adaptive Management Area Plan and I-90 Land Exchange (US Forest Service, 1997 and 1999) and Washington State Dept. of Fish and Wildlife studies of cougar movements using radio collars.

Recent land acquisitions and national forest management changes have dramatically improved the outlook for habitat quality near the project. In recent years, purchases, donations, and exchanges have brought more than 50,000 acres of land valued at $200 million into public ownership and protection. The Forest Service is committing to additional habitat restoration, such as road removal.

In light of these changes to the landscape and the large investment of the crossing structures, the coalition is acting to contribute to the data collection of current and future wildlife usage of habitat in the project vicinity. The coalition has sponsored digital remote cameras that have been installed at proposed crossing structure locations to gather still photograph and video images of wildlife moving through the area. These cameras are maintained by coalition volunteer teams, and data is shared through the website. This winter the coalition has launched a partnership with the Wilderness Awareness School to begin snow tracking monitoring at selected proposed crossing structure locations to compliment our current remote camera program. Both of these programs have begun this year, and are intended for long term monitoring.

The coalition has grown out of a history of grassroots activism and collaboration around the Central Cascades region. Citizen involvement has played a critical role in the management policies of this area. The I-90 project will be a greater success due to the high level of attention, input, and assistance received from the public. Public involvement peaked in the spring of 2005 with the release of the Draft Environmental Impact Statement bringing in thousands of public comments. Involvement continues throughout the state through efforts of education such as our annual *Bridging Futures* contest, advocacy, and monitoring by the coalition.

### Introduction

Interstate 90 over the Cascades is significant barrier to over 250 species of wildlife, including cougar, elk, deer, mustelids (otters, fishers, badgers, etc.), amphibians and reptiles. In the vicinity of Snoqualmie Pass, urban development to the west and agriculture and resort development on the east has shrunk the forest connecting north and south Cascades to less than 64.6 kilometers wide.

The Washington State Department of Transportation (WSDOT) is proposing to expand a 24.15-kilometer stretch of Interstate 90 just east of Snoqualmie Pass through a particularly critical zone for north-south wildlife corridors. These corridors have been identified through numerous studies, and the state has made ecological connectivity a project goal, along with increasing capacity, straightening curves, and repaving. A preferred alternative design for this project was chosen in summer 2006 that includes numerous high quality crossing structures, and was endorsed by the I-90 Wildlife Bridges Coalition.

The I-90 Wildlife Bridges Coalition is made up of over 40 local and national conservation organizations and has been working with WSDOT, other public officials, transportation interests, and the public to promote high quality wildlife crossing structures in this project while educating the public in our state about transportation and ecology issues. An additional role beyond advocacy and education that the coalition has engaged in during 2006 is citizen wildlife monitoring at the proposed crossing structure locations.

Good data is available to inform where to build crossing structures. WSDOT and the US Forest Service collaborated on a study entitled I-90 Snoqualmie Pass Wildlife Habitat Linkage Assessment (Singleton and Lehmkuhl, 2000) that used tracking and and road-kill counts to map existing crossing activity. Additional relevant information comes from analysis leading to the Snoqualmie Pass Adaptive Management Area Plan and I-90 Land Exchange (US Forest Service, 1997 and 1999) and Washington State Dept. of Fish and Wildlife studies of cougar movements using radio collars.

Recent land acquisitions and national forest management changes have dramatically improved the outlook for habitat quality near the project. In recent years, purchases, donations, and exchanges have brought more than 50,000 acres of land valued at $200 million into public ownership and protection. The Forest Service is committing to additional habitat restoration, such as road removal.

In light of these changes to the landscape and the large investment of the crossing structures, the coalition is acting to contribute to the data collection of current and future wildlife usage of habitat in the project vicinity. The coalition has sponsored digital remote cameras that have been installed at proposed crossing structure locations to gather still photograph and video images of wildlife moving through the area. These cameras are maintained by coalition volunteer teams, and data is shared through the website. This winter the coalition has launched a partnership with the Wilderness Awareness School to begin snow tracking monitoring at selected proposed crossing structure locations to compliment our current remote camera program. Both of these programs have begun this year, and are intended for long term monitoring.

The coalition has grown out of a history of grassroots activism and collaboration around the Central Cascades region. Citizen involvement has played a critical role in the management policies of this area. The I-90 project will be a greater success due to the high level of attention, input, and assistance received from the public. Public involvement peaked in the spring of 2005 with the release of the Draft Environmental Impact Statement bringing in thousands of public comments. Involvement continues throughout the state through efforts of education such as our annual *Bridging Futures* contest, advocacy, and monitoring by the coalition.

## Citizen Monitoring Program Overview

The Citizen Monitoring Project uses trained volunteers to monitor the location and movement of wildlife in the vicinity of proposed wildlife crossing sites along Interstate-90 in the Washington Cascades between Snoqualmie Pass and Easton. As a high profile project at a major recreation destination, there is substantial interest from citizens who would like to understand and be involved in the decision making process. The Cascade project aims to improve understanding of the impact on wildlife of this major highway renovation, while also aims to involve and educate the public regarding road ecology and wildlife tracking. This document reports results from the first year of monitoring.

The project has been designed to answer these questions:

1. What species of wildlife are present in the habitat adjacent to the interstate and what are their current patterns of use in areas proposed for construction of crossings?
2. Will these patterns be affected by the addition of crossing structures and if so how?
3. There are ungulates and rare carnivores in the area which are of high interest to conservationists and wildlife managers. Which of these are present in the areas of the proposed crossings, and what are their discernable behaviors in relation to the road?
4. How effectively can a volunteer based citizen science effort carry out a rigorous scientific endeavor to answer the first three questions?

Through snow tracking surveys, volunteers collected data on the location and movement patterns of wildlife along the Interstate at sites with planned crossing structures. Through this report and reports to come in subsequent years, findings will be made available to land managers, the Washington State Department of Transportation, and public interest groups with the intention of helping to guide final decisions about the location and type of construction. Monitoring will continue during and after the construction period. Data obtained before, during and after highway construction will help test the function of crossing structures and assess changes in permeability of the Interstate for medium and large mammals. During the first field season (winter 2006-2007) six transects were monitored using snow tracking methods. Five of the survey sites coincide with planned wildlife crossings (Gold Creek, Price/Noble Creek East, Price Noble Creek West, and Easton Hill North and South). The remaining location, Hyak/Silver Fir, is the site of a proposed expansion to the Snoqualmie Summit ski resort and is not adjacent to the Interstate (see Appendix A for site maps.) Over 50 volunteers participated in this field season to produce the findings in this report.

Animal tracking, and particularly snow tracking, is increasingly recognized as a reliable and rigorous method for wildlife research. Indeed, snow tracking is one of the key methods recommended by the United States Forest Service for certain kinds of wildlife surveys, for example in the detection of rare carnivores (Zielinksi and Kucera 1995). Some studies have found snow tracking to be more effective for detecting target species than other methods when compared (Bull et al. 1992, cited in Zielinksi and Kucera 1995; and Copeland, J., cited in Zielinksi and Kucera 1995). Collection of tracking data during non-snow seasons requires observers with a higher degree of skill but has been incorporated into other road ecology surveys (Barnum 2003, van Manen et al. 2001).

Tracking is a relatively established methodology for monitoring animals at wildlife crossing structures and along road corridors (for instance: Clevenger et al 2002, van Manen et al 2001, Barnum 2003, Singleton and Lehmkuhl 2000). The procedures vary depending on the natural conditions on the ground, time of year, and specific goals of the research. Methods include the use of track plates and artificially prepared ground specifically at crossing sites (Clevenger 2003, Singleton and Lehmkuhl 2000), and transects along which track and sign data is collected (Barnum 2003, Singleton and Lehmkuhl 2000).

One previous study of wildlife connectivity was conducted in the I-90 Cascades corridor by Singleton and Lehmkuhl (2000) as part of the planning process for the I-90 Snoqualmie East Project. Singleton and Lehmkuhl combined snow tracking data with road kill records, habitat and terrain parameters, motion sensing cameras and track plates to inform the choice of locations for the planned I-90 wildlife crossings.

In addition to winter snow tracking surveys, several motion-sensing cameras are managed by volunteers along the Interstate corridor. Cameras are active year round and supplement information gathered through tracking surveys. Starting in the Spring of 2007, tracking surveys will be piloted quarterly during non-snow seasons. Camera locations existed at three key connectivity zones in the I-90 project: Gold Creek, Hyak Creek, and Price/Noble Creek. A team of 15 volunteers maintain and routinely check the cameras for maintenance.

The remote camera program captures wildlife in the area by offering solid proof of presence through photographs. The location of cameras to date has been based on field review of the habitat near proposed structures, but in the future will combine the knowledge learned from snow tracking results. Remote cameras are used widely by agencies to record presence of wildlife in specific locations, and are utilized at a larger scale than this project by the Southern Rockies Ecosystem Project's Citizen Monitoring.

**Snowtracking Field Results**

*Data*

No Level 1 species (see appendix for species ratings) were detected during the field season (see Appendix D). A single cougar (Puma concolor) was detected and subsequently trailed, at Price-Noble Creek. Bobcat (Lynx rufus) comprised nearly half of all reliable detections, and was found at all highway transect sites (figure 1). Coyote (Canis latrans) was detected at all sites, including the lower elevations of the Hyak site, except Easton Hill, and after bobcat, was the most frequently detected species. American marten (Martes Americana) was detected with regularity, though only at the highest elevation portions of the Hyak/Silver Fir site. It is likely that these records represent a single individual. The species was not detected at any of the highway sites. We found evidence of two species, raccoon (Procyon lotor) and river otter (Lutra Canadensis), predicted by habitat to be marginal or absent within the study area (table 1). The only large mammal species predicted but not detected was porcupine (Erethizon dorsatum).

It is important to note that detection frequency would be best regarded primarily as an indicator of presence, and secondarily as an index of intensity of use. Detection frequency is not an index of population size, or of density. Even in the imaginary situation in which all species were distributed at equal densities across the landscape, it is unreasonable to assume equal probability of encountering sign of all species, due to ecological differences between them.

Of the four animals trailed at highway sites three (bobcat, coyote, and cougar), clearly moved along parallel to the highway for distances of 100 yards or more. The single cougar trailing effort was cut short due to nightfall before a relationship to the road was discerned, though the data that was collected suggests that the animal was moving parallel and perpendicular to the road.

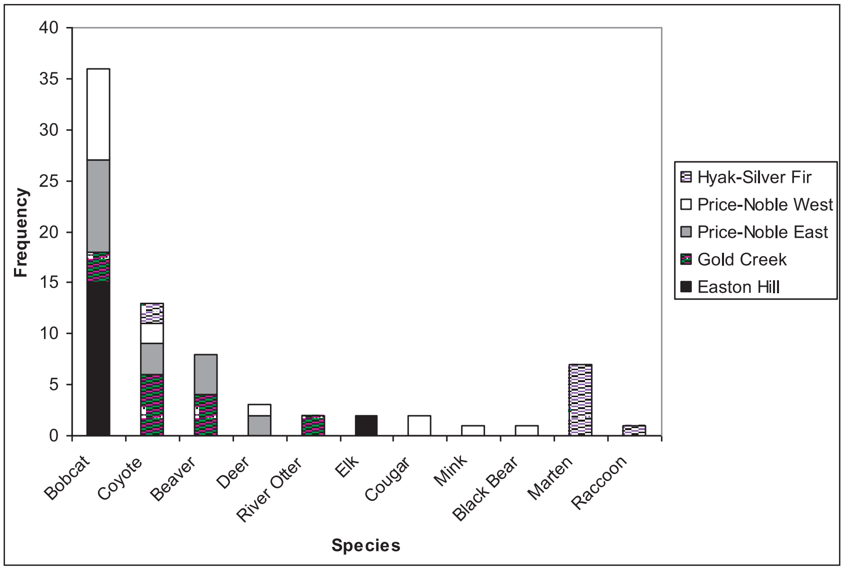



Figure 1. Frequency of species detections partitioned by site.

| Species | Detected | Washington GAP Status/Notes |
|---|---|---|
| Beaver | x | present |
| Black Bear | x | present/seasonal |
| Bobcat | x | present |
| Cougar | x | present |
| Coyote | x | present |
| Elk | x | present |
| Fisher | | extinct |
| Hoary Marmot | | marginal/seasonal |
| Marten | x | present |
| Mink | x | present |
| Mountain Goat | | marginal |
| Mule Deer | x | present |
| Porcupine | | present |
| Raccoon | x | marginal/absent |
| Red Fox | | rare |
| River Otter | x | marginal |
| Wolverine | | extremely rare |

Table 1: Expected and detected species. Expected species list based on 1997 Washington GAP Analysis (Johnson and Cassidy 1997)

| Site | Visits | Detections/Visit | Shannon's Diversity Index (H' = -∑plnp) |
|---|---|---|---|
| Easton Hill | 2 | 8.5 | 0.3622 |
| Gold Creek | 3 | 5 | 1.3095 |
| Price-Noble East | 3 | 6 | 1.2236 |
| Price-Noble West | 2 | 8 | 1.3634 |
| Hyak-Silver Fir | 3 | 3.33 | 0.8018 |

*Discussion*

Shannon's H', confirming what cursory analysis suggests, shows that Easton Hill and Hyak-Silver Fir sites are less diverse that other sites sampled, though this hypothesis was not statistically tested, as environmental factors were not accounted for in our sampling methods. Of the four highway sites, Easton Hill is the only site which can be said to be exclusively upland, with all other sites incorporating a diversity of upland and riparian habitats, and it is likely this factor which accounts for the observed differences in H'. Likewise, it is apparent on the ground at the Hyak-Silver Fir site that there is far less diversity associated with cover and habitat structures than at the riparian associated sites along I-90.

As one of the goals of the CWMP study is to detect rare carnivores within the I-90 corridor, we consider the almost one-to-one correspondence between expected and detected large mammal species, as well as the detection of species predicted by GAP Analysis as absent or marginal, to be indicative of sound methodology in regard to ability to construct an accurate, representative presence-absence database.

Based on location data (See Figure 5, Appendix A), it is likely that a baited camera trap placed in the vicinity of Hyak Lake would be successful in documenting the presence of American marten, a species of concern, during non-winter months. It may be possible in the future to utilize trailing records to create and assess the utilization distributions of individual animals within the study area, such as the presumed individual marten at the Hyak Creek. However, such work is typically accomplished via telemetry, and the methodologies to do so using trailing data have been neither developed nor tested.

### Remote Camera Field Results

*Data*

Three camera locations were selected in the first year of monitoring at Gold Creek, Hyak Creek, and Rock Knob. No Level 1 species were documented at any of the locations. Due to technical problems with old equipment at the Gold Creek location, no photographs of wildlife resulted. Difficulties included separation of the sensor from the camera, film exposure prior to processing, and camera failure.

The Hyak Creek camera recorded one Level 2 species, a pine marten, in April 2006. This was supported with numerous photographs of Level 3 species elk, snowshoe hare, deer, and coyote.

The Rock Knob camera is located in between Price and Noble Creeks in habitat just north of the proposed Rock Knob overpass in the I-90 Snoqualmie East Project. The camera detected Level 3 species such as bobcat, deer, elk, and coyotes.

*Discussion*

The photograph of a pine marten in the Hyak Creek corridor is significant in displaying the importance of this forest type in this location, which is being considered for development through an adjacent ski area. The other species recorded were expected within this corridor, and compliment the tracks found through the snowtracking data.

### Coordination With Other Information

To further compare and compliment the data of our citizen monitoring, we reached out to other observations in this landscape throughout the year. In February 2006, a report from a University of Washington graduate student was sent to the US Forest Service of wolverine tracks in the Alpine Lakes Wilderness about 3 miles from Gold Creek. The report was submitted with photographs that help to verify the potential presence of this species. In October 2006, a photograph by the Yakama Nation's remote cameras captured a wolverine prescence south of Interstate 90 in Klickitat County area.

Our fiscal sponsor organization and steering committee member, Conservation Northwest, runs an annual Rare Carnivore Remote Camera Program in conjunction with the US Fish and Wildlife Service. In the summer of 2006, a camera they located in habitat north of Interstate 90 in the Nappequa Valley of the Glacier Peak wilderness documented a wolverine through several photographs as well as many Level 3 species such as black bear and elk.

## Conclusion

In our first season of our Citizen Monitoring Program we identified the success and importance of our efforts, as well as the areas where we could improve. The combination of our snowtracking and remote camera programs did confirm the current presence of species in the I-90 corridor, as well as noting additional presence as recorded by other sources. Through the first year we have not fully recorded the patterns of use within these corridors with our limited equipment and data collection points. More specifically than noting the presence of species, our efforts did detect a Level 2 species in an important corridor.

The level of effectiveness of our volunteer effort can be viewed through our results of the first year, the coordination of this information with other studies, and how the program grows in the future. There is a clear impact of not only the information that this study generates, but in the engagement of citizens in collecting data to invest them in the landscape and transportation project. It is also evident that the data is not as valuable if it stands alone, but in coordination of what we are learning through other citizen and agency actions it does add value. Finally, there is room for growth in our program for better equipment and locations to improve on our data collection.

## Appendix A: Species Priority List

Tracking priority for this study in descending order

*Level 1*
Wolverine
Fisher
Lynx
Wolf
Mountain Goat
Grizzly Bear

*Level 2*
Cougar
Marten
Elk
Mule Deer
Mountain Red Fox

*Level 3*
Black bear
Bobcat
Coyote
Raccoon
River Otter
Beaver
Mink
All other species larger than Snowshoe Hare

Do not record: Snowshoe Hare and smaller animals

KEY
Level 1 species were to be trailed wherever possible, and as far as possible to gather maximum information about these critical rare species. These species would be trailed even before a transect was completed if there was risk of considerable track degradation before the return leg.

Level 2 species were trailed in the absence of Level 1 species, after completing the outward leg of a transect, where time was available. Animals were trailed towards the road primarily, and their behaviors recorded.

Level 3 species were recorded on the transect data sheet with all other species but were not trailed unless all other transect activities were completed.

# Habitat, Highway Features, and Animal-Vehicle Collision Locations as Indicators of Wildlife Crossing Hotspots

**Sarah Barnum** (603-224-9909, sbarnum@nhaudubon.org) New Hampshire Audubon, 3 Silk Farm Road, Concord, NH 03301 USA
**Kurt Rinehart** (802-685-4845, kurt@wildlifetrackers.com) and
**Mark Elbroch** (mark@wildlifetrackers.com), Ichneumon Wildlife Services, 151 Mountain School Road, Vershire, VT 05079 USA

**Abstract:** Tracking techniques were used along US 2 and NH 115 in the towns of Jefferson and Randolph, NH to record geo-referenced wildlife highway-crossing data for GIS-based analysis. Over 7000 track sets from 22 species were recorded from December 2005 through May 2006. Moose, red fox, white-tailed deer, and coyotes left most tracks. A substantial number of fisher and bobcat were also recorded. This data set is unique in size and the number of carnivores recorded. Analyses completed for this report indicate that variations in landscape scale habitat composition in the study area were correlated with variations in wildlife crossing rates at the landscape scale. Different species also showed different affinities for the roadside at this scale. At the local scale, the rate of moose crossing was higher in locations with mixed forest cover types and where guardrails end, but not in locations with high moose/vehicle collision rates. Crossing by predators, excluding red fox, increased with the presence of coniferous cover types, and the rate of deer crossing increased with the presence of open cover types. Additional analyses at the roadside scale will be conducted and results will be available at a later date.

## Introduction

Identifying locations where wild animals are most likely to cross highways is key to informing environmentally sensitive highway planning. With this information in hand, highway and conservation planners can collaborate to protect key habitat linkages by guiding highway design. Approaches include reducing the barrier effect of the highway through design or by placing crossing structures, or avoiding construction/upgrade of highways in sensitive locations altogether. Ideally, the characteristics of preferred crossing locations along existing roadways can be modeled from known crossing "hotspots", and the best locations to maintain connectivity can be identified as part of the design process.

Defining the characteristics of preferred crossing locations along existing roadways requires repeated observations of animal presence over large segments of roadway to identify crossing hotspots. Because highway departments have long-term, state-wide accident data that includes animal-vehicle collision (AVC) locations for most public roads, most analyses of hotspot locations to date have used AVCs as indicators of crossing (Allen and McCullough 1976, Finder et al. 1999, Hubbard et al. 2000, Joyce and Mahoney 2001, Nielsen et a. 2003, Malo et al. 2004).

However, using AVC locations to identify crossing hotspots has a number of inherent drawbacks. AVC locations have historically been recorded imprecisely (e.g., to the nearest mile marker), and because AVC are generally only reported when the collision renders the vehicle inoperable, they are heavily biased to deer, elk, and moose. Therefore, analysis based on these data can only identify broad landscape characteristics correlated with the presence of ungulates along the road. Many of the species most in need of adequate landscape scale connectivity are predators (Ruediger 1998). Additionally, animals may be hit and killed in locations where they approach the roadside to use resources, rather then to cross, and/or high AVC/kill locations may simply indicate a particularly dangerous crossing location, as opposed to the preferred place to cross.

Other approaches to identifying hotspot locations included recording the locations of road-killed animals (Bashore et al. 1985, Romain and Bisonette 1996) and roadside tracking studies (Alexander and Waters 2000, Singleton and Lehmkuhl 2000, Barnum 2003). Roadkill studies that rely on "second hand" reports suffer from the same limitations of AVC based studies, and many smaller species (i.e., predators) are also absent form these data sets as they are rapidly removed from the road by scavengers, collectors, or are simply overlooked. Tracking studies have the greatest potential to record a wide range of species, and their behavior, at the roadside.

## The Research Approach

This project used tracking techniques to identify locations where wild animals crossed two unfenced highway, at-grade. I divided the track data into three groups moose, deer, and wide-ranging predators (WRP; coyotes, fisher and bobcat). I then used descriptive statistics to examine how crossing varied among groups at the landscape scale, and regression analyses to determine the characteristics of crossing locations at the local scale, and roadside scale, for each species group.

"Local", "landscape", and even "roadside" are relative terms defined by the context of their application. For this study, I considered the immediate roadside to be within 75 m of the pavement, and the local scale to be within 500 m of the roadway. I defined the landscape scale as the area with in 1.5 km of the highway. I did not complete the roadside scale analysis prior to writing this report, and do not address it further in this document.

To determine what factors were associated with crossing rates (dependent variable), I chose variables that described the natural cover type, topography, amount of human activity, and characteristics of the roadway (independent variables). The location of moose/vehicle collisions (MVC) was also considered for association with moose crossing locations. Collision location data for other species was unavailable. The independent variables were chosen as existing research suggests that they influence highway crossing behavior by wildlife. The complete list of variables that I considered for quantitative analysis in the local and landscape scale analyses is given in table 1. The variable list for the landscape scale is comprised of all variables that I measured. For the local scale analysis, some variable categories were collapsed to achieve adequate sample sizes for regression analysis, or when a smaller group of variables adequately addressed the variability of that category.

Table 1: Variables quantitatively evaluated for their association with locations where animals cross a highway at the local (500m) and landscape (1500m) scales

| Variable Type | Name* for Regression | Local Scale 500m – Multiple Regression | Landscape Scale 1500m – Chi Squared |
|---|---|---|---|
| **Dependent** | | | **Track Records** |
| | MOOSElog | Number Moose TR | Percent Moose TR |
| | DEERlog | Number Deer TR | percent crossing v. not crossing |
| | WPRlog | Number WPR TR | Percent Deer TR |
| | | | percent crossing v. not crossing |
| **Independent** | | **Cover type** | Percent WPR TR |
| | DECID | Percent deciduous cover type | percent crossing v. not crossing |
| | MIX | Percent mixed cover type | |
| | ALCONlog | Percent mixed + coniferous cover | **Cover type** |
| | OPENlog | Percent open cover type | Percent coniferous cover type |
| | WETbin | Wetland – present /absent | Percent deciduous cover type |
| | VEGDI | Diversity of cover at location | Percent mixed cover type |
| | | | Percent open cover type |
| | | **Topography** | Percent wetland cover type |
| | SLODIlog | Diversity of slope at location | Diversity of cover at location |
| | | | **Topography** |
| | | **Human Activity** | Percent slope $\leq$ 5 |
| | PDMNbin | Low parcel density – pres/abs | Percent slope 6 – 10 |
| | PDMXbin | High parcel density – pres/abs | Percent slope 11-15 |
| | PDDIinv | Parcel density diversity | Percent slope > 16 |
| | | | Diversity of slope at location |
| | | **Roadway Feature** | **Human Activity** |
| | GREbin | Guardrail end present | Percent low parcel density |
| | BRIDbin | Bridge present | Percent moderate parcel density |
| | | | Percent high parcel density |
| | MVCbin | **MVC** – present/absent | Percent very high |
| | | | Percent highest |
| | | | **Roadway Feature** |
| | | | Average highway width |
| | | | **Number MVC** |

* Variables with the postfix "log" were log transformed to meet the assumption of normalcy for regression. Variables with the postfix "inv" were inverted to meet the assumption of normalcy for regression.. Variables with no postfix met normalcy assumptions without transformation. Variables with the postfix "bin" were converted to a binary format (present/absent).

## Study Site Description

My study site was located along 31 km (19 miles) of US Route 2 and 10 km (6 miles) of NH 115 in the Towns of Jefferson and Randolph, New Hampshire, USA (Figure 1). These two towns are located in the White Mountain Region of the state, have a substantial wildlife population, and have large areas of protected lands separated by the subject highways and their attendant low-density development. The study area was located along valley bottoms. Many of the surrounding peaks exceed 1225m in elevation, but within the study area elevations ranged from approximately 300m to 500m. The cover type, which is described in greater detail below, is predominantly forested. The study area hosted a substantial population of moose (*Alces alces*) and white-tailed deer (*Odocoilius virginianus*). Other common terrestrial species included red fox (*Vulpes vulpes*), coyote (*Canis latrans*), fisher (*Martes pennanti*), long-tailed and short-tailed weasel (*Mustela frenata, M. erminea*), and snowshoe hare (*Lepus americanus*). Less common species incuded bobcat (*Lynx rufus*), raccoon (*Procyon lotor*), gray fox (*Urocyon cinereoargenteus*), porcupine (*Erethizon dorsatum*), otter (*Lutra candensis*), and American marten (*Martes americana*).

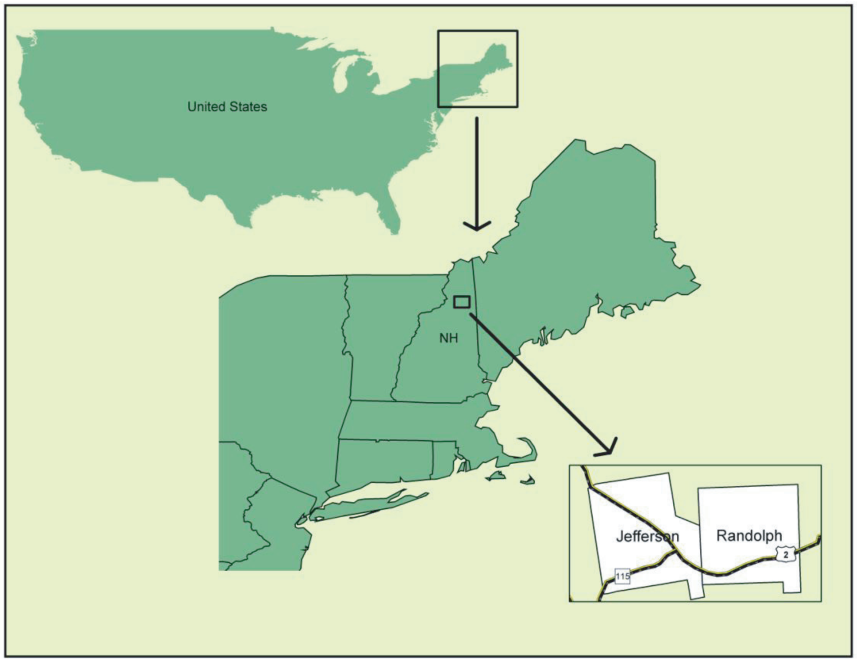



Figure 1. Study site location.

Based on variations in the characteristics of the natural and built environment within the study area, I divided it into three sub-areas, Route 2 east (Rt2E), Route 2 west (Rt2W) and NH 115 (NH115) for descriptive and analysis purposes. Rt2W passes through the Town of Jefferson, and in addition to some sections of forested land, is bordered by low density residential development, a few businesses, a golf course, pasture, and hay fields. Rt2E passes by (as opposed to through) the Town of Randolph, and is bordered by extensive sections of forested land, with very few businesses, some pasture, and a few individual residences. NH115 passes through primarily forested land, with some pasture and a few individual residences. There are no businesses. Additional variations in landscape structure are summarized in table 2. In general, Rt2W has a greater proportion of low angle slopes, more unforested land, and less low-density parcel area then the other two sub-areas. Cover type and parcel density also show greater diversity in Rt2W. Rt2E has the greatest amount of deciduous cover, steepest slopes, and highest slope diversity of the three sub-areas.

Table 2: Comparison of landscape characteristics among the three study area sub-areas

| | Rt2W | NH115 | Rt2E |
|---|---|---|---|
| **Roadway Length** | **13.5 km** | **9.8 km** | **17.9 km** |
| | | | |
| **Cover type (%)** | | | |
| Deciduous | 27 | 42 | 60 |
| Coniferous | 24 | 14 | 11 |
| Mixed | 14 | 17 | 12 |
| Wetland | 4 | 4 | 2 |
| Open | 27 | 19 | 12 |
| Diversity Index | 4.45 | 3.81 | 2.49 |
| **Slope Class (%)** | | | |
| 0-5 | 67 | 68 | 39 |
| 6-10 | 24 | 19 | 36 |
| 11-15 | 7 | 6 | 16 |
| 16 + | 3 | 7 | 9 |
| Diversity Index | 1.95 | 1.97 | 3.17 |
| **Parcel Density Class (%)** | | | |
| Low | 38 | 54 | 54 |
| Low-Med | 32 | 26 | 22 |
| Medium | 19 | 15 | 14 |
| Med-High | 8 | 5 | 7 |
| High | 2 | 0 | 2 |
| Diversity Index | 3.45 | 2.60 | 2.74 |
| **Protected Land (%)** | | | |
| | 6.15 | 8.65 | 36.09 |

The roadway in Rt2W has only two short sections of guardrail over 13.5 km, and is two lanes throughout, with little to no shoulder. Total pavement width is generally between 24 and 30 feet with two small sections that are between 40 and 44 feet in width. The roadway in Rt2E has extensive sections of guardrail, and multiple sections with two lanes, three lanes, no shoulders, and shoulders of varying widths. Total pavement widths vary from 28 to 46 feet. NH115 also has extensive sections of guardrail and both two and three lane sections, but total pavement widths are consistent between 40 and 44 feet. The average annual daily traffic volume on US 2 ranged from 4600 to 5000 vehicles (NHDOT 2005), and just under 3000 on NH 115 in the study area.

## Methods

### Tracking

A two-person field crew recorded track locations along the study area roadways with a hand-held GPS device\data logger (Geo Explorer III, Trimble). The tracking crew was highly skilled, and able to record an extensive amount of information about each track, in addition to location and date. Recoded information included species, number of animals, activity (cross, enter, exit, turn-away, parallel), age of track, and, in some cases, sex. I downloaded data files from the data logger and converted them to Excel spreadsheet and ArcView shapefile formats for analysis.

While snow was on the ground, the field crew drove slowly ($\leq$10 mph) through the study area searching for and recording track locations. The entire study are could be sampled in one day using this approach. Once the snow melted out, the site was surveyed on foot, and a complete survey of the study area required three days. The bulk of the data was collected while snow was on the ground (Dec, 2005 – March 26, 2006). Snow cover allows the tracks of a wide range of species to be observed, including smaller species such as snowshoe hare, fox, weasel, and marten. Once the snow cover melted out, the field crew depended on impressions left in mud, sand, and short vegetation, were restricted to looking for larger tracks, and focused on finding moose and bear tracks. By mid-May the growth of roadside vegetation rendered most of the study area untrackable in any efficient fashion.

### Animal Density Index

To compare the density of a species along the road, as compared to the surrounding habitat, sweep surveys were conducted in habitats adjacent to the road. To conduct a sweep, an observer walked a transect and recorded all tracks encountered. The transect locations and lengths were not pre-determined, and a total of 19 transects were surveyed. No attempt to differentiate between individuals was made, and the same animal may have been recorded multiple times. However, this is also true for the roadside tracking.

### Habitat and Highway Measurements

Except for the location of guardrails and bridges within the study area, which were recorded in the field, I made all habitat and highway data measurements from digital data layers, using the ArcView software package. Cover type was derived from National Land Cover Data (NLCD), reclassified into seven categories (developed, deciduous forest, coniferous forest, mixed forest, wetland, open water, unforested) and slopes were derived from Digital Elevation Models (DEMs). Parcel density was derived from parcel maps supplied by Jefferson and Randolph. A point was placed in the center of each parcel and the ArcView extension Spatial Analyst was used to generate a density surface, based on a 500m search radius. Pavement width was derived from NHDOT coverage.

### Analysis

To summarize the track data, I summed the total number of species and total number of TRs recorded along the roadside and in the surrounding habitat, and compared the composition of these two groups by species percentages.

To determine if crossing rates varied at a landscape scale, I counted the number of crossers and non-crossers recorded along the roadside in each sub-area, from each species group. I used these counts to describe how crossing varied among groups at the landscape scale, and a chi-squared analysis to detect significant differences in the distribution of the recorded tracks.

To determine which characteristics of the habitat and roadway were most strongly correlated with crossing rates the local scale, I used ArcView to divide the roadway into 700 m segments, then buffered the midpoint of each segment with a 500 m radius. I choose to overlap the buffers to smooth any effects of creating artificial boundaries. Automated ArcView scripts then counted the number of TRs within the buffer and measured the characteristics of the landscape within the buffer. I then used multiple regression to investigate the relationship between number of animals crossing within an area (dependent variable) and the characteristics of that area (independent variables). A backwards stepwise (Systat 11) technique was used. I choose the subset of variables for consideration was by looking at the degree of correlation within each group of independent variables (cover type, topography, human activity, roadway feature). I choose at least one from each group that reflected the variation of that group, and that was correlated (Pearson, $r \geq 0.0300$) to the crossing rate.

## Results and Discussion

### Tracking Results

Table 3 presents the total number of roadside TRs. Over 7,000 TRs representing 22 species were recorded. Table 4 presents the total number of sweep TRs, and compares the frequencies of each species occurrence in the landscape to its occurrence along the roadside. Because the two types of survey had different levels of effort, the comparison of frequencies should be regarded as index only. However, there is a clear indication that different species have different affinities for the roadside. Even though red fox left many TRs and crossed the roadway often, their occurrence was so disproportionately linked to the roadside I did not include them in further analysis. A visual analysis of the distribution of red fox TRs suggests that this species uses the roadside and directly adjacent areas as their primary habitat. Thus, their crossing does no represent linkage to the surrounding landscape.

Table 3: Counts of all species and their crossing behavior, recorded at the roadside

| Species | Cross | Enter | Exit | Parallel | Turn-Away | TOTAL |
|---|---|---|---|---|---|---|
| Moose | 1428 | 413 | 434 | 420 | 14 | 2709 |
| Red fox | 1090 | 340 | 300 | 189 | 20 | 1939 |
| White-tailed Deer | 900 | 56 | 47 | 62 | 16 | 1081 |
| Coyote | 336 | 57 | 63 | 29 | 3 | 488 |
| Gray fox | 142 | 44 | 46 | 12 | 4 | 248 |
| Snowshoe Hare | 89 | 10 | 10 | 24 | 6 | 139 |
| Fisher | 104 | 2 | 2 | 7 | 4 | 119 |
| Mink | 81 | | | 9 | | 90 |
| Long-tail weasel | 59 | 3 | 2 | 14 | 1 | 79 |
| Raccoon | 43 | 2 | | 1 | 2 | 48 |
| Black Bear | 36 | | 1 | 3 | 1 | 41 |
| Ermine | 25 | | | 8 | | 33 |
| Bobcat | 29 | | | | 1 | 30 |
| Turkey | 15 | 1 | | 2 | 2 | 20 |
| Striped Skunk | 5 | 2 | 2 | 3 | | 12 |
| Squirrel spp. | 8 | | | 1 | | 9 |
| Dom. cat | 6 | | | | | 6 |
| American Marten | 6 | | | | | 6 |
| Porcupine | 3 | | | 1 | 1 | 5 |
| Otter | 4 | | | | | 4 |
| Dom. dog | 3 | | | | | 3 |
| Canada Lynx | 1 | | | | | 1 |
| unk weasel spp | 1 | | | | | 1 |
| Total | 4414 | 930 | 907 | 785 | 75 | 7111 |

Table 4: Counts of all species recorded at the roadside and during sweeps. The percent of each species with a group (roadside or sweep) is given in parentheses

| Species | Roadside | (%) | Sweep | (%) |
|---|---|---|---|---|
| Moose | 2709 | (38.37) | 492 | (13.58) |
| Red fox | 1939 | (27.46) | 261 | (7.20) |
| White-tailed Deer | 1081 | (15.31) | 329 | (9.08) |
| Coyote | 488 | (6.91) | 546 | (15.07) |
| Gray fox | 248 | (3.51) | 27 | (0.75) |
| Snowshoe Hare | 139 | (1.97) | 911 | (25.14) |
| Fisher | 119 | (1.69) | 335 | (9.24) |
| Mink | 90 | (1.27) | 64 | (1.77) |
| Long-tail weasel | 79 | (1.12) | 154 | (4.25) |
| Raccoon | 48 | (0.68) | 18 | (0.50) |
| Black Bear | 41 | (0.58) | 21 | (0.58) |
| Ermine | 33 | (0.47) | 84 | (2.32) |
| Bobcat | 30 | (0.42) | 220 | (6.07) |
| American Marten | 6 | (0.08) | 112 | (3.09) |
| Porcupine | 5 | (0.07) | 47 | (1.30) |
| Otter | 4 | (0.06) | 3 | (0.08) |
| Canada Lynx | 1 | (0.01) | 0 | (0.00) |
| | 7060 | 100% | 3624 | 100% |

A simple visual analysis the distribution of TRs revealed variation in their distribution by species across the study area. Additionally, as summarized in table 5, the behavior of each species group at the roadside varied as a whole and between the sub areas. Based on the length of the roadway in each sub-area, no species group was distributed as expected among the sub-areas ($X^2 > 12.75$, $p = 0.001$, d.f. 2). Moose and WRP were recorded far less often then expected along Rt2W, while deer were recorded far more often. Deer crossed the road the majority of the time they approached it in all sub-areas, while moose crossed the road just over half the time they approached it along NH115 and Rt2E. WRP were also more likely to approach the road, but not cross, along Rt2E.

Table 5: Number of animals recorded at the roadside in each sub area, by species. Percent of animals recorded as crossing is given in parenthesis

| Species | Rt2E | NH115 | Rt2W |
|---|---|---|---|
| Moose | 249 (71%) | 1123 (56%) | 1212 (51%) |
| Deer | 796 (86%) | 207 (82%) | 153(69%) |
| WRP | 176 (74%) | 230 (78%) | 392 (63%) |
| Coyote | 154 (71%) | 171 (74%) | 326 (59%) |
| Fisher | 10 (90%) | 44 (86%) | 61(84%) |
| Bobcat | 12 (100%) | 15 (93%) | 5 (80%) |

The landscape scale variation in distribution along the roadside among the three species groups reflects their general habitat preferences. Moose prefer forested cover types with wetlands and softwoods. Deer prefer edges and are more likely to forage in open cover types, as compared to moose. Although coyotes are habitat generalists, bobcat and fisher are forest associated, and all three predators have an affinity of cover. The observed variations in crossing behavior support these patterns.

Along NH115 and Rt2E, which are surrounded by suitable habitat, both moose and coyotes are less likely to cross the roadway when they approach, as compared to Rt2W, which is more open and has a higher intensity of human use. This pattern suggests that the roadside offers resources to these species in certain settings. Local experts and residents concur that moose frequently use wet areas alongside the road, some of which were created as a result of the road's construction. Roadways are also known to provide resources for generalist predators, including road kill, small mammals associated with mowed shoulders, and trash (Spellerberg 1988, Hordequin 2000).

### Variables Associated with Crossing at the Local Scale

*Moose Associated Variables*

For this analysis, the study area was divided into 52 sections, and moose were recorded at 49 of them. The maximum number crossing at one section was 235, and the mean was 36.4 (s.d. = 52.6). After log transformation to achieve normalcy there were 45 non-zero cases with max = 2.37 and mean = 1.20 (s.d. = 0.63). The independent variables I considered in the multiple regression model for moose are listed in Table 6. Although my goal was to include at least one variable from each category, the correlations to the topography variables were so low, I did not include any of them. The most conservative model that explained a substantial amount of the variation in the dependent variable was:

MOOSElog = 0.398 + GREbin(0.567) + MIXED(0.044), r = 0.650

Both the presence/absence of guardrails ends and the amount of mixed forest cover in the local area around the road had a significant effect (p = 0.000, 0.001, respectively) on the crossing rates of moose. As the amount of mixed cover increased, the number of moose crossing increase, and moose crossing increased with the presences of guardrail ends.

Moose may prefer mixed cover as it provides both foraging and cover opportunities. Locations where guardrails end may show increased rates of crossing because they represent a change in roadside topography. Guardrails are typically situated along steep embankments that moose may avoid. These changes in topography may also coincide with small wetland areas that attract moose. Although wetland presence was not significantly correlated to the rate of moose crossing (table 6), it is important to note that the NLCD data used to quantify wetland cover is relatively coarse, and the small, roadside wetlands within the study area are therefore not well represented.

Table 6: Local-scale variables included for consideration in the multiple regression analysis. The r-value (continuous variables) is the single variable Pearson correlation with the dependent variable. The p-value (dichotomous variables) is for a two-sample t-test, comparing the mean of the dependent variable to locations where the variable is present to locations were it is not

| Moose | | Deer | | WRP | |
|---|---|---|---|---|---|
| OPENlog | r = -0.295 | OPENlog | r = 0.479 | ALLCONlog | r = 0.322 |
| MIXED | r = 0.427 | Decid | r = - 0.427 | VEGDI | r = 0.488 |
| VEGDI | r = 0.300 | SLODIlog | r = - 0.397 | SLODIlog | r = 0.209 |
| GREbin | p = 0.000 | MNPDbin | p = 0.237 | MXPDbin | p = 0.138 |
| MXPDbin | p = 0.010 | GREbin | p = 0.008 | GREbin | p = 0.602 |
| MNPDbin | p = 0.065 | | | | |
| MVCbin | p = 0.355 | | | | |

The crossing rate of moose was not significantly related to MVC locations. The MVC location data was not systematically collected. Instead, it is derived from roadkills reported to NH Fish and Game personnel from 1984 through 2004, by a variety of sources. These sources include conservation officers, other law enforcement personnel, highway maintenance workers, and the general public. Most of these MVC locations are reported relative to well-known landmarks (e.g., intersections, business, etc.), and lack the precision of the tracking data. Therefore, the lack of correlation between the two data sets is not surprising.

*Deer Associated Variables*

Deer were recorded as crossing at 51 of the 52 sections. The maximum number crossing at one section was 175, and the mean was 24.9 (s.d. = 52). After log transformation to achieve normalcy, there were 47 non-zero cases, with max = 2.34 and mean = 0.99 (s.d. = 0.61). The independent variables I considered in the multiple regression model for deer are listed in Table 6. Because my goal was to include at least one variable from each category, I included MNPDbin even though its p-value was non-significant. Conversely, I did not include GREbin despite its highly significant p-value, as it was an artifact related to landscape structure. Most deer were recorded along Rt2W, which provided their preferred habitats, and had very few guardrails. The most conservative model that explained a substantial amount of the variation in the dependent variable included only one independent variable:

DEERlog = -0.421 + 1.032OPENlog  r = 0.479

The rate of deer crossing the road is positively correlated with the presence of open cover types. Because the entire study area is predominately forested, the presence of open cover types is an indication of “edge” habitats, for which deer have a well-known affinity. However, it is difficult to interpret this local-scale correlation. More then twice as many deer crossed Rt2W, compared to both the other sub-areas added together, and Rt2W also had the highest proportion of open cover types. Therefore the correlation with crossing rate at the local scale may be driven by a landscape scale habitat preference. Studies that compared the landscape-scale characteristics of areas with many deer/vehicle collision locations to locations with few or none also report a strong correlation with edge habitats (Allen and McCullough 1976, Finder et al. 1999, Hubbard et al. 2000, Nielsen et al. 2003).

*WPR Associated Variables*

WRP were recorded as crossing at all sections. The maximum number crossing at one section was 61, and the mean was 14.9 (s.d. = 13.1). After log transformation to achieve normalcy, there were 49 non-zero cases, with max = 1.78 and mean = 0.98 (s.d. = 0.46). The independent variables I considered in the multiple regression model for WRP are listed in Table 6. Because my goal was to include at least one variable from each category, I included GREbin, even though the difference in the mean value of WRP was not significantly different for locations with GREs as compared to locations with out GREs. The most conservative model that explained a substantial amount of the variation in the dependent variable included only one independent variable:

WRPlog = 0.177 + VEGDI(0.252),   r = 0.488

The greater the VEGDI in the area surrounding the road, the more WRPs crossed at that location, and this variable was highly influential (p = 0.000). VEGDI at the study site was driven primarily by the presence of coniferous cover types, and secondarily by the presence of open and wetland cover types. In individual tests of correlation between WRP and the independent variables, the number of WRP crossing was highly correlated to coniferous cover types, and weakly correlated to open and wetland cover types, suggesting the positive association to conifers to VEGDI drives the association of WRP with VEGDI.

The next most influential variable was MXPDbin, the presence of the highest parcel density class in area surrounding the road. Although the influence of this variable was not significant (p = 0.232) when included in a model with only VEGDI, including it did improve the fit of the model slightly (r = 0.511) and had a reasonably large coefficient value (-0.142). Additionally, this variable was consistently marginally significant when included in fuller models. Crossing by WRPs was negatively correlated to the presence of the highest parcel density class, and this variable had the strongest relationship with rate of WRP crossing among the non-cover type variables considered.

## Summary

Tracking techniques can provide a wealth data related to the presence and behavior of wild animals along the roadside. This information in turn can provide an excellent resource for locating the crossing hotspots that may provide key habitat connectivity benefits. In my study area, the variables that were correlated to the crossing rates for moose and deer were different from each other, and also differed from the variable(s) correlate to WRP crossing rates. These results suggest that if highway and conservation planners wish to maintain or improve connectivity across highways for all suites of species, the needs of each group should be considered separately. However, the needs of multiple species can coincide. A visual analysis of the distribution of TRs across the study area does reveal many locations with substantial crossing by two species groups, and a few that are well used by all three. To maintain adequate habitat linkages across highways, planners should considering crossing areas that are suitable for single species as well as multiple species, to achieve true landscape-scale connectivity.

**Biographical Sketches:** Ms. Barnum holds a BS from the University of Vermont and an MS from Utah State University in Wildlife Biology. She received her Ph.D. from the University of Colorado at Denver in Conservation Planning, in 2003. Previous job experience includes working as an environmental planner for the Colorado Department of Transportation. Currently Ms. Barnum is the Vice President of Conservation at New Hampshire Audubon.

Kurt Rinehart and Mark Elbroch are the principles of Ichneumon Wildlife Services, an environmental consulting service that specializes in inventorying wildlife through tracking. Kurt is a wildlife biologist specializing in carnivore ecology and wildlife/biodiversity inventory and monitoring. Kurt has contributed to projects studying jaguars, cougars, wolves and fishers and is also the author of *The Naturalist's Guide to Observing Nature*, an ecological handbook for the field naturalist. Mark is the Senior Field Specialist, and has contributed to research projects of diverse mammals, from bears to cougars to mice, and has authored a number of award-winning books on wildlife tracking and other subjects. Mark has earned a *Senior Tracker Certificate* in Kruger National Park, South Africa and offers the only rigorous system in North America for certifying field tracking skills and observer reliability.

## References

Alexander, S. M., Waters, N. M., 2000. The effects of highway transportation corridors on wildlife: a case study of Banff National Park. Transport. Res. *C-Emerg. Technol*., 8, 307-320.

Barnum, S. A. 2003. Characteristics of Wildlife Highway-Crossing Zones and Applying this Information to Reduce Wildlife/Highway Conflicts. Ph. D. Dissertation, University of Colorado at Denver, Design and Planning.

Bashore, T. L., Tzilkowski, W. M., Bellis, E. D., 1985. Analysis of deer-vehicle collision sites in Pennsylvania. *J. Wildl. Manage*., 49, 769-774.

Finder, R. A., Roseberry, J. L., Woolf, A., 1999. Site and landscape conditions at white-tailed deer vehicle collision locations in Illinois. *Landsc. Urban Plann*., 44, 77-85.

Hordequin, M., 2000. Introduction to special section: Ecological effects of roads. *Conserv. Biol*. 14, 16-17.

Hubbard, M. W., Danielson, B. J., Schmitz, R. A., 2000. Factors influencing the location of deer-vehicle accidents in Iowa. *J. Wildl. Manage*., 64, 707-713.

Romin, L. A., Bissonette, J. A., 1996. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle Resevior, Utah. Great Basin Nat. 56, 1-12.

Ruediger, B., 1998. Rare carnivore and highways – moving into the 21st century. In: Evink, G. L., Garret, P., Zeigler, D., and Berry, J., (Editors), *Proceedings of the International Conference on Wildlife Ecology and Transportation*. FL-ER-69-68, Florida Department of Transportation, Tallahassee, FL, pp. 10-16.

Singleton, P. H., Lehmkuhl, J. F., 2000. I-90 Snoqualmie Pass wildlife habitat linkage assessment. Final Report, USDA Forestry Sciences Lab Cooperative Agreement PNW-98-0513-CC. 97 pp.

Spellerberg, I. F., 1998. Ecological effects of roads and traffic: a literature review. *Global Ecol. Biogeog*. 7, 317-333.

# Surveying and Modeling Road Kill

**Shyh-Chyang Lin** (0919786750, sclin1116@yahoo.com), Department of Construction Engineering, National Kinmen Institute of Technology, 1 University Road, Jining, Kinmen, Fax: 886-82-313394 Taiwan

## Abstract

Transportation is the backbone of developing regional economies and the evolution of our civilization. Well planned road systems are essential to connect dispersed communities or cities. However, roads are one of the major destructive forces to regional ecosystems and the natural environment. The effects of roads on their adjacent ecosystems may include road kills, habitat fragmentation, barrier effect to animal movement, road edge effects, introduction of exotic species, pollution and noise, change of micro-climate, etc. This study undertakes a comprehensive survey of road kills in Kinmen (Taiwan) and analyzes their causes. The road crossing behaviors of animals have been utilized in deriving survival probability by employing Traffic Flow Theory. Two models, Traffic Flow Model and Linear Model, have been proposed in this study and comparisons of survey results and the models are also carried out. Comparing the survey results and predictions of models, both models yield similar results for moderate traffic flow and provide excellent agreement in predicting frequency of road kill of birds and small mammals. It is found that traffic volume, adjacent landscape and road condition are the major factors in road kills. Higher traffic volume near animals' habitats always augments the probability of road kill, however roadside trees, adjacent landscapes, and road longitudinal slope may also affect the probability of successful crossing by small animals, especially birds. The barrier effect of roadside trees forces birds to fly between tree trunks and enter onto a collision course with oncoming vehicles, so that dense roadside trees may lead to higher bird casualties. On the other hand, roads with abrupt turns or steep longitudinal slopes may block the view of small animals and may be a significant factor in increasing the probability of being run over by vehicles. Based upon the findings of this study, some mitigation measures to lower road kill probability are proposed and the recommendations based upon this research could be applied in future road planning and design.

## References

AASHTO, 2001. American Association of State Highway and Transportation Officials. p. 56.

Adams, L.W. and A. D.Geis,1983. Effects of Roads on small mammals. *J. App. Ecol.* 20, 403-415.

Bevanger, K. and H. Brøseth, 2004. Impact of power lines on bird mortality in a subalpine area. *Animal Biodiversity and Conservation*. 27. (2). 67-77.

Blumstein, D. T., L. L. Anthony, R. Harcourt and G.. Ross, 2003. Testing a key assumption of wildlife buffer zones: is flight initiation distance a species-specific trait? *Biol. Conser.* 110, 97-100.

Clevenger, A. P., R. Chruszcz and K. E. Gunson, 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. *Biol. Conser.* 109, 15-26.

Dhindsa, M. S., J. S. Sandhu, P. S. Sandhu and H. S. Toor, 1988. Roadside birds in Punjah (India): Relation to Mortality from Vehicles. *Envir. Conser.* 15, (4) 303-310.

Erritzoe, J. 2002. Bird Traffic casualties and road quality for breeding birds. http://www.birdresearch.dk/unilang/traffic/trafik.htm#methods (viewed in 2006).

Fahrig L., J. H. Pedlar, S. E. Pope, P. D. Taylor and J. F. Wegner, 1995. Effect of Road Traffic on Amphibian Density. *Biol. Conser.* 7, 177-182.

Foppen, R. and R. Reijnen, 1994. The effect of car traffic on breeding bird populations in woodland. II. Breeding dispersal of male willow warblers (Phylloscopus trochilus) in relation to the proximity of a highway. *J. Appl. Ecol.* 31, 95-101.

Forman, R.T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine and T. C. Winter, 2003. *Road Ecology, Science and Solutions*. Island Press, Washington.

Fremlin, J., 1985. Why do birds collide with cars? *New Scientist*. 4, 60-61.

Gillespie, G. R., 2002. Impacts of sediment Roads, tadpole density, and food type on the growth and development of tadpoles at the spotted tree frog Litorra spen ceri: an in-stream experiment. *Biol. Conser.* 106, 145-150.

Gunther, K. A., M. J. Biel and H. L. Robison, 1998. Factors influencing the frequency of road-killed wildlife in Yellowstone National Park. *Proceedings of the International Conference on Wildlife Ecology and Transportation*, February 10-12, Fort Myer, Florid, (Ed) Gary L. Evink, Paul A. Garrett, David Zeigler, and Hon Berry. pp.32-36

Hels, T. and E. Buchwald, 2001. The effect of road kills on amphibian populations. *Biol. Conser.* 99, 331-340.

Jaarsuma, C. F. and G..P.A.Willems, 2002. Reducing habitat fragmentation by minor rural roads through traffic calming. *Landscape and Urban Planning*. 58, 125-135.

Kinmen Daily News. 2006. Female Soldier Hit Sidewall for Avoiding a Small Animal. April, 15.

Lee, L., 2006. Private communication.

Lin, S. C., 2006a. The ecologically ideal road density for small islands: The case of Kinmen. *Ecol. Eng.* 27, 84-92.

Lin, S. C., 2006b. A review for the types of wildlife passages. *Journal of National Park*, 16, (1):83-98 (In Chinese).

Marsh, D. M., G. S. Milam, N. P. Gorham and N. G. Beckman, 2004. Forest roads as partial barriers to terrestrial salamander movement. *Conser. Biol.* 19, (6) 2004-2008.

Matson, T. M., W. S. Smith and F. W. Hurd, 1971. *Traffic Engineering*. McGraw-Hill, New York.

May, A. D., 1990. Traffic Flow Fundamentals. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Mech L. D., 1989. Wolf population survival in an area of high road density. *Amer. Midland Naturalist*. 121, 387-389.

Mech D., S. H. Fritts, G. L. Radde and W. J. Paul, 1988. Wolf distribution and road density in Minnesota. *Wildlife Society Bull*., 16, 85-87.

Nankinov, D. N. and N. M. Todorov, 1983. Bird casualties on highway. *Soviet Journal of Ecology*. 42, 594-596.

Ohtaishi N., M. Ibe and Y. Masuda, 1998. Mitigation Measures for Wildlife Traffic Accidents. Hokkaido University Press, Japan (In Japanese).

Reijnen, R. and R. Foppen, 1994. The effects of car traffic on breeding bird populations in woodland. I. Evidence of reduced habitat quality for willow warbler (Phylloscopus trochilus) breeding close to a highway. *J. Appl. Ecol*. 31, 85-94.

Reijnen, R., R. Foppen, C. ter Braak and J. Thissen, 1995. The effects of car traffic on breeding bird populations in woodland III, Reduction of density in relation to the proximity of main roads. *J. Appl. Ecol.* 32, 187-202.

Ramp D., V. K. Wilson and D. B. Crof, 2006. Assessing the impacts of roads in peri-urban reserves: Road-based fatalities and road usage by wildlife in the Royal National Park, New South Wales, Australia. *Biol. Conser.* 129, 348-359.

Seiler, A., 2001. Ecological Effects of Roads, A review. Grimso Wild life Research Station, Dept. of Conservation Biology, University of Agriculture Sciences, s-730 91 Riddarhyttan, Sweden.

Slater, P., 1994. Wildlife road casualties. *British Wildlife*. 5, 214-221.

St, Clair, C. C., 2002. Comparative permeability of roads, rivers, and meadows to songbirds in Banff National Park. *Conser. Biol.* 17, (4) 1151-1160.

Thiel, R. P., 1985. The relationship between road densities and wolf habitat suitability in Wisconsin. *American Midland Naturalist.* 113, 404-407.

Tyne, J. V. and A. J. Berger, 1959. Fundamentals of Ornithology. John Wiley and Sons, Inc., New York.

van Dyke, F. B., R. H. Brocke, H. G. Shaw, B. B. Ackerman, T. P. Hemker and J. S. Lindzey, 1986. Reactions of Mountain Lions to Logging and Human Activity. *J. Wildl. Manage.* 50, 95-102.

van Langevelde, F. and C. F. Jaarsma, 2004. Using traffic flow theory to model traffic mortality in mammals. *Landscape Ecol*. 19, 895-907.

Vos, C.C. and J. P. Chardon, 1998. Effects of habitat fragmentation and road density on the distribution pattern of the moor frog Rana arvalis. *J. Appl. Ecol.* 35, 44-56.

Wallman, J. and J-C. Letelier, 1993. Eye movements, head movements, and gaze stability in bird. Vision, Brain, and Behavior in Birds, edited by H. P. Zeigler and H-J, Bischof, The MIT Press, Cambridge, Massachusetts, USA.

Wilson, E. O., 1989. Threats to biodiversity. *Scientific American*, 261, (3) 108-116.

# Use of Existing Mitigation Measures by Amphibians, Reptiles, and Small to Medium-Size Mammals in Hungary: Crossing Structures Can Function As Multiple Species-Oriented Measures

**Miklós Puky, Ph.D.** (00-36-27-345023, h7949puk@ella.hu), Senior Research Fellow, Hungarian Danube Research Station, Institute of Ecology and Botany, Hungarian Academy of Sciences, 2131 Göd, Jávorka S. u. 14 Hungary

**János Farkas** (36-1-2090550, farkasj@elte.hu), Department of Systematic Zoology and Ecology, Eötvös Loránd University, 1113 Budapest Pázmány P. sétány 1/C. Hungary

**Mária Tóth Ronkay** (36-1-2090550, musti2@freemail.hu), Department of Systematic Zoology and Ecology, Eötvös Loránd University, 1113 Budapest Pázmány P. sétány 1/C. Hungary

**Abstract:** The effects of roads and railways on animals such as direct mortality caused by these infrastructure elements were recognised as early as the end of the nineteenth century. In the first half of the twentieth century further evidence gathered related to different vertebrate groups. Besides the increasing amount of information available on the environmental impact of roads and railways in the second half of the twentieth century, crossing structures, game bridges, amphibian tunnels and game passages were built as mitigation measures to provide corridors over or under roads and railways, especially in Europe. In most cases, however, they were aimed to help one animal group or species. With the development of an ecosystem-level approach, however, the investigation of the possible involvement of these constructions in helping non-target groups also started together with building green bridges. A further recognition of the special needs of certain species also led to the development of new structural elements, for example tunnels built within green bridges to help burrowing animals to cross.

Mitigation measures representing all animal crossing structures in Hungary were selected to study their use by amphibians, reptiles and small to medium-sized mammals. They included a toad tunnel system with eight tunnels and approximately five-hundred meter concrete fences along road 8518. and six tunnels under the bicycle road running along the same road stretch at Lake Fert?, one wet and two dry passages of one meter in diameter under the M1 motorway with 60 centimetre high concrete fences and two twelve meter wide game bridges with game fences over the same motorway. All sites are located in the same, Arrabonicum fauna district in the western part of Hungary. Due to differences in the studied animal groups a complex sampling methodology was applied. Besides site visits during the day to find the shed skins of reptiles, footprints of mammals on sand beds or their droppings in the passages, the mitigation measure use of amphibians was also investigated in night visits especially during the breeding season while mammals were also caught by baited traps and hair traps were also used. To check the efficiency of the toad tunnel system the frequency of amphibian road kills were also studied.

Amphibians were found both in the tunnel system and the wet passage under the road, but their presence was not proved either in the dry passages or on the game bridges. The tunnel system worked very efficiently, i.e. it lowered road kills by at least 90%, which can even be improved by maintenance. As a consequence, more amphibians died on the bicycle road and a side road nearby than on the main road. The mitigation measure use of reptiles was proved at all investigated sites even if none of the constructions were planned to provide corridors for that animal group. Grass snakes were found in toad tunnels and passages, sand lizards on game bridges. An important difference between them was that snakes moved through the tunnels while lizards lived on them and used game bridges as a habitat. Small mammals used all investigated measures, vole and mice species were trapped in all of them. What is more, they used tunnels as part of their habitats. Besides, shrews were present in toad tunnels as well the presence of foxes and martens was also indicated. However, their road kill was low in the section studied.

During the study period eight species of amphibians as well as mammals and two reptiles were proved to utilise the investigated crossing structures. Besides providing corridors, large constructions, such as game bridges also function as habitats e.g. for lizards. The use of large, mammal-oriented mitigation measures by amphibians and reptiles is needed to study further as well as efforts should be made to construct more passages or alter existing structures in the future to lower habitat fragmentation along transportation infrastructure.

## Introduction

The effects of roads and railways on animals, such as direct mortality caused by these infrastructure elements, were recognised as early as the end of the nineteenth century (Barbour 1895). In the first half of the twentieth century further evidence gathered related to different vertebrate groups (as an example, see Savage 1935). Different impacts of transport infrastructure have been proven to exist in all continents (for less studied regions, see, for example, Fischer et al. 2004 for South America, Sing and Sharma 2001 for India) and for all terrestrial vertebrate classes. There was a continuous increase of information on the environmental impact of roads and railways in the second half of the twentieth century, e.g., on the negative correlation of road density and the amphibian abundance (DeMaynadier and Hunter 2000; Houlahan and Findlay 2003), especially with more vagile species (Carr and Fahrig 2001) as well as genetic isolation (Vos et al. 2001), road crossing differences between U.S. snake species (Andrews and Gibbons 2006) and the limitation of small mammal movement by roads and heavy traffic (Oxley et al. 1974, Richardson et al. 1997, Wilkins 1982). An important tool to lessen the effects of already existing roads was vertebrate road mortality analyses, which were conducted in different parts of the northern hemisphere to select road mortality hotspots (Ascen?ao and Mira 2006). Recommendations were also made to take these effects into consideration even in landscape level planning (Mazerolle 2004). As a result of all these findings and citizen movements to save amphibians as well as safety issues, crossing structures, game bridges, amphibian tunnels and game passages were built as mitigation measures to provide corridors over or under roads and railways, especially in Europe and North America. Later, a further recognition of the special needs of certain species also led to the development of new structural elements, for example, tunnels built within green bridges to help burrowing animals to cross. In most cases, mitigation measures were aimed to help one animal group or species. With the development of an ecosystem-level approach, however, the investigation of the possible involvement of these constructions in helping non-target groups also started together with building green bridges.

### Aim of study

The building of mitigation measures becomes more frequent along Central-European roads after the millenium, especially on motorways (for an overview on amphibian tunnel systems in the region, see Puky 2003). However, their monitoring and improvement are often missing. Consequently, little is known about their effectiveness and even less information is available on what non-target species use these constructions. To improve our knowledge, different types of mitigation measures were selected in the northwestern part of Hungary to gather information on their use by target as well as by non-target species. The aim of this paper is to summarise the characteristics of amphibian, reptile, and small to medium-size mammal use of the studied mitigation measures, describe their possible ecological functions for the different groups and make suggestions to help the crossing of a wider range of animals through these constructions.

## Sites and Methods

### Sampling sites and dates

Sampling sites were selected according to a number of factors. Mitigation measures in good condition (e.g., with no missing fences) surrounded by semi-natural vegetation and different habitats suitable for all three investigated taxa were favoured. Roads with high traffic volume were chosen, three of the four sites (two game bridges and one culvert system) are situated along the M1 motorway, and the fourth site is situated along road 8518, which is a busy local road. All sites are located in the same Arrabonicum fauna district in the western part of Hungary.

The 136.805-835 km passage system of the M1 motorway (see photo 1) consists of three 34-m passages with a diameter of 1 m each. They are connected by 60-cm-high concrete fences and extending to an additional 50-m stretch from the passage on the side in both directions. Light shafts in the middle of the passages help more natural light and moisture conditions to develop. There is a forest patch on the left side of the road at the mitigation measure, and a stream flows through the central passage forming a standing water area before entering it on the left side. The right side of the road is for agricultural use (see figure 1).

Photo 1. M1 Motorway

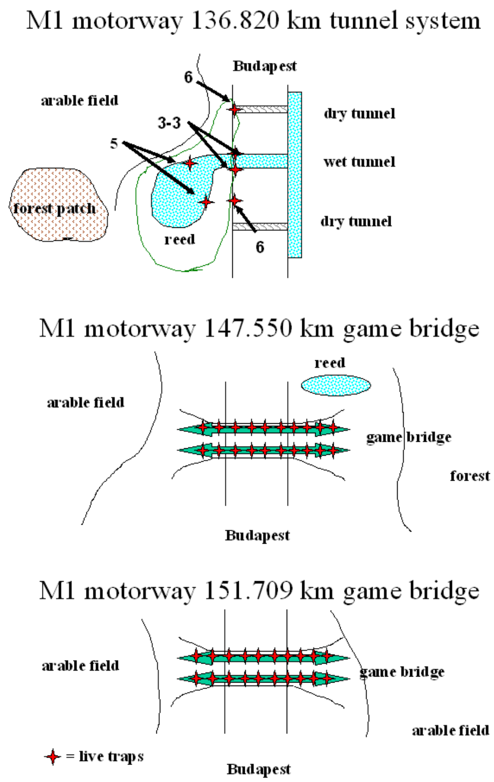



Figure 1. M1 Motorway.

The 147.514-km game bridge of the M1 motorway (see photo 2) has a width of 12 m. There is a forest patch on its right side together with a temporary water body. On the left side there are agricultural fields and extensive water bodies of the Hanság area. There is game fence to lead roe deer and other game species onto the game bridge, which has planted bushes along its edges (see figure 1).

Photo 2. 147.514-km Game Bridge of the M1 Motorway.

The 151.709-km game bridge of the M1 motorway (see photo 3) has a width of 12 m. Its vegation is similar to that of the other game bridge, but it is surrounded by arable fields on both sides. On the left side there is a dirt road and a deep ditch running along the motorway. A game fence leads roe deer and other game species onto the game bridge (see figure 1).

Photo 3. 151.709-km Game Bridge of the M1 Motorway

The fourth sampling site has been the focus of amphibian road mortality mitigation in Hungary for nearly two decades. Amphibian patrol by volunteers was gradually replaced by temporary and then by permanent mitigation measures (Kárpáti 1988, Frank et al. 1991). There is a sophisticated amphibian tunnel system between 16.870 and 17.256 km of the 8518 road at Fert?boz consisting of eight 8- to 9-m long tunnels of 0.59-0.88 m in diameter (square shape tunnels also exist) under the main road and an additional six tunnels with 33-57 cm diameter under the adjacent bicycle road (see photo 4). Five of the eight tunnels under the road have light shafts. An approximately 500-m concrete fence of a 50-cm height connects the tunnels along both sides of the road and the left side of the bicycle road. There is a forest on the left side of the road, while a mosaic of different habitats including reed can be found to the right of the bicycle road, towards Lake Fert? (see figure 2).

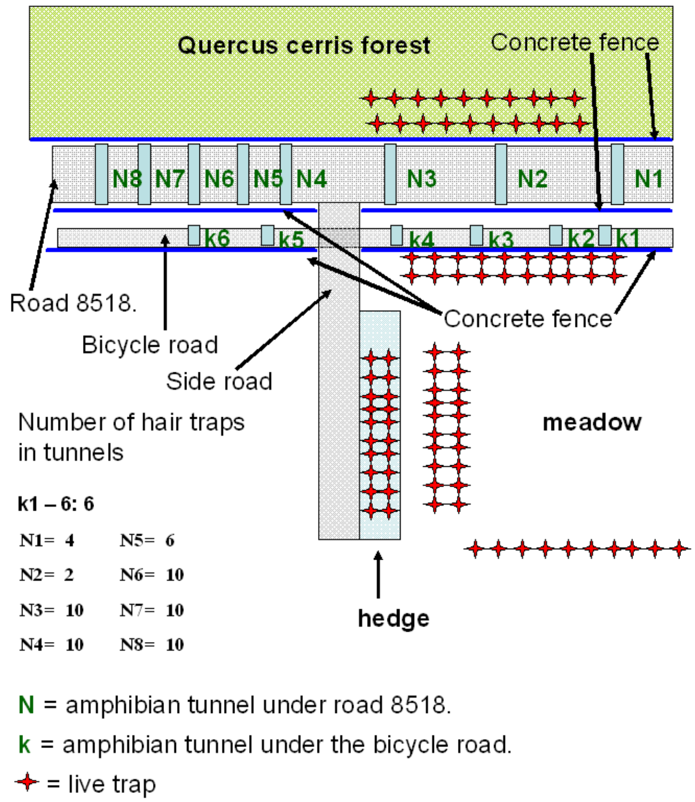



Figure 2. Sampling was carried out between 31 January 2004 and 19 October 2004.

Photo 4. Sophisticated amphibian tunnel system.

## Methods

Due to differences in the studied animal groups, a complex sampling methodology was applied. Besides conducting site visits during the day to find the shed skins of reptiles, footprints of mammals on sand beds, or their droppings in the passages, site visits at night were also conducted to determine the mitigation measure use of amphibians, especially during the breeding season. Amphibian-specific methods (audial surveys, netting, road transects at night, torching, visual encounter surveys) were discussed in previous papers presented at ICOET in 2003 (Puky 2003). As with routinely used other methods applied for all groups (road kill investigation, track registration), they are not discussed here in detail. Reptiles were also detected by the visual encounter surveys of the mitigation measures and, as a by-product of a new sampling method, hair trapping.

Routine wildlife monitoring usually includes several sampling methods, such as infrared photography and track plots (see Austin and Garland 2001). Besides the general methods, in this study mammals were also detected by live trapping using the capture-mark-recapture method at each site. Depending on the habitat type they were arranged in a line transect or a quadrat. The traps were baited with a piece of toast spiced with onion. Seeds of sunflower and corn were put into the trap to reduce the mortality (see photo 5). Animals were marked by tattooing or by cutting fingers. Several parameters, for example, length of the body, legs and tail, weight, state of sex, etc., were also recorded.

Photo 5. Seeds of sunflower and corn were put into the trap to reduce the mortality.

Hair samples were also collected along the 8518 road, as they convey a large amount of information. They carry several qualitative and quantitative macroscopic and microscopic characters of the cuticular and medullar patters that enable taxonomic identification even in the absence of any other attributes (see photos 6 and 7).

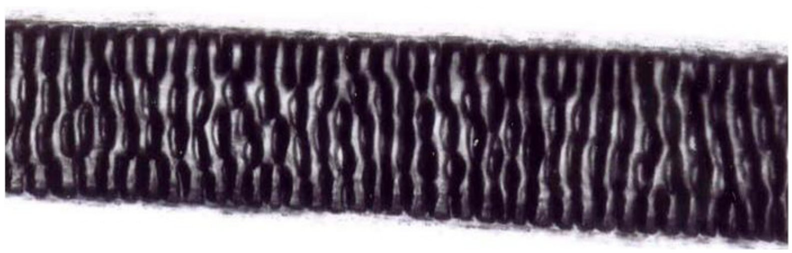


Photo 6. Hair sample collected along the 8518 road.

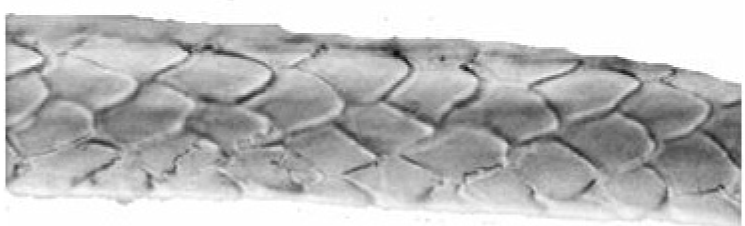


Photo 7. Hair sample collected along the 8518 road.

The basic idea of this method was to beguile the small mammals using some bait into a plastic (or metal) tube that has a sticky surface on its backside (Suckling 1978, Dickman 1986). The visitors of the traps leave their informative dorsal hair on that surface without any disturbance or downer. The principle of applying hair traps remained the same, but the technical parameters and the type of the bait became more diverse, harmonizing with the size and life history of the target animals. In the current project, 101 plastic bottles were used as hair traps in the amphibian tunnels running under road 8518 and the parallel bicycle path. Seeds, bacon, and fruit were used as baits. The 55-m diameter of these plastic bottles seemed to be effective to detect small mammals there. Mammals entering could not pass through them; they appear as blind alleys. This trap provides more hair samples than PVC tubes open at both ends because the animals have to cross it twice, go in, and back out. According to previous studies the visiting rate of hair traps is about 10 percent (Tóth 2002). As suggested by the specific literature, the effectiveness of this method was improved by applying it together with the live-trappings (Lindenmayer et al. 1999).

Table 1 summarizes what methods were used at the individual sites.

| | 136.805-835 km M1 culvert system | 147.514 km M1 game bridge | 151.709 km M1 game bridge | 8518. road amphibian tunnel system |
|---|---|---|---|---|
| **General methods** | | | | |
| Track etc. registration | X | X | X | |
| Road kill investigation | (X) | (X) | (X) | X |
| **Methods to detect amphibians** | | | | |
| audial surveys | X | X | X | X |
| Netting | X | X | | X |
| Road transects at night | | | | X |
| Torching | X | X | X | X |
| Visual encounter surveys* | X | X | X | X |
| **Methods to detect mammals** | | | | |
| Live trapping | X | X | X | X |
| Hair trapping* | | | | X |

() limited application due to safety reasons.

* Reptiles were also detected by this method.

## Results and Discussion

### Amphibians

Table 2 shows the presence of amphibian species at the mitigation measures. At the 136.805-835 km culvert system of the M1 motorway five taxa were found; two of them stayed in the central culvert, through which a stream flows. The others could also possibly use this route to move to the other side of the motorway. This is of great importance because due to its heavy traffic load the motorway is a complete barrier for the investigated species. This is also true for the game bridge sections, where no other possible corridor is available for amphibians. In spite of this, however, no amphibian was found on those mitigation measures, although altogether six taxa were detected around them. In earlier years amphibians migrated across the 8518 road by the hundreds of thousands due to historical, geographical, and ecological reasons (Tunner and Kárpáti 1997). Due to the lowering of the water level of Lake Fert? it was less intensive in the middle of the 2000s (pers. comm. of dr. László Kárpáti, head of the Fert?-Hanság National Park Directorate) Still, some migration occurred, and the amphibian tunnel system protected effectively most of the individuals reaching the road at the concrete fences. In comparison with neighbouring road stretches, the number of road-killed amphibians was 30-120 times lower along the mitigation measure, and during the autumn migration there were more dead green frogs on the side road and even on the bicycle road (see figure 2) than the main road itself.

### Reptiles

Table 2 shows the presence of reptile species at the mitigation measures. Grass snakes were caught or seen in both underpass systems. Their presence was proved during visual encounter surveys as well as, unexpectedly, by hair trapping as either the shed skin or juveniles were found sticked to the glued surface of the bottle traps (see photo 8). Sand lizards were observed to live on both game bridges of the M1 motorway, and similarly to other roads, such as the M3 motorway, where sand lizards live around the stone heads of amphibian tunnels, no road avoidance was recorded for this species. As observations of snakes and lizards on mitigation measures are relatively rare (for an exception, see Teufert et al. 2004) and incidental (see, e.g., Zuiderwijk 1989), these are important new findings for the area and for these types of mitigation measures as well.

Table 2: Presence of Reptile Species at the Mitigation Measures

| | 136.805-835 km M1 culvert system | 147.514 km M1 game bridge | 151.709 km M1 game bridge | 8518. road amphibian tunnel system |
|---|---|---|---|---|
| **Amphibians** | | | | |
| Smooth newt *Triturus vulgaris* | X | X | | X |
| Danubian crested newt *Triturus dobrogicus* | | X | | |
| Fire-bellied toad *Bombina bombina* | X | X | X | |
| Common toad *Bufo bufo* | | X | | X |
| European treefrog *Hyla arborea* | X | X | X | X |
| Agile frog *Rana dalmatina* | X | | | X |
| Green frogs *Rana esculenta* c. | X | X | X | X |
| **Reptiles** | | | | |
| Sand lizard *Lacerta agilis* | | X | | |
| Grass snake *Natrix natrix* | X | | | X |

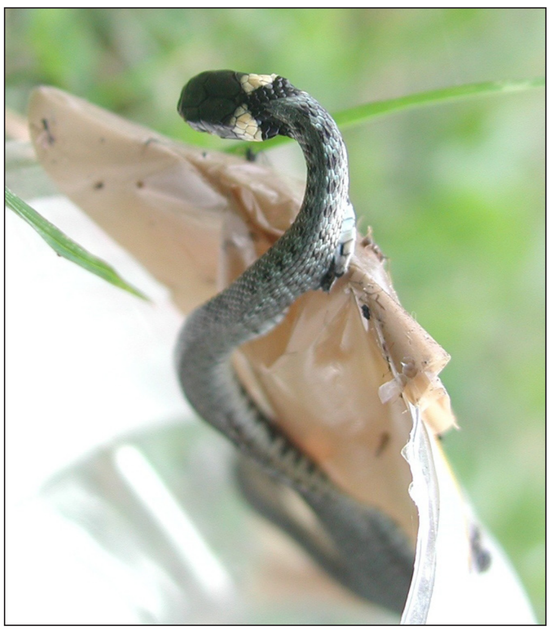


Photo 8.

## Mammals

Table 3 shows the presence of small mammals at the mitigation measures. Besides the taxa caught, several other species might exist at the investigated sites; however, their density was too low to detect them.

The two game bridges and the passage system along the M1 motorway had the same fauna composition, altogether five species were detected in the sampling sites, suggesting a similar dominance structure in the small mammal fauna along the investigated stretch of the motorway. Three of these taxa were actually caught in/on the mitigation measures. Only the relative frequency of the two vole and one mouse species differed between those sites (see figure 3). Besides the species caught by trapping, several others, such as deer, were also detected, mainly by their footprints. The most surprising finding was the footprints of a roe deer calf walking into the wet passage.

Table 3: Presence of Small Mammals at the Mitigation Measures

| | 136.805-835 km M1 culvert system | 147.514 km M1 game bridge | 151.709 km M1 game bridge | 8518. road amphibian tunnel system |
|---|---|---|---|---|
| Striped field mouse *Apodemus agrarius* | | | | X |
| Yellow-necked mouse *Apodemus flavicollis* | X | X | X | X |
| Wood mouse *Apodemus sylvaticus* | X | X | X | X |
| Harvest mouse *Micromys minutus* | | | | X |
| Bank vole *Clethrionomys glareolus* | X | X | X | X |
| Field vole *Arvicola terrestris* | X | X | X | X |
| Common vole *Microtus arvalis* | X | X | X | X |
| Water shrew *Neomys fodiens* | | | | X |
| Common shrew *Sorex araneus* | | | | X |
| Bi-coloured white-toothed shrew *Crocidura leucodon* | | | | X |

Altogether, 10 small mammal species were trapped in the patchy habitats around the amphibian tunnel system on the 8518 road (see figure 3). The greatest species number was found in a reed stand at the edge of the meadow, while the lowest was recorded in the open meadow, where the individual number of the animals was also the lowest (see figure 4). Similar to other studies investigating the use of drainage culverts and other underpasses under roads or railway lines (e.g. Clevenger et al. 2001, Ng et al. 2004, Rodriguez et al. 1996), small mammals were proven to be present in the tunnels. The same species were detected in both tunnel types, and more individuals were caught in the smaller tunnels under the bicycle road than in the larger ones under the main road. While the species composition of the different microhabitats characteristically differed, traps in road verges on both sides caught more animals than those in the parallel rows 10 m further in the appropriate habitats (meadow on the right, Quercus forest on the left side), indicating edge effects. As such, no road avoidance was recorded for these species. Other sampling methods, e.g., road kill surveys, resulted in a number of mammalian fauna casualties; red squirrel (Sciurus vulgaris) and red fox (Vulpes vulpes) were among them together with a low number of small mammals. Some of them were found on the bicycle road (see figure 2).

**Mitigation measure improvement**

As a result of the survey of amphibians, reptiles, and small mammal use of the 136.805-835 km passage system, and the two game bridges of the M1 motorway, and the amphibian tunnel system of the 8518 road, the following recommendations have been developed:

1. The high traffic volume of the M1 motorway creates a complete barrier for the taxa studied. As a consequence, the investigated mitigation measures are important crossing opportunities. The step-like entrance of the dry passages in the 136.805-835 km passage system should be improved to provide a better access for amphibians (and small mammals).
2. The 147.514-km game bridge should be developed to provide a corridor for amphibians living in wetlands nearby by setting up amphibian fences.
3. Maintenance (cleaning of tunnels, removal of branches) and, if possible, closing gaps in fences should be applied at the amphibian tunnel system along the 8518 road.

**Ecological functions of the studied mitigation measures**

The construction of mitigation measures to help animals crossing roads usually has the function of creating corridors for target species. However, the present study proved the use of these constructions other than for migration by altogether two amphibian, two reptile and four small mammal species. Amphibians usually migrate through tunnels and passages, and do not spend much time of them. However, two semi-aquatic taxa of amphibians—fire-bellied toads and green frogs—were detected to use the wet passage from the 136.805-835-km passage system of the M1 motorway as parts of their habitats. It might be more common than originally thought as similar to these results, Danube crested newt, *Triturus dobrogicus*, larvae were found in a similar culvert (M. Puky unpublished data) during another road-related survey along the route of a planned ring-road around Budapest (Puky and Kecskés 1992). In the 136.820-km wet passage, a grass snake was also found most probably hunting for amphibians as they are an important food source for this reptile species. As far as the other reptile findings are concerned, snakes caught in tunnels were in their migration period, but sand lizards also lived on game bridges and used them for hiding places, basking, and feeding grounds. Small mammals were also recorded to use amphibian tunnels for different functions, and they always ran into them after they were released from the traps, although they had other escape routes, indicating they utilised the tunnels as hiding places. Five vole burrows also started in the leaf litter and earth cover of larger amphibian tunnels under the 8718 road. This was also inevitable on game bridges, where several burrows were found, besides animals were also trapped on them.

**Acknowledgements:** This study was financially supported by the Hungarian Technical and Information Services on National Roads (contract number: 3810.4.1./2002, consultant: Ildikó Varga and József Zsidákovics.). We thank Hana Chobotská (Czech Republic), Katalin Csabai, Norbert Erdei, Júlia Kertész, Veronika Kiss, Marcus Moonen (Netherlands), Zsuzsanna Puky Kacsóh, dr. László Ronkay and dr. Cristina Sandu (Romania) for their help in collecting data in the field.

**Biographical Sketches:** Dr. Miklós Puky is a senior research fellow at the Hungarian Danube Research Station of the Institute of Ecology and Botany of the Hungarian Academy of Sciences, and the chair of the IUCN SSC Declining Amphibian Populations Task Force Hungary. Most of his work is dedicated to different conservation and environmental education programmes, and he also teaches conservation ecology at the University Eötvös, Budapest. Miklós started amphibian road kill research and conservation in 1986, which was a first attempt in the Central-European region. For organising and leading international programmes, he was presented several conservation and education awards, such as Pro Natura, For the Environment, the Henry Ford European Conservation Award, and he was also a winner of the Ten Outstanding Young People competition.

Dr. János Farkas is an assistant professor at the Department of Systematic Zoology and Ecology of the Eötvös Loránd University. He is the leader of the Mammal Research Group there and the vice president of the Zoology Section of Hungarian Biology Society. His main research fields are the population dynamics and habitat preferences of small mammals, effects of fragmentation, effects of roads and traffic, investigation of strictly protected mammals by morphometric, bioacustic and genetic methods, investigation of the relationships between environmental conditions, behavior and genetical background of small mammals.

Dr. Mária Tóth is an assistant professor at the Department of Systematic Zoology and Ecology of the Eötvös Loránd University. Her main research interests are the taxonomy, biogeography, and conservation biology of carnivore mammals. Her specialty is the morphology of mammalian hair and the biogeographical and evolutionary analysis of fur pattern and colour. She applied and tested the hair snare and the "bird nest analysis" methods in the faunistical monitoring of protected mammals and led a program to monitor the urbanization process of the stone marten. She teaches zootaxonomy, zoogeography, urban wildlife management, and conservation biology.

## References

Andrews, K. M. and Gibbons, J. W. (2006): Dissimilarities in behavioral responses of snakes to roads and vehicles have implications for differential impacts across species. In: Irwin, L. C., Garrett, P. and McDermott, K. P. (eds): On the road to stewardship. *Proceedings of the 2005 International Conference on Ecology and Transportation*. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC. pp. 339-350.

Ascenŝao, F. and Mira, A. (2006): Spatial patterns of road kills: a case study in Southern Portugal. In: Irwin, L. C., Garrett, P. and McDermott, K. P. (eds): On the road to stewardship. *Proceedings of the 2005 International Conference on Ecology and Transportation*. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC. pp. 641-646.

Austin, J. M. and Garland, L. (2001): Evaluation of a wildlife underpass on Vermont State Highway 289 in Essex, Vermont. In: Irwin, L. C., Garrett, P. and McDermott, K. P. (eds): A time for action. *Proceedings of the 2005 International Conference on Ecology and Transportation*. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC. pp. 616-624.

Barbour, E. H. (1895): Bird fatality along Nebraska railroads. Auk. 12: 187.

Carr, L. W. and Fahrig, L. (2001): Effect of road traffic of two amphibian species of different vagility. *Conservation Biology*. 15(4): 1070-1078.

Clevenger, A. P., Chruszcz, B. and Gunson, K. (2001): Drainage culverts as habitat linkages and factors affecting passage by mammals. *Journal of Applied Ecology*. 38: 1340-1349.

DeMaynadier, P. G. and Hunter, M. L. Jr. (2000): Road effects on amphibian movements in a forested landscape. *Natural Areas Journal* 20:56-65.

Dickman, C. R. (1986): A method for censusing small mammals in urban habitats. *Journal of Zoology*. 210: 631-636.

Fischer, W. A., Ramos-Neto, M. B., Silveira, L. and Jacomo, A.T. (2004): Human transportation network as ecological barrier for wildlife on Brazilian Pantanal-Cerrado corridors. In: Irwin, L. C., Garrett, P. and McDermott, K. P. (eds): Making Connections. *Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment*, North Carolina State University, Raleigh, NC. pp. 182-194.

Frank, T., Pellinger, A. & Selyem, J. (1991): Kétéltő- (Amphibia) és hüll?- (Reptilia) védelem a Fertő-tó mentén (1987-1990) (Amphibian (Amphibia) and reptile (Reptilia) protection along Lake Fertő/Neusiedlersee (1987-1990). A Magyar Madártani és Természetvédelmi Egyesület III. Tudományos Ülése. MME, Szombathely. 330-337.

Houlahan, J. E. and Findlay, C. S. (2003): The effects of adjacent land use on wetland amphibian species richness and community composition. *Canadian Journal of Fisheries and Aquatic Sciences*. 60(9): 1078-1094.

Kárpáti, L. (1988): Massensterben der Herpetofauna (Amphibien und Reptilien) infolge des Kraftverkehrs. Möglichkeiten und Ergebnisse des Schutzes am Südurfer des Neusiedlersees (Mass mortality of the herpetofauna (Amphibians and reptiles) due to road kill. Conservation opportunities and tasks along the southern shore of Lake Fert?/Neusiedlersee). BFB Bericht. 68: 71-79.

Lindenmayer, D. B., Cunnigham, R. B. and Pope, M. L. (1999): A large scale "experiment" to examine the effects of landscape context and habitat fragmentation on mammals. *Biological Conservation*. 88: 387-403.

Mazerolle, M. J. (2004): Amphibian road mortality in response to nightly variations in traffic intensity. *Herpetologica*. 60(1): 45-53.

Ng, S. J., Dole, J. W., Sauvajot, R. M., Riley, S. P. D. and Valone, T. J. (2004): Use of highway undercrossings by wildlife in southern California. *Biological Conservation*. 115: 499–507.

Oxley, D. J., M. B. Fenton and G. R. Carmody. 1974. The effects of roads on populations of small mammals. *Journal of Applied Ecology* 11:51-59.

Puky, M. (2003): Amphibian mitigation measures in Central-Europe. In: Irwin, L. C., Garrett, P. and McDermott, K. P. (eds): Making Connections. *Proceedings of the International Conference on Ecology and Transportation*, The Center for Transportation and the Environment, Raleigh, North Carolina (24-29 August, 2003, Lake Placid, New York). pp. 413-429.

Puky, M. and Kecskés, F. (1992): Herpetological investigation along a planned road in and around Budapest - the M0 project. *Proceedings of the 6th Ordinary General Meeting of Societas Europaea Herpetologica*. pp. 367-370.

Richardson, J. H., R. F. Shore, and J. R. Treweek. 1997. Are major roads a barrier to small mammals? *Journal of Zoology* 243:840-846.

Rodriguez, A., Crema, G. and Delibes, M. (1996): Use of non-wildlife passages across a high speed railway by terrestrial vertebrates. *Journal of Applied Ecology*. 33: 1527-1540.

Savage, R. M. (1935): The infuence of external factors on the spawning date and migration of the common frog, Rana temporaria. *Proceedings of the Zoological Society of London*. 2: 49-98.

Singh, A. P. and Sharma, R. C. (2001): Conflicts between linear developments and Asian elephants in sub-Himalayan zone of Uttranchal. In: Irwin, L. C., Garrett, P. and McDermott, K. P. (eds): A time for action. *Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment*, North Carolina State University, Raleigh, NC. pp. 423-432.

Suckling, G. C. (1978): A hair sampling tube for the detection of small mammals in trees. Australian Wildlife Research. 5: 249-252.

Teufert, S., Cipriotti, M. and Felix, J. (2004): Die Bedeutung von Grünbrücken für Amphibien and Reptilien - Untersuchungen an der Autobahn 4 bei Bischofswerda/Oberlausitz (Sachsen). Zeitschrift für Feldherpetologie. 12(1): 101-109.

Tóth, M. A. (2002): A sz?rcsapdázás alkalmazásának lehet?ségei és korlátai (Opportunities and limits of using hair trapping). *Vadbiológia*. 9: 117-122.

Tunner, H. G. and Kárpáti, L. (1997): The Water Frogs (Rana esculenta complex) of the Neusiedlersee region (Austria, Hungary) (Anura: Ranidae). *Herpetozoa*. 10(3-4): 139-148.

Vos, C. C., Antonisse-De Jong, A. G., Goedhart, P. W. and Smulders, M. J. M. (2001): Genetic similarity as a measure for connectivity between fragmented 1populations of the moor frog (Rana arvalis). *Heredity*. 86: 598-608.

Wilkins, K. T. 1982. Highways as barriers to rodent dispersal. *Southwestern Naturalist* 27:459- 460.

Zuiderwijk, A. (1989): Amphibian and reptile tunnels in the Netherlands. In: Langton, T. E. S. (ed): *Amphibians and Roads*. ACO Polimer Products Ltd., London. 67-74.

# Utilizing a Multi-Technique, Multi-Taxa Approach to Monitoring Wildlife Passageways on the Bennington Bypass in Southern Vermont

**Mark A. Bellis** (413-519-7908, mbellis@forwild.umass.edu), Graduate Program in Natural Resources Conservation, University of Massachusetts, Amherst, MA 01003 USA

**Scott D. Jackson** (413-545-4358, sjackson@umext.umass.edu), Department of Natural Resources Conservation, University of Massachusetts, Amherst, MA 01003 USA

**Curtice R Griffin** (413-545-2640, cgriffin@forwild.umass.edu), Department of Natural Resources Conservation, University of Massachusetts, Amherst, MA 01003 USA

**Paige Warren** (413-545-0061, pswarren@forwild.umass.edu), Department of Natural Resources Conservation, University of Massachusetts, Amherst, MA 01003 USA

**Alan O. Thompson** (802-244-8131, aothompson@gmail.com), Northern Stewards, 224 Michigan Avenue, Waterbury, VT 05676 USA

**Abstract:** Roadways affect wildlife habitat disproportionate to the area of land they occupy while impacting wildlife directly through direct loss of habitat, road mortality and disruption of movement. Roadways indirectly impact wildlife by isolating populations and disrupting gene flow and metapopulation dynamics. A variety of strategies have been used with mixed success to mitigate the impacts of transportation systems on wildlife. Underpasses are commonly used to facilitate movement of wildlife across roadways in Europe, Australia, Canada and the U.S.

Through 2005, 460 terrestrial and 300 aquatic crossing structures have been identified throughout the United States but only a small portion of these crossings have monitoring incorporated into their project design. Most monitoring is limited to usage of the passage structures with little data collected on movement through the adjacent landscape. Monitoring of the passage structures helps determine wildlife use of the structures but is limited in the ability to determine landscape level impacts.

A variety of techniques are utilized in monitoring passageway effectiveness, primarily camera traps and track beds. Building on prior studies, the Bennington Bypass project takes a broad, multi – taxa approach to monitoring crossing structures on a newly constructed highway in southern Vermont. We are utilizing a variety of techniques to assess movements of an array of species at the passage structure and in the surrounding landscape.

Techniques utilized in our study include: small mammal trapping, track beds/plates, remote camera sensing, snowtracking, road kill surveys, roadside track beds, amphibian recording devices, snake pit tagging and observational studies. We are also using this broad approach to monitoring as an opportunity to test and refine many of the techniques used in the study. By monitoring a wide variety of animal movements rather than focusing exclusively on wildlife use of the passages, we expect to more accurately assess the effectiveness of the mitigation structures. We anticipate that the results from this work will assist in developing monitoring protocols for future studies in Vermont and throughout the United States.

## Introduction

As long linear features on the landscape, roads and highways (roadways) impact wildlife and wildlife habitats over areas that are disproportionate to the land they occupy. Roadways affect wildlife through direct loss and fragmentation of habitats, as a source of additive mortality for wildlife and by disrupting animal movements. Through isolation of wildlife populations, roadways can also disrupt gene flow and metapopulation dynamics (Andrews, 1990; Bennett, 1991; De Santo and Smith, 1993; Jackson, 1999; Trombulak and Frissell, 2000).

Road kill is the leading direct human cause of vertebrate mortality; approximately one million vertebrates are killed daily on roads in the United States (Forman and Alexander 1998). In addition to direct mortality of wildlife, road kill is also a significant human safety issue. Wildlife/vehicle collisions can result in large amounts of vehicular damage leading to potential injury or fatalities.

A variety of strategies have been used with mixed success to mitigate the impacts of transportation systems on wildlife (Jackson and Griffin, 1998; Jackson, 1999). Underpasses are commonly used to facilitate movement of wildlife across roadways in Europe, Australia, Canada and the U.S. However, the effectiveness of these underpasses to facilitate wildlife movement depends on a number of variables, including: size, proximity to natural wildlife corridors, noise levels, substrate, vegetative cover, moisture, temperature, light, and human disturbance. For example, cover can play a key role in passageway effectiveness for small mammals. The installation of gutters in culverts significantly increased small mammal movement (Foresman 2001). Similarly, van der Linden (1987) reported that stump rows facilitated small mammal movements through underpasses. Different species have different requirements. Thus if passage systems are designed for use by a singles species they may act as barriers for other species with different requirements.

A 2005 review found 460 terrestrial crossing structures in the United States (Cramer and Bissonette 2005). Only a limited number of these structures have been monitored for effectiveness. Those that have been monitored generally focus on whether animals are using the structures. They employ methods like tracking beds, cameras and counters. These methods provide little information on those species or individuals that fail to use a structure.

A sampling of 21 studies reveals that on average 4 species are monitored per study, with larger carnivores (e.g. - bear, bobcat, coyote) and ungulates the taxa groups most frequently targeted. Some studies focus on a single species (Kaye et al. 2005, Gordon and Anderson 2003) but most studies record general use of the structures.

Radio-tracking, mark-recapture trapping and tracking studies are more useful for determining the extent roadways inhibit wildlife movements and the degree to which passage structures mitigate these effects. Thus, to fully assess the effectiveness of wildlife passageways, a combination of monitoring techniques are needed to evaluate structure use and the extent to which transportation systems affect animal movements at the landscape scale (Jackson, 1999).

To evaluate the effectiveness of wildlife passage structures it is important to have an idea of how much wildlife passage is enough to determine that a particular project is a success. Wildlife use of passage structures has to be assessed relative to some baseline level of passage determined either by 1) data on pre-construction wildlife movements in the area or b) an evaluation of the extent to which the highway (including passage structures) inhibits wildlife movement through the area. Thus, unless good pre-construction data on wildlife movement are available, post-construction monitoring strategies need to evaluation passage use as well as other wildlife movements that indicate the degree to which wildlife are failing to use the passage structures.

Wildlife crossings have evolved considerably since the first documented structure was completed in Florida in 1950. Florida continues to be a leader in the area of highway mitigations along with other states such as Arizona, Montana and Vermont. Through cooperative efforts of the Agency of Transportation and Department of Fish and Wildlife, Vermont has constructed nine crossings along with the scheduling of a half dozen more over the next 5 years (Cramer and Bissonette 2005). A focal project for the state of Vermont is the Bennington Bypass which has incorporated three wildlife crossing structures into its construction.

## Study Area

The Bennington Bypass (Hwy. 279) is a 7km long highway connecting NY Rte. 7 in Hoosick Falls, NY to VT Rte. 7 in Bennington, VT. It is a two lane highway with several three lane areas designed as passing zones. Highway 279 is the first part of a three phase highway project which will circumvent downtown Bennington. This western phase of the highway opened in October 2004 and includes three wildlife passage structures, including two extended bridges and a large culvert.

Both bridges were constructed as overpasses over two streams, East Airport Brook (EAB) and West Airport Brook (WAB). The two streams are separated by .9km and both occur in the eastern half of the 7km long bypass. They both flow south to north into the Walloomsac River. East Airport Brook is a 2m-wide intermittent stream, whereas the similar-sized West Airport Brook is perennial. The brooks within both passageways run off center, closer to the western edges of the openings.

The extended bridge over the EAB is 43.3m long, 8m wide and 18m above the terrain directly below it. The bridge over WAB is 56.55m long, 8m wide and 12.17m above the terrain directly below it. The length and height of the bridge creates a relatively large passageway underneath the highway. The drainage culvert (passageway) is located approximately 200m west of West Airport Brook. The 1.65m wide, 124m long culvert connects two retention ponds located to either side of the highway.

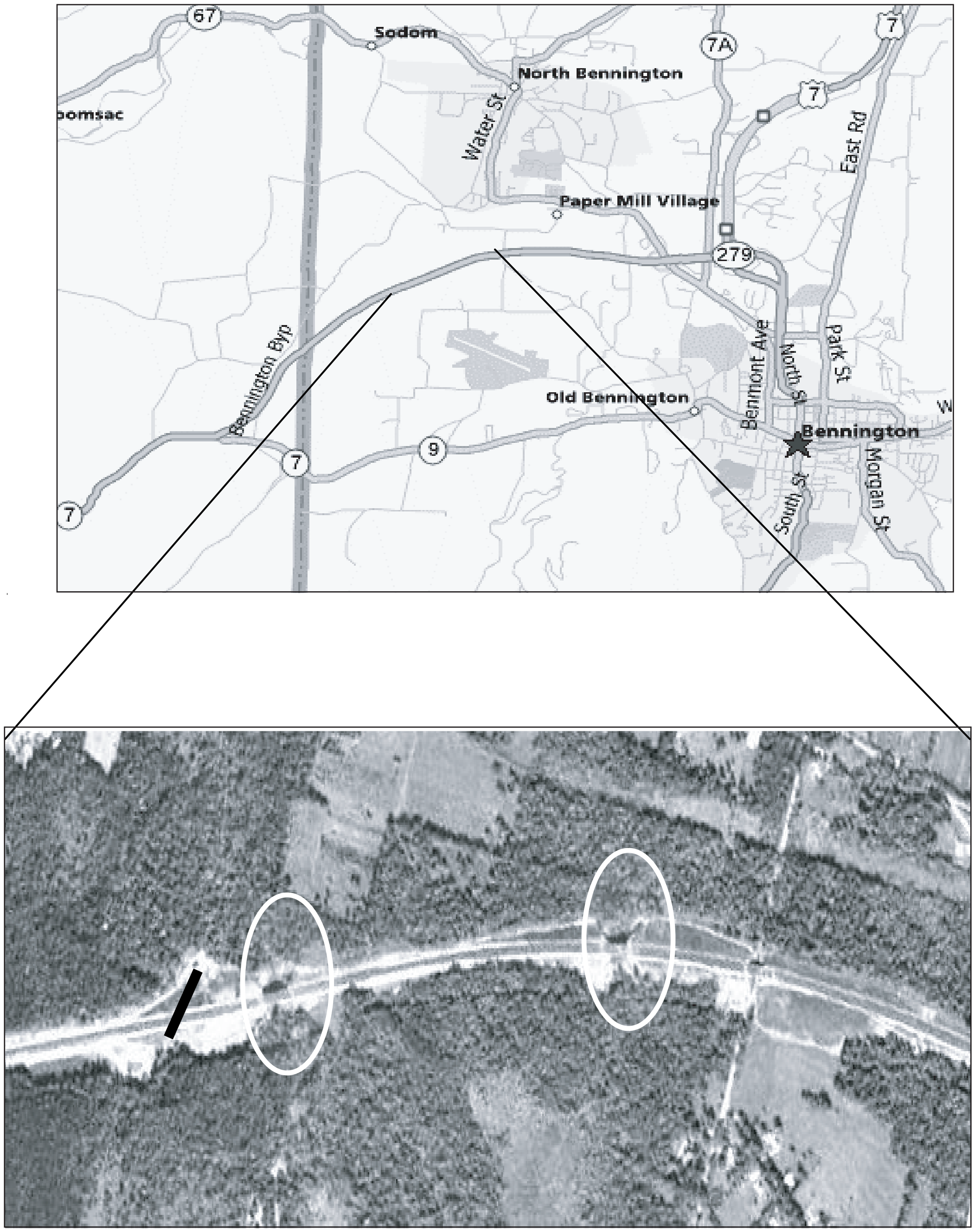



Figure 1. Location of 7 km long Highway 279 and primary study area with locations of passage structures (white circles) and drainage culvert (black line to west of structures). Passage structures are .9 km apart.

The vegetative community adjacent to the bypass is a Northern hardwoods broad leaf complex dominated by American Beech (*Fagus grandfolia*), Maple (*Acer* spp.) and Eastern hemlock (*Tsuga canadensis*). Much of the under story is dominated by Canada honeysuckle (*Lonicera Canadensis*). A 15m right of way, buffering the road from the forest, occurs along both sides of the roadway.

## Objectives

Continuous, long term monitoring of wildlife crossing structures are key components to assessing the true conservation value of mitigation passages for wildlife (Clevenger and Waltho 2003). Due to budgetary and logistical constraints, long term monitoring of passage structures is often implausible. Clevenger and Waltho (2003) evaluated 18 studies over the past 30 years, and revealed that the average monitoring period for those studies was 17.3 months. With a limited temporal scope to evaluate effectiveness, we felt it important to design a study that took a broad, multi-taxa approach to monitoring.

The objectives of the Bennington Bypass project are:

1. Evaluate the effectiveness of wildlife passageways for mitigating the impacts of the Bennington Bypass on wildlife
2. Test and refine monitoring techniques for evaluating wildlife use/avoidance of passageway structures.
3. Develop monitoring protocols for assessing the impacts of roads on wildlife for integration into future highway projects in Vermont and throughout the United States.

This study is monitoring the effectiveness of these passageways and comparing rates of wildlife movement across the highway in mitigated and unmitigated sections. We are also evaluating various techniques for monitoring wildlife use that may be used in future highway projects such as the proposed Route 78 project in northern Vermont. This project is part of a cooperative, phased research program by Vermont's Agencies of Transportation and Natural Resources (Department of Fish and Wildlife) to evaluate and mitigate the impacts of roads on wildlife.

**Conceptual Model**

A variety of techniques have been utilized in assessing wildlife passageway effectiveness. A sampling of passageway studies revealed that the most prevalent techniques used are remote camera sensing and track beds (Gordon and Anderson 2003, Servheen et al. 2003, Reed et al. 1982, Brudin 2003, Veenbas and Brandjes 1999, Foresman 2003, Krawcheck et al. 2005, Mata et al. 2005, Land and Lotz 1996, Yanes et al 1995, Mansergh and Scotts 1989, Clevenger and Waltho 2005 and Norman et al. 1998). In many studies cameras are used in conjunction with track beds to verify crossing occurrences. These techniques primarily provide information on the wildlife use of the structures. The most comprehensive study discovered in our sampling was a project in Victoria, Australia by Abson and Lawrence (2003), which incorporated 14 techniques to evaluate passage use by mammals, reptiles, amphibians and birds.

This project seeks to incorporate a multi-taxa approach by also monitoring impacts on taxa including carnivores, mesopredators, small mammals and amphibians. In order to illustrate the potential movements of animals relative to a highway and crossing structure, we developed a conceptual model (fig. 2) with accompanying techniques matrix (table 1) that may be helpful in deciding appropriate methods for monitoring those movements.

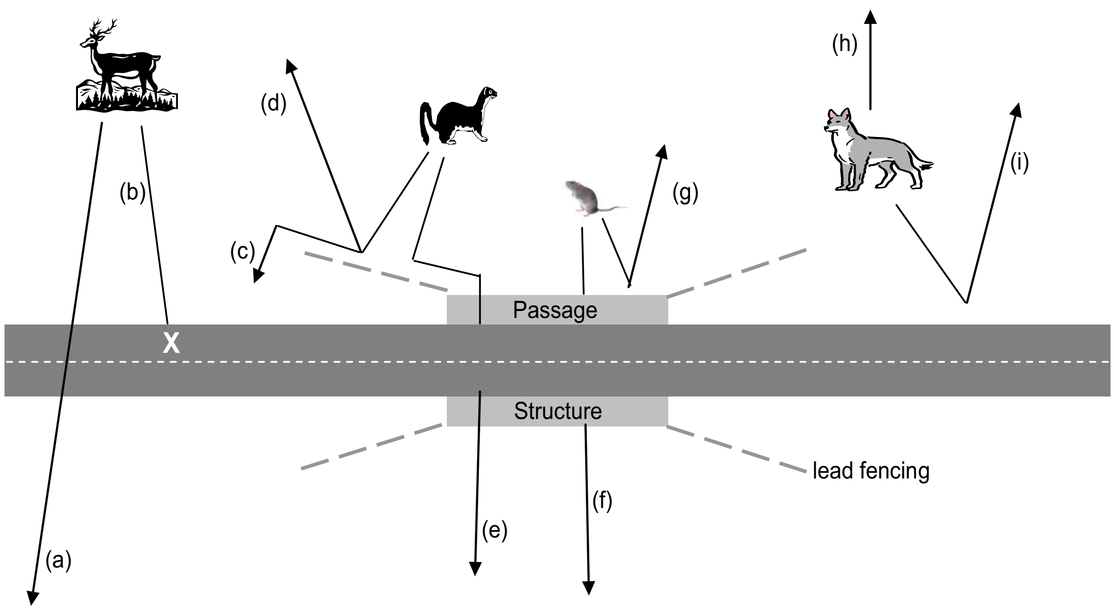



Figure 2. Potential wildlife movement relative to roadway and passage structure. (a) move successfully across the roadway, (b) vehicle collision, (c) approach lead fencing, moving away from passageway around lead fencing, (d) approach lead fencing and move away from roadway, (e) approach lead fencing and move successfully through passageway, (f) move through passageway unabated, (g) approach and avoid passageway (h) avoid roadway and (i) approach and avoid roadway.

Table 1: Techniques matrix – monitoring technique and movement monitored (see figure 2)

| Method | Taxa group | Movement monitored |
|---|---|---|
| Small mammal mark/recapture | Small mammals | a, e, f |
| Snowtracking | Medium and large mammals | a, b, c, d, e, f, g, i |
| Track beds/plates | All | e, f |
| Remote cameras | Medium & large mammals | a, c, e, f |
| Roadside track beds | Medium & large mammals | a, b, i |
| Road kill surveys | All | b |
| Amphibian recording devices | Frogs and toads | n/a |

## Study Design

Understanding movement patterns relative to the roadway and passage structures are important elements in gaining a better understanding of effectiveness of mitigation strategies. By incorporating a variety of monitoring techniques the ability to evaluate effectiveness may be improved. The Bennington Bypass study incorporated an array of monitoring techniques in an attempt to understand movement patterns listed in figure 2. In some cases a single technique is used while in other cases a combination of techniques is used to quantify a single movement pattern. We here summarize the key findings for each technique.

### Small Mammal Movements

Small mammals play pivotal roles in ecosystem processes as prey for reptilian, avian and mammalian predators and as consumers of invertebrates and plants (including seeds and fruits). Small mammals disperse many plant species and consume some invertebrates that have potential to alter ecosystems (Carey and Johnson 1995). Roads inhibit the movement of small mammals (Oxley et al. 1974), which may lead to local extinctions, social disturbance and morphological divergence (Dickman and Doncaster 1987). We are using a mark/recapture study to assess the degree to which movements are affected by the roadway and enhanced by the passageways.

Sampling Procedures. We captured small mammals and ear-tagged them to assess movement patterns in areas adjacent to the roadway and passageway structures. We placed Sherman live traps (n = 276) at 25m intervals along eight 500m long transects spaced 50m apart, starting 50m from the roadway (fig. 1). In front of the two passageways (~35m), we spaced traps 10m apart to better detect small mammal movements associated with the passageways.

Traps are baited with peanut butter and placed at habitat features (i.e. logs, trees, burrows) within 1m of each trapping point in the late afternoon. Once trapping begins, each trap is checked daily (mornings). Captured animals are identified, weighed, sexed and aged. Animals are marked with metal ear tags, and released where captured. We considered the area along the transects, 125m to either side of the center of each passageway as the treatment areas, the area most likely affected by the passageway structures. We considered the 250m portion of the transects located on the western edge of the survey area as the control areas, least affected by the passageways.

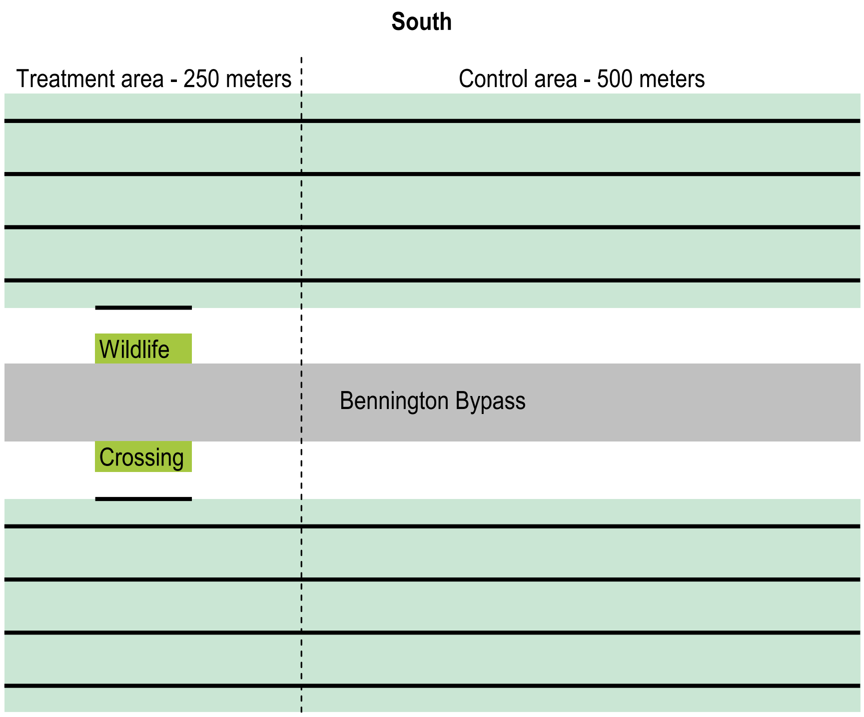



Figure 3. Small mammal trapping grid. 1) Large shaded area depicts forest, 2) black lines = transects. Traps are spaced 25m apart except in along short transects at forest edge aligned with passageways where they are spaced 10m apart.

High disturbance rates from squirrels and raccoons in year 1 required us to change trapping protocol from 5 night sessions conducted once a month to 2 night sessions conducted weekly. This shorter, but more frequent method of trapping allowed for more flexibility around rainy weather and also decreased disturbance rates. We achieved our objective of obtaining an 80% recapture rate by the end of the field season.

Key Finding

- More frequent, shorter duration trapping periods appear to be an efficient method in areas of frequent precipitation or high disturbance

Analysis. Using the recapture data, we calculated the distances between recapture locations to determine travel distance probabilities. These probabilities will be used to determine if small mammals are crossing the passageways in similar proportions to their average movements in the natural habitat. Preliminary analysis suggests that the passageways appear to be mitigating the effects of the highway

*Future modification*. In order to determine whether additional cover will increase passage usage, we plan on building a wall of tree-stumps as suggested by van der Linden (1994).

**Monitoring of Mitigation Structures**

Monitoring animal movement within the passageways is important in determining whether the structures are functional. We are using track beds/plates and remote cameras to obtain information for large and medium sized mammals including: deer, moose, bear, bobcat, fox, coyote, otter, raccoon, opossum, skunk, long tailed weasels, ermine, fisher, woodchuck and mink. Both passageways and one large culvert passage structure are being monitored.

1. Track beds

Sampling procedures. Track beds are located in the middle of the underpasses and track plates at both ends of the culvert. Various track bed methods were experimented with during the first year of our study. Two methods utilizing play sand were utilized: 1) sand laid atop tarp material 1m wide along the entire width of the passageways and 2) sand laid directly on top of existing substrate. Our pilot study revealed that the optimal method was to lay the sand on bare ground after grass, rocks and roots have been removed.

A second group of methods utilizing marble dust was also utilized. Marble dust is a fine powder that allows for the finest resolution of footprints. Three marble dust methods were experimented with: 1) sift the marble dust onto tarp material, 2) sift the dust onto natural substrate and 3) sift the dust onto 4' X 4' squares of plywood. We concluded overall that the optimal method was the sifting of the dust onto plywood. The hard foundation allowed for more reliable tracks, required less dust and issues of vegetation growth and uneven surface were alleviated.

We monitor the track beds at least three times a week to document those species using the passageways. We record species (or at a minimum, family), direction of travel, time and weather variables. The beds are reset as necessary. These data will be collected for all three years of the study because some species may not immediately habituate to mitigation structures (Clevenger and Waltho 2000).

Key finding.

- Marble dust placed atop plywood serves as the preferred tracking substrate for our study but issues of color contrast may need to be addressed.

2. Track plates

Sampling procedures. We utilize sooted track plates to monitor the culvert passageway. The track plates consist of 3' X 3' sheets of metal, sooted with an acetylene torch. A strip of contact paper is placed in the middle of the metal sheets in order to record the soot laden footprints of animals walking over the plate. One plate is placed on each end of the culvert in order to verify crossings. The plates are checked 2-3 times a week and species, date and direction are recorded.

Key findings.

- Sooted track plates provide higher resolution of animal tracks than any of our track bed methods but are difficult to implement on larger scales, such as spanning our 43 or 56 meter passageways.
- Structures that may seem unsuitable for wildlife movement (such as long, narrow culverts with no natural substrate) serve as passage for animals that may be reluctant to use larger structures.

3. Remote cameras

Sampling procedures. A single 35mm camera is rotated bi-weekly among the four sections (streams bisect both passageways) of track bed that are present under the two passageways. Data from this camera is used to confirm track bed data and record animal movements not captured by the track beds. Digital cameras are placed along the streams to monitor those areas not suitable for track bed construction. All cameras are checked weekly.

Key findings.

- Cameras are important for validating track bed data and monitoring areas unsuitable for track beds.
- Digital cameras (set for 10 – 15 picture sequencing) are excellent tools for recording animal behavior relative to passage structures. They may serve as a low cost alternative to video cameras.
- The pairing of cameras on opposite sides of a roadway may provide data on wildlife that cross over the roadway rather than through the passages.

Analysis. Information gathered from track beds/plates and remote cameras are used to provide an index of passage use by taxa group. Weekly and monthly rates of passageway use are calculated for track beds. In addition, information from this portion of the study will be compared to that from snow tracking to identify potential seasonal differences.

**Snow Tracking**

Snow-tracking during winter provides the opportunity to 1) evaluate animal movements relative to the roadway and passageways, and 2) document the presence of animals in the study area not detected by track beds/plates. Data from track beds/plates and remote cameras during 2005 documented the occurrence of woodchucks, raccoons, white tailed deer, mink and muskrat within the passageways. However, species such as bobcat, coyote fisher, otter, porcupine and beaver were not detected, yet occur in the area. The snow-tracking provides us the opportunity to assess the movements of these animals relative to the roadway and passageways.

Sampling procedures. The grid design for snowtracking consists of four transects parallel to the highway, extending 500m to the east of the East Airport Brook passageway and 500m to the west of West Airport Brook passageway (Fig 2). Two transects occur on each side of the highway with one along the highway edge and the other 100m in the forest. Additionally, six transects extend perpendicular to the roadway on each side. Four of these perpendicular transects on each side extend 100m out from the edges of the passage structures and two occur on either end of the tracking grid connecting the two long transects parallel to the roadway. The parallel transects along the highway edge are designed to identify movements in relation to the roadway and crossing points. The transects that occur in the forest allow us to monitor movements not directly associated with the passageways or roadway. The perpendicular transects provide us information about the behavior of animals as they approach the passageways and the associated lead fencing. During each snow-tracking day we also check the passageways for movement through the structures.

Snowtracking sessions occur 48 hours after snowfalls of ½" or more. We use Palm Pilots with cybertracker software integrated with GPS to record species, track and gait measurements, gait pattern, direction of movement, markings (e.g. – scat, scent marking), highway location crossings, weather, days since last snowfall, snow depth, date and time. The order of transect coverage is reversed on subsequent tracking sessions.

During the 2005/06 and 2006/07 snow-tracking seasons, we frequently were not able to walk the entire grid in a single day. When this occurred, we initiated tracking the following day from the last point covered the previous day, weather permitting.

When we encounter deer tracks that have crossed the roadway we trace their movements from forest edge to forest edge. For carnivores crossing the road we backtrack and foretrack for distances up to 200m from the highway. Snow plowing typically disturbs the snow pack ~5 meters to either side of the highway, thus areas just beyond the “snowplow zone” are checked carefully to capture tracks that are heading towards the highway. Efforts are made to match up tracks on the opposite side of the roadway for potential road crossings. When matched tracks are not found, the tracks are marked and classified as a likely crossing but not used in the data analysis. In addition, if we encounter deer or carnivore tracks that approach the highway but do not cross, we record these tracks to and from the forest edge. These data are important for understanding possible barrier effects of the highway.

We also backtrack and foretrack carnivores that cross the 100m forest transect, as far as clear tracks will allow. This information will be used to identify potential wildlife corridors and to identify areas adjacent to the roadway that may serve as significant habitat in winter. These data can also be used to determine if behaviors of animals change as they approach the roadway and passageways by comparing movements away from and near the roadway. Individual animal movements are also monitored along the perpendicular transects that extend directly out from the passageways and within the passageways.

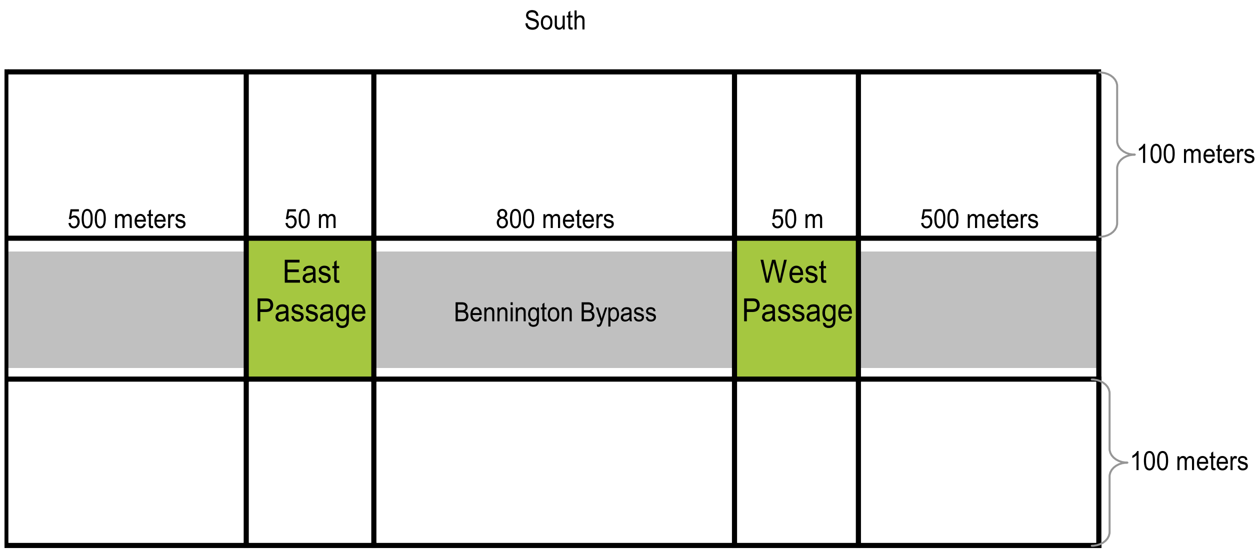



Figure 4. Snowtracking grid. Black lines represent transects.

Key findings.

- From monitoring perspective, snowtracking is the most comprehensive method of detecting animal movements. Unfortunately it is viable only during a limited portion of the year and in latitudes that provide snow cover.
- It can serve as a low cost alternative to radio telemetry
- It is an excellent method to assess non-passage movement of animals
- Information derived from snowtracking may assist in determining placement of other monitoring techniques such as cameras and roadside track beds that can monitor movements not associated with passageways in seasons other than winter.

Preliminary Results. Snow-tracking data provide us information on animal movements relative to the roadway and nearest passageways. Our 2005/06 and 2006/07 data suggests there are two primary highway crossing areas for bobcat and coyote apart from the passageways. Further, we documented that roadway crossings were more frequent than crossings through the passageways. This portion of the study can also provide a baseline that can be used to evaluate changes in movement behavior over time. The preliminary data suggests that fencing plays a key role in mitigation. Animals cross the highway in the highest numbers away from the 8-foot lead fencing, where the 4-foot right of way fencing serves as the only barrier preventing access to the highway. We have documentation that this fencing is easily jumped over or dug under by wildlife.

**Road Kill Surveys**

Wildlife passageways can potentially reduce vehicle/wildlife collisions by minimizing road crossings, thereby also reducing animal mortality. In our study, the control portion of the highway is a 1.1 km section of the highway located on the far western end of the 7km long Bennington Bypass, away from the passage structures. The treatment section of the highway is a 1.1 km section of highway that encompasses both passage structures. The null hypothesis for this segment of the study is that road kill rates will not vary between the control and treatment areas. If the passageways are effective, road kill rates should be higher in areas farther from the passageways.

Sampling procedures. The entire 7km of the bypass is being surveyed for road kills. Surveys are conducted 3 times a week (M, W and F). Driving at 15 mph, each side of the road is monitored and species or group (i.e. – small mammal), direction traveling, and location to the tenth of a mile (using odometer readings) are recorded for each road kill found. In addition, we use monthly traffic counts provided by VTrans to assess the impact of traffic volumes on rates of roadkill.

Key findings.

- In high traffic areas, the majority of roadkill is unidentifiable.
- Roadway features such as guardrails, right of way vegetative cover, slope of embankments and location of retention ponds may influence rates/species of roadkill

Analysis.

Two hypotheses will be tested during this portion of the study.

Hypothesis 1 – Road kill will be higher on the control (unmitigated) portion of the highway

Hypothesis 2 - Road kill will increase at distances further from the passage structures

Preliminary results. Data from the first two field seasons suggest there is no statistical difference in road kills, control vs. treatment and roadkill rates do not change at varying distances from the passage structures.

**Roadside Track Beds**

This monitoring technique has great potential. Unlike our snowtracking sessions, it is difficult in the warmer months to discern animals moving across the highway without the use of radio telemetry. We utilize pond fill as a tracking substrate. Pond fill is mud with a silt and clay component that allows it to hold up well in most weather conditions except torrential rain. Efforts will be made this upcoming field season to modify this technique and to make it a key monitoring method in our study.

Sampling procedures. Two pairs of roadside track beds were constructed and monitored along the roadway to monitor highway crossings. The beds are 100’ long x 3’ wide and constructed using pond fill supplied by VTrans. We constructed these beds in areas where we had observed high use during the previous snowtracking season. Unfortunately, unusually high rainfall washed out the track beds within 7 days after installation. Thus, we only recorded four deer crossings during five days of monitoring. No other species were recorded on the track beds.

Key findings.

- In the absence of snowtracking or telemetry, roadside track beds may provide the most useful data on wildlife road crossings not associated with passage structures.
- Pond fill is an excellent tracking substrate but may require frequent repair during times of high precipitation

**Calling Amphibian Monitoring**

To better evaluate the potential changes in amphibian populations over time, we use automated acoustic recording devices (Frogloggers) to monitor the density of calling males at several sites. Following the procedures of Peterson and Dorcas (1994), frogloggers are set to record for 12 seconds every 10 min throughout the night during the breeding season (March-August). Microphones are suspended above breeding pools from a tree limb to minimize the relative contribution of any single individual to the chorus. This allows comparison of the intensity of calling effort across sites. Choruses are identified to species and chorus intensity is measured according to the following scale developed by Mohr and Dorcas. (1999): 1) one individual, 2) distinguishable individuals, and 3) many indistinguishable individuals. Chorus ratings are summed over species to provide a relative index of anuran density at each site (Mohr and Dorcas 1999). Overlapping sites (sites within range of more than one microphone) are excluded from this study to reduce the probability of detecting the same individuals more than once. Recording devices are checked weekly for maintenance purposes.

Sampling Procedures. Frogloggers are placed at the wetland located 200m southwest of the Airport Brook West passageway and at the southern retention pond, located 200m to the west of WAB. Additionally, we are monitoring two ponds along the proposed route of the northwest extension of the Bennington Bypass. These data will provide baseline data to potentially be used in any post construction studies for that section of the highway.

Key findings.

- Frogloggers are user friendly and hold up well in inclimate weather
- Background noise such as crickets and birds may require sophisticated equipment such as a sonogram for deciphering of amphibian calls

### Observational Studies

We tested a method for determining whether animals display evidence of aversion or excessive wariness in the vicinity of the passage structures. In addition, we used direct observation in an attempt to detect animal movement through the passageways that was not captured by the track beds or cameras.

Sampling procedures. We used night vision goggles to observe animals in the passageways between 1830 hrs and 2230 hrs. An observation period consisted of a 2-3 hour period during which the observer recorded all animal movement and behavior in the passageway. Each passageway was observed 4 times between July 2 and July 29. Only one sighting (a family of raccoons) was recorded during the month of July.

Key finding.

- This method may be of limited value due to the number of hours required to obtain significant results.

### Snake Distribution and Abundance

Two methods of monitoring snake movement were utilized during the first year of the study (2005). The goal of this portion of the project was to assess the impacts of the highway on snake movements. A mark/recapture method using pit tags was to be implemented.

Sampling procedures. The first method was the use of fence arrays with accompanying funnel traps and pitfall traps. We used 1 meter high drift fence to set up an "X" fence array. Each arm of the array was 5 meters long. Half meter long funnel traps were placed midway along each side of the 4 arms of the array. A second design incorporated the "X" design with a pitfall trap placed at the center of the "X". The pitfall trap was a sunken 5 gallon bucket. Funnel traps were aligned along each side each side of the 4 arms in this design also. In both designs the funnel traps and pitfall traps served as a passive technique for snake capture.

A second method was the use of cover boards. Cover boards serve as artificial sources of cover and warmth for snakes. We experimented with two types of cover boards. The first was the use of corrugated aluminum and the second was the use of tar roofing sheets, both cut into 1m x 1m squares. The cover boards were placed 10m apart along three 150m transects. The three transects were parallel with the highway, centered on the WAB passage structure. They were placed at three distances from the highway; 1) at the forest edge, 2) 20m from the forest edge and 3) 60m from the forest edge. Two fence arrays were constructed along each transect, one at 50meters and one at 100 meters.

Over a one month period, we only captured one snake using these methods. This portion of the study was discontinued after the first field season.

Key finding.

- Monitoring of snake movement may require extensive coverage, hence high labor/materials cost, which may be desirable only in a snake specific study.

## Discussion

Most studies of the effectiveness of crossing structures have been narrowly focused on evaluating passage use. Yet without some clear sense of the mitigation objectives or clear criteria for success it is hard to imagine how these types of studies can determine whether or not a mitigation project can be considered effective. Data on the movement of individual animals through a passage structure is, at best, only an indirect measure of the success of a mitigation project.

For mitigation projects built for the primary purpose of preventing animal-vehicle collisions (for conservation or human safety) a more direct measure of success would be a reduction in the number of collisions or the risk of collisions. Where wildlife conservation is the primary concern long-term effects on wildlife populations are the only direct measure of success. Although desirable, it is not likely that long-term population monitoring will be regularly used to evaluate the effectiveness of wildlife mitigation measures. However, population modeling can help define the desired level of movement through the landscape needed to maintain populations over time. Combined with population modeling monitoring projects that evaluate the full range of wildlife movement can serve as a reasonable approach to evaluating mitigation success.

### Developing Metrics and Establishing Criteria for Success

Using the conceptual model in Figure 2 we can create metrics for determining success based on project objectives. If the objective of a project is solely to prevent animal-vehicle collisions then the following metric would be appropriate.

$\sum (a, b, c)$

In cases where the number of collisions that can be tolerated is low (moose, elk, Florida panthers) the criteria for success would be set at a very low number. In this case continued use of the roadway by wildlife (movement types a & c) or ongoing roadkill (b-type movement) would indicate that the mitigation has not been successful. Where the objective is to reduce but not necessarily eliminate roadkill (amphibians on a causeway through extensive areas of habitat) then the criteria for success would be set at a higher number.

Many mitigation projects have combined objectives of reducing animal-vehicle collisions and allowing some degree of movement through the area. If the conservation objective is to maintain population continuity or metapopulation dynamics then it may be acceptable to pass only a portion of population (some inhibitory effect would be acceptable). In this case a useful metric might be:

$$\frac{\sum (e,f)}{\sum (a,b,c)}$$

This metric places the number of successful movements through the structure in the context of the number of movements at risk for animal-vehicle collisions. The criteria for success would be set at a high number if the level of desired passage (as determined by population modeling) is high and the acceptable risk of collisions is low (ungulates, turtles). The criteria for success might be lower for species whose movement requirements (based on population modeling) are lower and/or the impact of roadkill is less severe.

Where the objective is to prevent roadkill and provide access to vital habitats for a population, then the metric should seek to evaluate the amount of successful passage in the context of road avoidance or unsuccessful passage (roadkill).

$$\frac{\sum (e,f)}{\sum (a\text{-}d,\ g\text{-}i)}$$

Other projects may be relatively unconcerned about roadkill (low traffic volume; strongly r-selected species) but seek to facilitate movement across a road or highway in cases where the road has a strong psychological inhibitory effect on passage (small mammals). If the objective is population continuity or metapopulation dynamics then the following metric might be appropriate.

$$\sum (a,e,f)$$

If the project objective is to provide access to vital habitat (mountain pygmy possums) then the following metric might be more appropriate.

$$\frac{\sum (a,\ e,f)}{\sum (b\text{-}d,\ g\text{-}i)}$$

**Bennington Bypass Study**

During the initial 2 years of this project, our varied techniques approach has provided us movement data on a wide variety of species. Table 2 outlines the various species detected by each of the techniques implemented.

Table 2: Species detected by various monitoring techniques

| Method | Species detected |
|---|---|
| Small mammal mark/recapture | white footed mouse (*Peromyscus leucopus*), deer mouse (*Peromyscus maniculatus*), southern red-backed vole (*Clethrionomys gapperi*), meadow vole (*Microtus pennsylvanicus*), eastern chipmunk (*Tamias striatus*), northern short tailed shrew (*Blarina brevicauda*), meadow jumping mouse (*Zapus hudsonius*), red squirrel (*Tamiasciuris hudsonicus*) |
| Snowtracking | bobcat (*Lynx rufus*), coyote (*Canis latrans*), fisher (*Martes pennanti*), white tailed deer (O*docoileus virginianus*), gray fox (*Urocyon cinereoargenteus*), raccoon (Procyon lotor), long tailed weasel (*Mustela frenata*), mink (*Mustela vison*), river otter (*Lontra canadensis*) |
| Track beds | bobcat, coyote, fisher, white tailed deer, raccoon, mink, river otter, wild turkey (*Meleagris gallopavo*), virginia opossum (*Didelphis virginiana*), eastern chipmunk, ermine (*Mustela erminea*), woodchuck (*Marmota monax*), striped skunk (*Mephitis mephitis*), gray squirrel (*Sciurus carolinensis*), red squirrel, eastern cottontail (*Sylvilagus floridanus*), muskrat (*Ondatra zibethicus*), porcupine (*Erethizon dorsatum*), domestic cat (*Felis catus*) |
| Track plates | ermine, mink, raccoon, woodchuck |
| Remote cameras | white tailed deer, bobcat, coyote, fisher, woodchuck, opossum, striped skunk, |
| Roadside track beds | white tailed deer |
| Road kill surveys | all species |
| Amphibian recording devices | eastern american toad (*Bufo a. americanus*), northern spring peeper (*Pseudacris c. crucifer*), gray treefrog (*Hyla versicolor*), bullfrog (*Rana catesbeiana*), green frog (*Rana clamitans melanota*) |
| Observational study | raccoon |
| Snake distribution | common garter snake (*Thamnophis sirtalis*) |

Data for each portion of the study is currently being analyzed but preliminary results reflect a wide array of responses to the passage structures and the highway. By collecting data on eight of nine movement patterns depicted in figure 2 our study should allow us to go beyond the simple consideration of passage use in evaluating success for this mitigation project.[1] Once data collection has been completed we intend to investigate the use of various metrics for evaluating mitigation success for the Bennington Bypass

[1]This study does not provide us the opportunity to collect data on animals totally avoiding the highway denoted by (h) in figure 2.

## Conclusions

As the field of highway mitigation continues to evolve we feel this study may provide useful tools in designing monitoring protocols for future passage structures. Our broad approach to monitoring has allowed us to refine effective techniques or discontinue ineffective ones and to pass on "lessons learned" from our study. This broader, landscape level approach to monitoring may aid researchers in developing study designs and to more rigorously evaluate the effectiveness of highway mitigation structures.

**Acknowledgements:** The Vermont Agency of Transportation (VTrans) provides funding for this project along with cooperative efforts from Vermont Fish and Wildlife Department (VFW). Logistical support is provided by Jennifer Fitch and Chris Slesar of VTrans along with John Austin, Forrest Hammond and Doug Blodgett of VFW. Tom Maier of U.S. Forest Service provided valuable information for the small mammal portion of this study. Invaluable field assistance was provided by Alan Thompson, Lauren Gilpatrick and Noah Charney. This study would not have been possible without the permission of private landowners to access their land.

**Biographical Sketch:** Mark Bellis is a current M.S. student at the University of Massachusetts. He received a B.S. in Marketing from Florida State University in 1985 and a B.S. in Wildlife Biology from the University of Montana in 2005.

## References

Abson, R. N. and R. E. Lawrence. 2003. Monitoring the use of the Slaty Creek wildlife underpass, Calder freeway, Black Forest, Macedon, Victoria, Australia. *Proceedings of the International Conference on Ecology and Transportation*. 303-308.

Andrews, A. 1990. Fragmentation of habitat by roads and utility corridors: a review. *Aust. Zool.* 26(3&4):130-141.

Bennett, A. F.. 991. Roads, roadsides, and wildlife conservation: a review. Pp. 99-118 In D.A. Saunders and R.J. Hobbs (eds.) Nature Conservation 2: The Role of Corridors. Surrey Beatty & Sons, London.

Brudin III, C. O.. 2003. Wildlife use of existing culverts and bridges in north central Pennsylvania. *Proceedings of the International Conference on Ecology and Transportation*. 344-352.

Carey, A. B. and M. L. Johnson. 1995. Small mammals in managed, naturally young and old growth forests. *Ecological Applications*. 5:336-352.

Clevenger, A.P. and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology*. 14: 47-56.

Clevenger, A. P. and N. Waltho. 2003. Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies. 293-302.

Clevenger, A. P. and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation*. 121:453-464.

Cramer, P. C. and J. A. Bissonette. 2005. Wildlife crossings in North America: The state of the science and practice. *Proceedings of the International Conference on Ecology and Transportation*. 442-447.

De Santo, R.S. and D.G. Smith. 1993. Environmental auditing: an introduction to issues of habitat fragmentation relative to transportation corridors with special reference to high-speed rail (HSR). *Environmental Management* 17:111-114.

Dickman, C. R., and C. P. Doncaster. 1987. The ecology of small mammals in urban habitats. I. Populations in a patchy environment. *The journal of animal ecology*. 56:629-640.

Foresman, K. R., 2003. Small mammal use of modified culverts on the Lolo south project of western Montana – an update. *Proceedings of the International Conference on Wildlife Ecology and Transportation*. 342–343.

Forman, T. T. and L. E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecological Systems*. 29:207-231.

Gordon, K. M. and S. H. Anderson. 2003. Mule deer use of underpasses in western and southeastern Wyoming. *Proceedings of the International Conference on Ecology and Transportation*. 309-318.

Jackson, S.D. and C.R. Griffin. 1998. Toward a practical strategy for mitigating highway impacts on wildlife. Pp. 17-22 In G.L. Evink, P. Garrett, D. Zeigler, and J. Berry (eds.) *Proceedings of the International Conference on Wildlife Ecology and Transportation*. FL-ER-69-98. Florida Department of Transportation, Tallahassee, Florida.

Jackson, S.D. 1999. Overview of transportation related wildlife problems, pp. 1-4. In Evink, G.L., P. Garrett and D. Zeigler, (eds) *Proceedings of the Third International Conference on Wildlife Ecology and Transportation*. FL-ER-73-99. Florida Department of Transportation, Tallahassee, Florida.

Kaye, D. R. J., Walsh, K. M. and C. C. Ross. 2005. Spotted turtle use of a culvert under relocated Route 44 in Carver, Massachusetts. *Proceedings of the International Conference on Ecology and Transportation*. 426-432.

Krawchuk, A., Larsen, K. W., Weir, R. D. and H. Davis. 2005. Passage through a small drainage culvert by mule deer, Odocoileus hemionus, and other mammals. *The Canadian Field-Naturalist*. 119:296-298.

Land, D. and M. Lotz.. 1996. Wildlife crossing designs and use by Florida panthers and other wildlife in southwest Florida. *Proceedings of the International Conference on Wildlife Ecology and Transportation*.1-6.

Mansergh, I. M. and D. J. Scotts. Habitat continuity and social organization of the mountain pygmy-possum restored by tunnel. *Journal of Wildlife Management*. 53:701-707.

Mata, C., Hervas, I., Herranz, J., Suarez, F., and Malo, J. E.. 2005. Complementary use by vertebrates of crossing structures along a fenced Spanish motorway. *Biological Conservation*. 124:397-405.

Mohr, J. R. and M. E. Dorcas. 1999. A comparision of anuran calling patterns at two Carolina bays in South Carolina. *The Journal of the Elisha Mitchell Scientific Society*. 115:63-70.

Norman, T., Lean, B. and A. Finnegan. 1998. The role of fauna underpasses in New South Wales. *Proceedings of the International Conference on Wildlife Ecology and Transportation*. 195-207.

Oxley, D.J., M.B. Fenton, and G.R. Carmody. 1973. The effects of roads on populations of small mammals. *Journal of Applied Ecology*. 11:51-59.

Peterson, C. R. and M. E. Dorcas. 1992. The use of automated data-acquisition techniques in monitoring amphibian and reptile populations. Wildlife 2001: Populations. Elsevier Applied Science, London. 369-378.

Reed, D. F., Woodard, T. N. and T. M. Pojar. 1975. Behavioral response of mule deer to a highway underpass. *Journal of Wildlife Management*. 39:361-367.

Servheen, C., Shoemaker, R. and L. Lawrence. 2003. A sampling of wildlife use in relation to structure variables for bridges and culverts under I-90 between Alberton and St. Regis, Montana. . *Proceedings of the International Conference on Ecology and Transportation*. 331-341.

Trombulak S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14(1):18-30.

Van der Linden, P. J. H., 1994. A wall of tree stumps as a fauna corridor. Habitat fragmentation and infrastructure – proceedings. 409-417.

Veenbaas, G. and J. Brandjes. 1999. Use of fauna passages along waterways under highways. Road and Hydraulic Engineering Division, Delft, Netherlands. 253-256.

Yanes, M., Velasco, J. M and F. Suarez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. *Biological Conservation*. 71:217-222.

## Major Roads: A Filter to the Movement of the Squirrel Glider Petaurus Norfolcensis

**Silvana Cesarini** (61399055680, silvana.cesarini@sci.monash.edu.au), Monash University, Biological Sciences, Clayton, Melbourne, Victoria 3800 Australia

**Abstract**

An understanding of the ecological effects of roads and related traffic in highly fragmented landscapes is critical because the viability of wildlife that persist through the adverse impact of habitat loss and fragmentation, due to causes such as agriculture or urban land-uses, may be further impaired by the presence of roads. The potential barrier effect can increase the level of population isolation, especially if traffic volume increases and roads are widened. This is particularly the case in landscapes where a large proportion of the habitat occurs in linear strips, such as in hedgerows or along roadsides or watercourses. Much of eastern Australia has been cleared and many threatened species occur in habitat adjacent to roads. Thus, management must minimise the negative effects of roads while maximising their value for conservation.

Gaps in habitat may result in impeded mobility of wildlife and potentially isolate populations, with subsequent consequences for population persistence. The squirrel glider Petaurus norfolcensis can be considered a model species for investigating the impact of roads on connectivity. A native arboreal marsupial, the squirrel glider has a very efficient way of locomotion which consists of gliding between trees, with very rare ventures on the ground, where the risk of predation is higher. Glider movement within home ranges and during dispersal is expected to occur along continuous vegetation, while cleared areas wider than the maximum gliding distance achievable could act as barriers. In this study we evaluated the filter effect of major roads on the squirrel glider in central Victoria (south-eastern Australia) using a combination of radiotracking and genetic techniques. We asked two important questions. First, does a major road act as a barrier or filter to the movement of gliders and if so, does the presence of tall trees between the carriageways facilitate their crossing.

A total of 58 adult individuals were radiotracked at six sites along the Hume Freeway (central Victoria), and at two control sites (minor roads with low traffic volume and small or non-existent gap in canopy cover) over a period of six months. The six sites consisted of small roads lined with old growth trees and dissected by the freeway. Three of these sites also had tall trees present in the median section of the freeway. The percentage of animals crossing at sites with vegetated median was similar to that at control sites, with 70% and 79% of all animals observed on the opposite side of the road or the centre median at least once, respectively. In contrast, only one male glider (10% of all animals) was observed crossing at sites with non-vegetated median. Overall, females were less inclined to cross roads, even at control sites and the intensity of crossing was also higher for males than females. The presence of trees in the median of the freeway was thus demonstrated to be a very efficient method of improving connectivity for gliders.

Data on dispersal collected via direct methods can be highly informative but also requires intense efforts in field work and usually long term studies. Genetic techniques are a useful alternative to infer dispersal events, through the use of spatial autocorrelation and relatedness/parentage analysis. These methods will be implemented to consolidate the preliminary results and estimate the net effect of observed crossings on gene flow.

Mitigation structures consisting of rope bridges and poles are being constructed to improve mobility of gliders as well as a number of other arboreal species and their effectiveness will be monitored using a combination of techniques. These will include motion-detecting infrared cameras, implantable transponders and radiotracking. Data will be compared on a pre- post-mitigation basis and at treatment and control sites.

# Management Considerations for Designing Carnivore Highway Crossings

**Bill Ruediger** (406-721-4868, wildbill@montana.com), Wildlife Biologist, Wildlife Consulting Resources, 1216 Creek Crossing, Missoula, MT 59802 USA

**Abstract:** Many agencies are contemplating building wildlife crossings to reduce wildlife mortality, to improve habitat connectivity, and to reduce vehicle collisions. For this to occur without problems and interagency disagreements, relationships between agencies and key individuals must be well-developed. Once relationships are in-place highway improvements and wildlife habitat objectives are more easily integrated. The second step in coordinating wildlife issues with transportation is development of interagency statewide, regional or highway specific wildlife habitat linkage plans. These determine a number of critical factors necessary to locate wildlife crossings, prioritize opportunities and focus funding and personnel. To be effective, transportation, wildlife management and land management agencies must be involved in these plans. The third step involves choosing the appropriate location, structure type and structure size for target species. This process must take into consideration more than biological criteria and includes cost factors and construction feasibility issues born by highway agencies. Last, monitoring will help improve future wildlife crossing efforts and help all agencies and the public gain confidence in their effectiveness.

## Background

Carnivores are intelligent mammals that are usually at the top of the food chain. As such, carnivores are less abundant, less dense on the landscape, may have lower fecundity and can be more vulnerable than other terrestrial wildlife. Environmental degradations such as habitat fragmentation, habitat loss and mortality often effect carnivores before other groups of animals (Ruediger 2004, 1998 and 1996). Highways have several deleterious effects on carnivores and other animals, some of these can be effectively mitigated by such measures as assessment of wildlife habitat linkages and effectively placed and designed wildlife crossings. While improvements have been made in the knowledge base for wildlife crossing designs, for many carnivores much remains to be learned.

Figure 1. Lynx crossing a Canadian highway. Clayton Apps.

For the purposes of this paper, carnivores are loosely defined as small, mid-sized and large. Small-sized carnivores include weasel (*Mustela nivalis*), mink (*Mustela vison*), skunks (*Mephitis* spp), red fox (*Vulpes vulpes*), gray fox (*Urocyon cinereoargenteus*), kit fox (*Vulpes macrotis*), swift fox (*Vulpes velox*), opossum (*Didelphis viginiana*), and American marten (*Martes americana*).

Mid-sized carnivores are arbitrarily grouped as river otter (*Lutra canadensis*), raccoon (*Procyon cancrivorus*), bobcat (*Lynx rufus*), lynx (*Lynx canadensis*), wolverine (*Gulo gulo*), ocelot (*Leopardus pardalis*), coyote (*Canis latrans*), jaguarondi (*Herpailurus yagouaroundi*), badger (*Taxidea taxus*) and fisher (*Martes pennanti*). Recommendations for most small and mid-sized carnivores are grouped together in this paper because often they are present together on the landscape, differential crossing prescriptions are not well understood and practical highway structure designs for many of these species would usually be similar.

Large carnivores include black bear (*Ursus americana*), grizzly bear (*Ursus arctos*), wolf (*Canis lupus*), mountain lion (*Felis concolor*) and jaguar (*Panthera onca*). These animals require substantially larger wildlife crossing structures and other special considerations compared to the smaller carnivore species.

Highway coordination standards and mitigation measures are not known for many of these species, especially the small and mid-sized carnivores. The premise of this paper is that highway construction and improvements will be on-going and that biologists, engineers and managers will be faced with difficult economic and environmental decisions without the luxury of understanding exactly how well some of the concepts will work. Recent history indicates that we will neither be able to delay highway projects or avoid considering various wildlife and fish ecological issues such as habitat fragmentation and mortality caused by vehicles on highways. Fortunately, we are beginning to have a number of good examples of collaborative highway mitigation measures across the United States and Canada. Specifically, those in Banff, Canada, Arizona, western Montana, Idaho, Wyoming, Colorado, Florida, California and Utah (Evink 2002).

Carnivores are part of a much more complex natural system of animals, plants and landscapes. Biologists and engineers need to focus on the broader ecological issues when considering wildlife crossings. Often, highway safety is a prime consideration to the public, to highway departments and to political figures. It has only been recently that the issues of collisions with deer (*Odocoileus* spp.), elk (*Crevus elaphus*), moose (*Alces alces*) and other large animals are considered legitimate highway safety issues. Biologists will be well-served by helping highway departments deal with wildlife collision issues. Many of the wildlife crossing structures needed to address "deer crossings" work well for most large and mid-sized carnivores. If elk crossings are being considered, as they often are in the western mountains, the needs of large carnivore will likely be included.

## Where Do We Begin?

This effort began when I was contacted in 2005 to provide a management advice at the Southwestern Carnivore Committee Meeting in Tucson, Arizona, due to a situation where some highway departments were not implementing wildlife biologist recommendations for wildlife crossings for listed carnivores. It was requested that an expert come in to straighten the situation out – mainly the highway departments. Of course, this approach is not a winning strategy and only adds to the communication problems already in place. Wildlife crossings should be the last step in developing a collaborative wildlife habitat/transportation connectivity plan. The following approach is recommended for developing a system of effective wildlife crossings – for carnivores and other wildlife.

One of the unexpected results of developing this paper has been a companion document and website that was prepared at the request of the Southwestern Carnivore Committee. That being the development of Safe Passage: A User's Guide to Developing Effective Highway Crossings for Carnivores and Other Wildlife (Ruediger and DiGiorgio 2007). The development of this document, which was supported by the USDA Forest Service, Federal Highway Administration, Wilburforce Foundation and Southern Rockies Ecosystem Project, involved taking the information from this paper and circulating it to approximately 35 other individuals and agencies for comment. To review this document go to: www.CarnivoreSafePassage.org. Copies of the document are also being enclosed in all registration packages at the 2007 International Conference on Ecology and Transportation Conference in Little Rock, Arkansas.

## Step One: Relationship Building

Nothing kills a good idea from maturing and being implemented like a poor relationship. This is true with wildlife concepts, road and highway plans and any other objectives humans must have cooperation to accomplish. The following provides some insights into how biologists and engineers can work effectively together:

*Considerations For Biologists:* If your wildlife crossing ideas are not being accepted, have you done the pre-work of getting to know your Forest, Regional, State Department of Transportation (DOT) or FHWA engineers? Do they understand the basic ecological issues of habitat connectivity, mortality and habitat loss? Probably not. Perhaps going to local and regional engineering meetings to present your information would help. Offer to have coffee or lunch with them. Get to know engineers you will be working with, before serious issues develop. Many engineers are not trained in ecological sciences and may need some basic information on local species, habitat fragmentation and wildlife mortality issues. Provide this information in easily-understood, clear presentations. Don't get mad or frustrated because another professional does not automatically understand issues you have taken years to develop. Biologist's need to understand that they are not the decision-makers and that a convincing, cost-efficient and effective wildlife mitigation program on a highway needs to be negotiated. And, that highway construction decisions can not wait until you have all the wildlife data you may desire. If you do not have experience with coordinating highways with wildlife, contact a biologist that does. Arrange for them to come to the project area and provide recommendations. Do this in consultation and coordination with the highway project manager from the State DOT so that the biologist chosen has credibility and support from the highway agency.

*Considerations For Engineers:* If your critical road project is going across public lands or sensitive wildlife habitat, invite local biologists from a variety of involved agencies to discuss what kinds of species and ecological issues might be important. Explain the transportation planning process and when your agency needs to have concerns and issues addressed so you can deliver your project on time and within the budget. Most resource agencies find the state transportation planning process confusing. Often, resource agencies such as the USDA Forest Service, US Fish and Wildlife Service, National Park Service and state wildlife agency do not expect to be involved until the NEPA alternatives are developed in the Draft Project EIS. This may be disastrously late for project engineers to learn about serious wildlife issues and conflicts. Engineers should understand that most biologists have little or no experience in what types of structures might be effective in a situation, and that the costs of mitigation measure may not be of equal concern. Take time to explain your need to deliver a project on time and build in some costs for wildlife crossings and other ecological mitigation measures. Often biologists do their best to provide valuable wildlife coordination advice, but chances are they have never worked on a major highway project before. Highway departments should be willing to consider paying resource agencies for resource agency biologist time to provide quality input and coordination. All resource agencies are operating on minimal budgets and do not get money to coordinate large, complex highway projects.

A critical part of the relationship building and successful wildlife crossing planning and implementation involves interagency cooperation. All successful wildlife crossings are a collaboration of: 1. State Department of Transportation and Federal Highway Administration. 2. Land management agencies and/or private landowners. 3. State wildlife management agencies and the US Fish and Wildlife Service. Often other agencies are involved such as the Environmental Protection Agency, Department of Defense etc. A common problem is that one or more of the key agencies do not view the highway project as a priority for their employees time. Land management agencies may not view habitat connectivity of public lands as important agency functions. State wildlife agencies may be over-worked and view highway projects as politically charged no-win situations that they are not paid to deal with. There are almost always interagency strife and turf issues that plague most serious issues in government. The lead for successful interagency coordination often comes from one agency that sees the importance of coordinating highways, land management and wildlife management. This agency may be from any of the "key agencies" and is rarely the same in any state. If your agency sees the need, take the leadership to involve and coordinate with the other agencies. Leadership, communications, problem-solving and hard work are elements common to all successful conservation, transportation and wildlife crossing efforts. Understand what your agency can contribute and come to the negotiating table willing to provide whatever resources or help that is needed.

Conservation groups and citizen committees also play key roles in many wildlife crossing and habitat linkage efforts. Several conservation groups are dedicated to helping agencies achieve successful wildlife crossings and other wildlife mitigation measures. These include Defenders of Wildlife, Southern Rockies Ecosystem Project, Rocky Mountain Elk Foundation, Wildlands Project, National Wildlife Federation, American Wildlands and many others. These groups can provide key planning and coordination services, but can not substitute for agencies that fail to coordinate well. Many of these groups can provide for meeting coordination, local citizen participation, linkage analysis, middleman land purchases and agreements, GIS and other services.

Last, the issue of highway safety often has far greater support and appeal among the general public, highway departments and politicians than conservation of large or small carnivores does. Reducing collisions with wildlife should be a concern to everyone. In many states, collisions with deer and elk are one of the most serious safety issues on rural roads. It may be prudent and effective to begin with reducing collisions with deer and elk – as all or most of these wildlife crossings will benefit carnivores. Then, if there is evidence that other crossings are needed specifically for other target species, approach these carefully, with your information and rationale well thought-out.

Interagency Training: Reading From The Same Page: Wildlife, land management and transportation agencies usually have very different priorities and missions. Effective wildlife habitat linkage assessments and wildlife crossing implementation require agencies and different professionals to work as a team. Progress occurs when agencies pool information and achieve consensus, as quickly as possible, on the locations and types of wildlife crossings that are needed. Agencies should consider working together on training sessions that help key players share expertise and reach consensus rapidly. Traffic safety, cost containment, and meeting deadlines should be part of this training, as well as habitat connectivity, wildlife mortality reduction, structure design and structure efficacy. Utah DOT and Arizona DOT have recently supported wildlife crossing workshops with cooperating agencies. The workshops are well attended and will expedite future transportation projects by having many biologists, planners and engineers that understand their roles and can begin working effectively from the start.

### Step Two: Wildlife Habitat Linkage Analysis – Determining Where Wildlife Crossings are Important

Setting up a statewide or regional plan for habitat connectivity is an essential part of developing a purposeful system of effective wildlife crossings. Most likely, the best scale to start a wildlife habitat connectivity plan is on a statewide basis, but often opportunities present themselves at smaller scales such as a DOT or Fish and Game Regional Area or high priority highways. Examples of existing processes and successes include the Arizona, New Mexico (figure 2), Colorado and Utah statewide wildlife habitat connectivity plans. An Assessment of Wildlife and Fish Habitat Linkages on Highway 93 – Western Montana (Ruediger et al 2004) and the Northeastern Idaho Region plan (Servheen and Wall unpublished).

Regardless of the scale of wildlife habitat connectivity being assessed, approximately the same tools are used. These include some or all of the following:

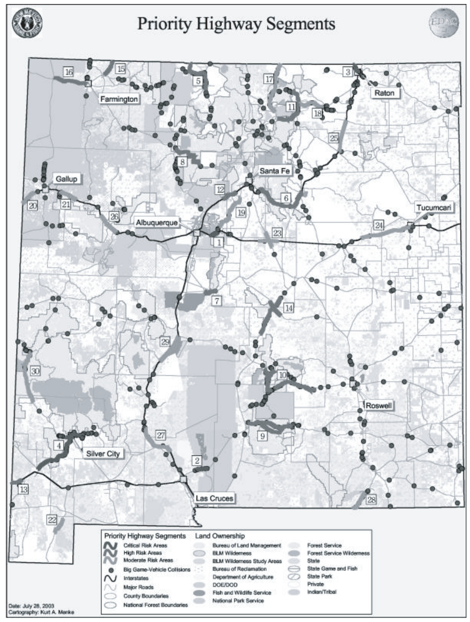



Figure 2. New Mexico Wildlife Connectivity Map.

1. **Aerial Photos:** Are available in various scales and image forms such as black and white, color, color infrared, and ortho-photos. These can be used to identify vegetation patterns, vegetation types, housing and human developments, water features, aspect and terrain and many other important clues. On some high quality images such as low elevation color infrared, game trails and paths may be evident.
2. **Land Ownership Maps:** Developing wildlife habitat linkages is infinitely more easy and acceptable when public lands are involved. These may be county lands used for "open space", state wildlife management or natural resource lands, or a variety of lands managed by the Federal government. Most public lands usually have protection of wildlife habitat as one of their mandates or guiding principles. In general the more private lands involved and the more owners involved, the more difficult securing long-term habitat protection will be. One of the primary benefits of wildlife habitat linkages is to minimize fragmentation of wildlife habitat on public lands.
3. **Vegetation Maps:** Essential for all scales, although too much detail can be confusing and unnecessary at times. Often, general vegetation types such as conifer or hardwoods, riparian or upland, marshes or grass-land will be adequate. The National Vegetation Land Class is suitable for most of the higher scale work such as statewide assessments and highway corridors.
4. **Topography Maps:** Provide important information such as draws, ridges, saddles, over-steepened lands, flats and often can be used to identify wildlife corridors. Riparian habitats are usually apparent including lakes, ponds, marshes, bogs, swamps, streams and rivers. Even on relatively flat landscapes, topography maps often provide important clues on where wildlife probably will interface with highways. Roads, highways, power lines and other human developments are often displayed on topographic maps.
5. **Wildlife Habitat or Range Maps:** These may range in quality from "unavailable" to exceptionally accurate. They can always be augmented with information provided by biologists, foresters, landowners and others that live or work in the area. In most situations wildlife habitat and range information will come from a variety of agency sources. These include state wildlife agencies, state heritage programs, US Fish and Wildlife Service and a variety of land management agencies such as the USDA Forest Service, Bureau of Land Management, National Park Service and the State Department of Natural Resources.
6. **Road-Kill Information:** Available from many State DOT's. Provides valuable information on the location and number of collisions, and usually the species of animals. Romin and Bissonette (1996) recommend factoring in a 16-50 percent increase when estimating animal-vehicle collisions from accident reports.

Once the natural resource information is gathered, it is most easily stored and viewed in a Geographic Information Systems (GIS). GIS data can be projected onto screens or walls for interactive sessions of large or small groups. It is essential that the land management, wildlife management and highway agency personnel be involved in selecting and prioritizing wildlife habitat linkages. Key citizens, conservation groups and others may also be critical. History indicates that if key agencies are not included, or choose not to be involved, that the habitat connectivity plans rarely result in on-the-ground wildlife crossings. Organizing the agencies and citizens to participate for a day or two of work to collaboratively assess wildlife habitat linkages and connectivity plans is often the most challenging aspect of building wildlife crossings.

State highway agency participation is particularly critical and should be included in the identification and prioritization of every wildlife linkage area. In most situations, if highway agency personnel are involved in the wildlife habitat linkage decisions and understand why an area is being identified, that other agencies support these areas and that the rationale for inclusion is solid, minimal problems occur during the implementation phases.

After Statewide, Regional or Highway Corridor Plans are developed, it is important that all agencies go back to their decision-makers and ensure that agency support follows. For agencies like the US Forest Service, Bureau of Land Management and National Park Service, wildlife habitat linkages need to be integrated into land management plans so that key lands are managed to support wildlife connectivity objectives. For State and Federal wildlife agencies, line officers need to be supportive if future problems develop and to avoid issues like difficult Section 7 Consultations. For state highway agencies, Wildlife Habitat Linkage Plans need to be integrated into the Statewide Transportation Improvement Plans (STIP's) as soon as possible so the information is immediately integrated into highway construction plans and programs.

Wildlife habitat linkages are often identified at workshops using the resource information above, plus knowledge from local biologists and others. The linkages are usually documented on GIS maps and key information recorded for future use. NOTE: The information to be gathered and the forms and processes to be used should be well thought out prior to the meetings. The recording processes vary, but often include computer stored forms that include:

a. Name and number of the wildlife habitat linkage.
b. Location map and description, including the best available boundaries.
c. The species of concern for connectivity and reduction in mortality. A description of the habitat used such as access to water, riparian habitat, winter ranges, or breeding areas.
d. Local people from agencies and groups that have knowledge or concern about the linkage area. This includes contact information such as phone numbers, e-mails and addresses so DOT's can easily reach the right people if construction plans are proposed.
e. The major purpose or purposes for the linkage zone. This might include highway safety, migratory big game herds, rare or listed carnivores, habitat connectivity, etc.
f. The priority of the linkage area compared to all others in the state or Region. This is often described as very high, high or moderate. Part of the priority ranking may hinge on how imminent a proposed project may be, the number of animals killed or accidents, the status of a species, or loss of connectivity due to imminent human developments.

The last step in planning wildlife linkages is documenting the results of the interagency meetings and obtaining buy-off from the DOT and other agencies. If the workshops and reports are professional and complete, this is normally not a problem. A well designed and edited Wildlife Habitat Linkage Plan does much to market the ideas and gives agency decision-makers confidence that appropriate thought and coordination has gone into the planning. Give everyone credit that was involved, regardless of the amount of effort.

### Step Three: Selecting Appropriate Wildlife Crossings for Carnivores

So, now there is an interagency integrated statewide, regional or highway corridor wildlife habitat linkage plan. There is also agency support to build wildlife crossings and one of the concerns is carnivores. What do you have to do assure use and effectiveness of the structures?

First, identify the target species of carnivores and other wildlife that will be using the crossing. Are they large or small? Large would include the bears, large cats and wolves. Small and mid-sized would include most other carnivores. Ocelot, wolverine and lynx will require special consideration because of their status or rarity.

The following are suggested factors to consider when building wildlife crossings for carnivores and other wildlife species:

1. **Keep It Natural:** The more naturally a wildlife crossing fits into the surrounding environment, the more likely animals will use it. Particularly for wary species like grizzly bears and wolves. Video footage from the United States and Europe indicates a wide array of behavioral responses of wildlife to crossings. When wildlife crossings are unnatural appearing to animals they will approach the crossing and watch it, sometimes for several hours. After watching the crossing, some animals will cross, some will not, some will run through and some will run or walk partway through and return without making a successful crossing. It may cost slightly more money to make a crossing appear more natural, but this is usually money well-spent.

   A natural appearance would be vegetation extending to the crossing structure that is similar to that in adjacent habitat. It would also include a minimal number of features that either would intimidate or obstruct wildlife such as livestock fencing, cattle guards, cement walkways, rip-rap, construction debris, vertical walls, unnecessary fill, signing, poles, or fencing that is over-confining.

2. **Location:** Location is a critical factor in use of wildlife crossings. In many situations, exact placement is required. Wildlife crossings should be located precisely where animals want to approach a highway, or where they have historically done so. Often, animals choose areas to cross where there is a specific terrain feature, vegetation, or a reduction in the number of lanes. Ridges, valley bottoms, stream and river courses, and wooded corridors often are choice locations. The general location of wildlife crossings can be assessed from aerial photos. The precise location of each structure should be made after considerable field work has been done to determine the best location.

3. **Approaches:** The approach to a wildlife crossing may be the deciding factor in whether or not animals use a structure. Approaches start with having a structure in the appropriate location where animals behaviorally are most comfortable crossing a highway. Approaches also include habitat factors like having vegetation near or at the crossing entrance. Several animals have shown preferences for using a location where the distance between cover is the shortest. On the Trans-Canada Highway, tracks indicate wolverine move long distances parallel to highways to find such "pinch" areas. When rights-of-way are cleared for highways, vegetation should be left at those locations where wildlife crossings are planned. Trees and shrubs should be planted in approaches and between lanes on divided highways.

   Vegetation provides many benefits for a wildlife crossing. It minimizes the distance animals must travel between habitats on both sides of the highway. It shields animals from light and noise. Obviously, it provides cover which is often important to animals that are sensing vulnerability.

   Fencing is another important factor in the approach areas. This includes both fencing that funnels animals into wildlife crossing structures and fencing that often crosses the approach to keep livestock from using crossings. Often, 5-wire barb wire fencing is used to exclude livestock from using the crossing structures. Unfortunately, such fencing also may exclude or discourage wildlife from using the crossing. Livestock fencing should be of 3-wire design with minimal use of barb wire. The bottom wire should be high enough (normally 16 to 18 inches) to allow young animals to travel under the fence.

   Other discord elements in the approach area often reduce a wildlife crossing's effectiveness. Sediment fences should be removed to allow wildlife to easily cross to adjacent habitat. Construction debris that could spook wildlife, like bright pieces of metal, wire, boxes should be removed. Farmers or ranchers may want to store equipment, hay, or other unnatural material in or near wildlife crossings or approaches. These should be prevented by contract agreement. Rip-rap is difficult for many species to traverse, ungulates and amphibians specifically. Also, excess road-fill should be stockpiled away from the wildlife crossing.

   Animals should be able to clearly see through a structure to habitat on the opposite side of the road. Road-cuts, steep drop-offs, dog-legs and cliffs may dissuade animals from making a successful crossing. Structures should be designed as flat and straight as terrain permits. Crossings with a steep grade reduce the "openness" of structures and dog-legs prevent animals from seeing habitat on the opposite side of the highway.

4. **Bottom Material and Design:** One of the most difficult design features of a wildlife crossing to achieve is a suitable bottom material. As near as possible, the bottom of structures should have similar soil as would occur if the structure was not there. Often, bottom material is made up of coarse material from road cuts, or other unnatural substances such as asphalt or cement. For many species, bottom material may not matter. Specifically, those species that are most adaptable like coyote, black bear, raccoon, opossum

   In situations where streams and wildlife will be using the same structure, it is usually preferable to allow a natural stream bank and let wildlife choose where to make trails or cross within a structure. Elaborate pathways are unnecessary and add cost. Hardened vertical walls on structures, such as those made of building blocks and cement, seem to be less desirable than natural fill material (soil or loose gravel). Avoidance of these design elements has come mostly from ungulates and may not apply to carnivores. Likewise, avoidance or fear of vertical walls made fade after animals adapt over time.

5. **Structure Design and Size:** Is another "essential element" for wildlife crossing structures. Size and design affect biological factors and important feasibility concerns such as cost. A 4 h x 7 w meter steel multi-plate underpass structure may cost $250,000. Note: for structure dimensions "h" is used to denote height and "w" for width.

   A similar sized open-span cement wildlife crossing (bridge) can cost $1.2 million, or more. And, a highway overpass wildlife crossing can cost $2 to $10 million. So, size and type of structure will matter to a highway engineer. Small increases in structure size or what may seem like subtle changes in design may have large differences in cost. All other things being equal, biologists should recommend the most cost efficient design that will work for the target species.

   Carnivores are not all equal in respect to acceptance of wildlife crossings. For example, the least expensive steel multi-plate 4 h x 7 w meter crossing will likely be acceptable for black bear, cougar and most other common carnivores. However, if grizzly bear or Rocky Mountain wolves are present, open-span wildlife crossing may be much more effective. In Banff National Park, the consensus of engineers and biologists is that the best overall design, based on a number of ungulate and carnivore species, is the open-span underpass. In Florida, both Florida panther and black bear use 8'h x 25' w cement box culverts.

Grizzly bear and wolves may be the most sensitive carnivore species with respect to wildlife crossing designs. Wolves in Banff National Park had a preference for open-span underpasses. Grizzlies prefer 52 meter overpasses and open-span underpasses. The open-span underpasses in Banff National Park are approximately 13'h x 50' w in size and are used by grizzly bear and other large species (Figure 3). Black bears used a variety of crossing structures and including 52 meter overpasses, open-span underpasses, 4 h x 7 w meter oval culverts and even 3 h x 2.5 w meter box culverts. Cougar, like black bear, used a wide variety of structures in Banff National Park (Forman 2003).

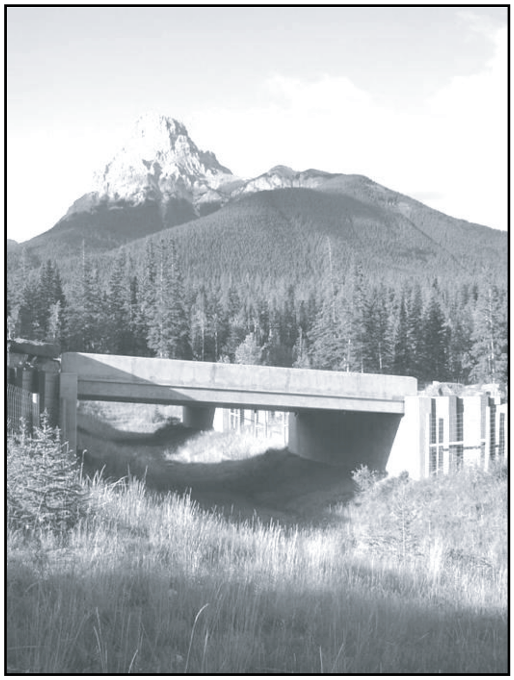


Figure 3. Open-span wildlife crossings, like this structure near Canmore, Canada are effective for large carnivores and other large wildlife. Tony Clevenger.

Deer, elk or moose are always target species for wildlife crossings where large carnivores are of concern in the United States and Canada. For most of the large carnivores and deer, 10 foot height structures should be considered minimal. If elk or moose are target species, 12-13 foot height should be considered minimum (perhaps higher for large Alaskan moose). Twenty feet widths are recommended minimums for deer and most common large carnivore species. Reed (Watson and Klingel 2000) recommends underpasses have an openness ratio or index of at least 2.0 to be effective. Openness ratio or index of a wildlife crossing is determined by height x width divided by length (dimensions must be in meters). In some cases, either the height or width may need to be less than recommended. If less width or height is required, it is almost always better to have a slightly smaller wildlife crossing than to have no crossing.

For species that have little or no research available to determine wildlife crossing size, particularly if they are listed or rare, it makes sense to use caution and design the crossings for larger animals. In the cases of ocelot, wolverine and lynx, 10' h x 20' w, or larger, structures should be used until better research is developed (Gordon 2003). These would also be suitable for deer, black bear and cougar, too. If elk are present, structures of 4x7 meters (approximately 13' h x 25' w) should be considered minimal. For jaguar, which there is no wildlife crossing data at this time, 10' h x 20' w structures should likely be considered minimal. This estimate is based on what cougar would likely use.

For smaller carnivores, smaller wildlife structures may suffice. For example, 36" pipes are commonly used for cross-ditching on large highways. A variety of small and mid-sized carnivores may use these. Generally speaking, species that dig holes, use burrows, or live or hunt in hollow logs or confined spaces frequently will likely accept 36" pipes or box culverts. These include American badger, raccoon, skunks, American marten, fisher, mink, weasel, foxes, bobcat and coyote (Clevenger and Waldo 1999). A number of smaller mammals, reptiles and amphibians also have been documented using culverts this size, or smaller. Thirty-six inch pipes are the absolute minimum size that coyotes and bobcats will use, if these are target species 48", or larger, pipes or box culverts are recommended. Cement pipes are preferable to corrugated steel, however, if steel pipes are used a thin layer of soil or gravel should be placed in the bottom. If deer are present, the minimum sized structures for this species will work fine for bobcats and coyotes.

Little is known about river otter, however, there is anecdotal information that otter may avoid narrow culverts or bridges on streams, and elect to move out of the stream course and across roadways. Suitable crossings should include a natural stream channel at all flows and an unrestricted stream bank for otter and other animals to use. Otter crossings have been designed in the Netherlands and elsewhere in Europe and are commonly used. Otter mortality has been greatly reduced in the Netherlands by modification of bridges, usually by incorporating a path or shelf where otter can walk. These modifications are considered an important conservation measure for otter and other species (Bekker 1998).

Highway bridges present an opportunity to provide wildlife habitat connectivity and to reduce wildlife highway mortality. Bridges are constantly being replaced as highways are improved or they become old and unsafe. Oregon Department of Transportation recently reviewed a large number of bridges that may have to be replaced and has assessed all of them for potential wildlife and fish crossing opportunities. Bridges that span waterways or gullies can be some of the most effective wildlife crossings available. This is because wildlife commonly follow riparian habitat or drainages and they usually already exist in places where wildlife prefer to cross highways. Bridges can be designed to facilitate carnivore passage with minimal design changes. Usually, use the same criteria as other wildlife crossings. Ten foot height clearances above the high-water zone are adequate for most common large carnivores and deer. Use 12-13 foot height clearance if elk, moose, grizzly bear or wolves are present. For smaller carnivores, at least three or four feet height clearance above the high-water zone is usually adequate.

Bridges often are high and open enough to allow enough sunlight to penetrate and allow growth of shrubs and grasses. There must be an adequate stream bank to allow use by target species. Bridge construction material should minimize traffic noise. Some bridges have been built with steel girders that make loud noises when traffic crosses. In Arizona, elk crossings using steel girders have been identified as noisy and extremely disturbing to elk trying to successfully cross.

While many bridges can serve as dual purpose structures, some design and construction practices can limit or eliminate wildlife use. These include livestock fencing that prevents access to the crossing by wildlife, rip-rap, sediment fences, debris and fill dumping and any other detracting elements. Bridge projects should be inspected during and after construction to ensure the end results meets expectations and are attractive to target species. After final wildlife fencing and site preparation is finished it can be difficult to get heavy equipment back to a bridge site. There is almost never money available after the final product is inspected and approved to return and fix problems.

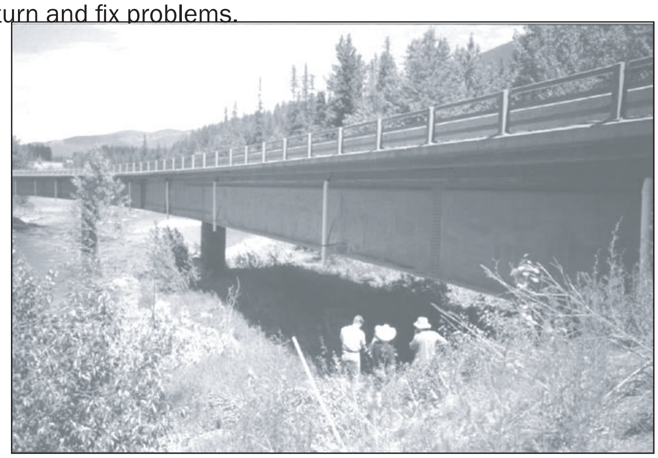


Figure 4. Bridges with adequate end-space can be excellent wildlife crossings. Bridges need to be both high and wide enough for target species.

Engineers and biologists must work hand in hand in designing and building wildlife crossings. First attempts to build wildlife crossings may result in less than perfect structures and outcomes. As engineers and biologists learn from successes and problems, subsequent wildlife crossings often are more effective. No two situations are exactly the same and new challenges are presented at every project. If engineers and biologists have experience working with each other, problems are usually solved quickly. If engineers and biologists do not have good working relationships or are not experienced in designing and building wildlife crossings, problem situations can result in perceived failure and taint future wildlife crossing efforts. Bringing in experts from other states or areas that have experience with wildlife crossing structures can reduce costly problems, expedite project starts and completion times and increase structure effectiveness. If you don't know, or are not sure what types and sizes of structures are effective, contact someone who is experienced.

6. **Fencing:** Is as critical as the wildlife crossing structures and approaches. Most wildlife is extremely wary and avoids confinement or strange situations. Given the choice between going through unfamiliar wildlife crossing structures and crossing highway pavement, many will choose the latter. Fencing forces most wildlife to use the wildlife crossings. As time goes by, research indicates wildlife species will be more comfortable using wildlife crossings. Young animals brought through wildlife crossings by their parents may readily accept crossings. It may take several years for wildlife to adapt to wildlife crossings. Without fencing, most of these animals would not use the structures (Clevenger et al 2001).

There are usually many fencing options. Continuous fencing such as in Banff National Park and in some parts of Florida is not feasible in most highway situation. In these cases, wing-fencing is employed. The question always arises: how far from the wildlife crossings must wing-fencing extend? There is no simple answer. Sometimes there are natural features that funnel animals into wildlife crossings and perhaps wing-fencing can be limited to a few hundred yards on each end. Most of the time, wing-fencing should be built for ½ mile, or more, if large carnivores and deer and elk are target species. Part of the equation in how long wing-fencing should be involves the approach and wildlife crossing design. If the approach brings animals to a crossing structure naturally, and the structure itself is large enough and well designed, it is likely fencing needs will be minimal. If animals have a high resistance to using the structure, they may travel long distances along fences trying to find less intimidating places to cross highways.

For large carnivores and deer and elk, 8 foot page wire is standard (Reed 1995). Bears, wolves, coyotes and other carnivores may try to dig under fences, or climb over them. Bears and mountain will occasionally climb fences. There are various remedies for these problems, which are expensive and usually not needed.

Note: Attach fencing to bridge or crossing abutments and do not run it continuously through wildlife crossings. The fenced approach to a wildlife crossing should be as wide as possible. When fencing between lanes of a divided highway, build the fencing parallel to the highway for a short distance so it does not look like a narrow, confining shoot.

Fencing is important for small and mid-sized carnivores, too. There is less information on what fencing is most effective. For most species, standard height highway fencing (4 foot page wire) will be adequate. Skunks and other small carnivores may be able to fit through 4" mesh size. In Europe, a variety of fencing material is used; including variable mesh fencing that has small-sized mesh openings at the bottom and 4"x 4" page wire on top. One half inch mesh screening is used in Europe for badger, amphibians and other small animals. Three or four foot high 2"x 4" page wire would be adequate to funnel small carnivores into 36" culverts.

7. **Highway Configuration:** Often highway configuration can be used to benefit wildlife crossings. Whereas the "openness ratio" of a 2-lane highway facilitates use of wildlife crossings by most ungulates and large carnivores, when there are 4 to 6 lanes of continuous lanes, wildlife crossings can take on the appearance of looking down a stove pipe. By dividing highways, an intimidating wildlife crossing on a 4-lane road becomes a less intimidating set of 2-lane crossings. When highways go through improvements from 2-lanes to 4-lanes, many will have divided sections. If a vegetated corridor exists between lanes, animals can move through one side of a highway, rest or loaf, and then cross the far lanes.

## Step Four: Wildlife Crossing Follow-Up and Learning From Your Successes

Scientific evidence for wildlife crossings and wildlife habitat connectivity is increasing throughout the United States and elsewhere in the world. There is evidence that large, interconnected wildlife populations are more "viable" or "persistent" than isolated small populations (Noss et al 1996; Noss 1987; Noss and Harris 1986; Noss 1983). Reducing or minimizing mortality is important for some species, particularly those that are rare, have low fecundity or that exist in small populations. Carnivore populations often fit these situations.

Based on the high investments required to provide effective wildlife crossings, additional scientific information is needed. The most expensive wildlife habitat connectivity efforts in the United States may cost upwards of $100 million for relatively short highway segments. Now that many State DOTs are providing wildlife crossings on regular basis, there is a new concern for keeping costs down. To do this, research must be designed to determine the types and sizes of wildlife crossings that are effective and have low costs. The choice agencies have may come down to settling on one or two higher priced wildlife crossings or several lesser cost structures.

Presently, there is not enough collaboration between states on road ecology research. Ideally, several states could cooperate on common wildlife crossing issues for a given species or group of species. TRB (Transportation Research Board) funds various kinds of research projects associated with transportation and could develop a comprehensive wildlife/highway research program based on specific issues or problems that need solutions. Road ecology research priorities should be established and the highest priority issues should receive funding.

There is a concern among some managers and biologists that too much monitoring money is being expended without rigorous scientific methodology or publication of results. Or, that research continues for species or issues that have been researched repeatedly. For example, there probably enough research for deer, black bear and cougar wildlife crossings. Many other wildlife species have little or no research. If the purpose of wildlife crossings and connectivity is to ensure long-term fitness of rare populations of carnivores, we have very little information on whether or not enough animals use wildlife crossings to make a difference genetically or demographically. Finding out the answers to this will not be either cheap or easy. Biologists and engineers in Europe may have answers to some of the concerns in North America. They have been building wildlife crossings for at least 40 years longer than we have, and many of their wildlife populations have greater genetic, demographic and habitat issues.

Monitoring is important on most wildlife crossing projects to see if the structures function well, or minimally. Often monitoring can result in better understanding of how to adjust existing structures to function more effectively, or how to build future structures better or more cost efficient. These results need to be shared with others in the biology and engineering fields. The efficacy of wildlife crossings is of great interest to biologists, engineers, wildlife agencies, land management agencies, politicians and the general public. Wildlife crossings and wildlife habitat connectivity measures must have credibility to avoid being labeled as "pork projects" or superfluous spending of taxpayer monies. The results of research and monitoring must include a dialog with the public, agency decision-makers and politicians. It is up to all of us to educate the public on this important work, especially the senior biologists and engineers.

**Biographical Sketch:** Bill Ruediger, wildlife biologist, consultant and retired ecology program leader for highways, USDA Forest Service has over 36 years experience with highway issues related to wildlife ecology and fisheries. This experience includes threatened and endangered species, many carnivores, elk, deer, moose and other ungulates, spotted owls and various cold water fishes. Ruediger is currently running Wildlife Consulting Resources out of Missoula, MT.

## References

Bekker, G.J.. 1998. Habitat fragmentation and infrastructure in the Netherlands and Europe. . In: Evink, G.L.; Garrett, P.; Ziegler, D.; and J. Berry (Eds.) Trends In Addressing Transportation Related Wildlife Mortality. *Proceedings the International Conference on Ecology and Transportation*. Pgs 151-165.

Clevenger, A.P., B. Chruszcz, and K. Gunson. 2001. Highway mitigation fencing reduces wildlife vehicle collisions. *Wildlife Society Bulletin*. 29: 646-653.

Clevenger, A. P., and N. Waldo. 1999. Dry drainage culvert use and design considerations for small- and medium-sized mammal movement across a major transportation corridor. In: *Proceedings of the Third International Conference on Ecology and Transportation*, edited by G.L. Evink, P, Garret and D. Zeigler. FL-ER-73-99. Florida Department of Transportation, Tallahassee, FL. Pages 263-277.

Evink, G.L. 2002. Interactions between roadways and wildlife ecology: a synthesis of highway practices. NCHRP Synthesis 305. Transportation Research Board, Washington D.C. 78 pgs.

Forman, R. T. T., and D. Sperling, J. A. Bissonette et al. 2003. *Road Ecology: Science and Solutions*. Washington D.C., Island Press. 481 pages.

Gordon, K. M. 2003. Mule deer use of underpasses in western and southwestern Wyoming. In: *2003 Proceedings of the International Conference on Ecology and Transportation*, edited by C. Leroy Irwin, Paul Garret, and K.P. McDermott. Raleigh, N.C. Center for Transportation and the Environment, North Carolina State University. Pgs 309-318.

Noss, R.F., H.B. Quigley, M.G. Hornocker, T. Merrill, and P.C. Paquet. 1996. Conservation biology and carnivore conservation in the Rocky Mountains. *Conservation Biology* 10(4):949-963.

Noss, R.F., and L.D. Harris. 1986. Nodes, networks, and MUMs: preserving diversity at all scales. *Environmental Management* 10:299-309.

Noss, R.F. 1987. Protecting natural areas in fragmented landscapes. *Natural Areas Journal* 7:2-13.

Noss, R.F. 1983. A regional landscape approach to maintain diversity. *BioScience* 33:700-706.

Reed, D.F. 1995. Efficacy of methods advocated to reduce cervid-vehicle accidents: research and rationale in North America. Conference presentee lors du colloque international "Route et faune sauvage", Strasbourg, Conseil de l'Europe, 5-7 juin 1985 and Sapporo, Japan, 27 Jan 1995.

Romin, L.A. and J.A. Bissonette. 1996. Deer-vehicle collisions: status for state monitoring activities and mitigation efforts. *Wildlife Society Bulletin* 24 (20:276-283.

Ruediger, B. and M. DiGiorgio. 2007. Safe passage: a user's guide to developing effective highway crossings for carnivores and other wildlife. USDA Forest Service, Federal Highway Administration, Wilburforce and Southern Rockies Ecosystem Project. 19 pgs.

Ruediger, B. 2004. Carnivore conservation and highways: understanding the relationships, problems and solutions. In: *People and Predators: From Conflict to Coexistence*, edited by Nina Fascione, Aimee Delach and Martin E. Smith. Island Press. Pgs: 132-150.

Ruediger, B. and J. Lloyd. 2003. A rapid assessment process for determining potential wildlife, fish and plant linkages for highways. In: *2003 Proceedings of the International Conference on Ecology and Transportation*, edited by C. Leroy Irwin, Paul Garret, and K.P. McDermott. Raleigh, N.C. Center for Transportation and the Environment, North Carolina State University. Pgs 309-318.

Ruediger, B. 1998. Rare carnivores and highways – moving into the 21st Century. In: Evink, G.L.; Garrett, P.; Ziegler, D.; and J. Berry (Eds.) Trends In Addressing Transportation Related Wildlife Mortality. *Proceedings the International Conference on Ecology and Transportation*. Pgs 10-16.

Ruediger, B. 1996. The relationship between rare carnivores and highways. In: Evink, G.L.; Garrett, P.; Ziegler, D.; and J. Berry (Eds.) Trends In Addressing Transportation Related Wildlife Mortality. *Proceedings of the Transportation Related Wildlife Mortality Seminar*.

Watson, M. and J. Klingel. 2000. Literature summary assessing methods for reducing deer-vehicle accidents. New Mexico Department of Fish and Game Website. http://www.wildlife.state.nm.us/conservation/habitat_handbook/Deer-VehicleAccidents.htm

# Patterns of Carnivore Road Casualties in Southern Portugal

**Clara Grilo** (966079307, cbgrilo@fc.ul.pt), **Carla Baltazar**, and **Margarida Santos-Reis**, Centro de Biologia Ambiental, Departamento de Biologia Animal, Faculdade de Ciências, Universidade de Lisboa, Portugal

**Clara Silva** and **Luis Gomes**, Unidade de Biologia da Conservação, Departamento de Biologia, Universidade de Évora, 7002-554 Évora, Portugal

**John A. Bissonette** (435-797-2511, john.bissonette@usu.edu), U.S. Geological Survey Utah Cooperative Fish and Wildlife Research Unit, Department of Wildland Resources, College of Natural Resources, Utah State University, Logan, UT 84322-5290 USA

**Abstract:** We examined spatial patterns of carnivore casualties by counting the number of animals killed on 574 km of national roads and highways in southern Portugal. We surveyed six national roads twice a month from July 2003 to December 2006. Highway casualty data were collected by Brisa Auto-Estradas de Portugal, S. A., a private concession. A total of 801 carnivores representing eight carnivore species were killed. We found an average of 47 vehicle-killed individuals/100km/year; foxes were most numerous with the 20 individuals killed/100km/year. The distribution of carnivore vehicle-kills was clustered except fox. We calculate the mean road kill rate on different classes of variables that may influence road mortality and compare among them to identify the level of risk posed by each class of variable. Casualties were more likely to occur near to suitable habitats preferred by carnivores, in high traffic volume areas, and close to streams. Livestock exclusion fences, the type of road, and the number of passages did not influence mortality. To improve the cost-effectiveness of mitigation measures for new and existing roads, the priority should be given to the road segments crossed by streams in a cork oak woodlands matrix. Short sections of buried fences near culvert openings (100m on each side) should reduce the number of casualties considerably. Habitats connectivity is a serious issue where high volume traffic discourages carnivores from crossing roads at-grade. Connectivity is enabled by appropriately-designed passages.

## Introduction

Roads exert a range of effects on ecological communities, including animal mortality, habitat loss and degradation, and barrier effects that impede animal movements (Forman et al. 2003). As roads are upgraded to accommodate greater traffic volume, the rates of successful wildlife crossings tend to decrease significantly (Iuell et al. 2003). Furthermore, populations of mammalian carnivores may be particularly vulnerable to road mortality because of their low population density, low fecundity, and large home ranges (Gittleman et al. 2001). In some cases, vehicles are the leading cause of local mortality (Ferreras et al. 1992, Clarke et al. 1998).

Recent research has demonstrated that vehicle-kills are spatially clustered and seems to depend on animal population density and biology, habitat type and landscape structure, as well as on road and traffic characteristics (Clevenger et al. 2003, Malo et al. 2004, Ramp et al. 2005). Moreover, the influence of traffic volume on road mortality and barrier effects have long been recognized (Forman and Alexander 1998). It appears that under a certain volume of traffic, mortality increases with traffic. Once a certain traffic volume threshold is reached, animals appear less likely to cross roads.

Here we provide an overview assessment of road impacts on small and medium-sized carnivores of Southern Portugal by analyzing the pattern of road kills. We compiled carcass data, estimated which species were more likely to be killed, and identified which spatial factors influenced the likelihood of road mortality. We expected that carnivore casualties would be non-random because their movement distributions tend to be linked to specific habitats features. We expected to detect a great proportion of carnivore road fatalities on cork oak woodlands. Additionally, we expected a higher mortality on higher volume highways than lower volume national roads.

## Methods

### Road Kill Survey Data Collection

We conducted the study along a 256km section of two highways and 318km in six national roads, in southern Portugal (fig. 1).

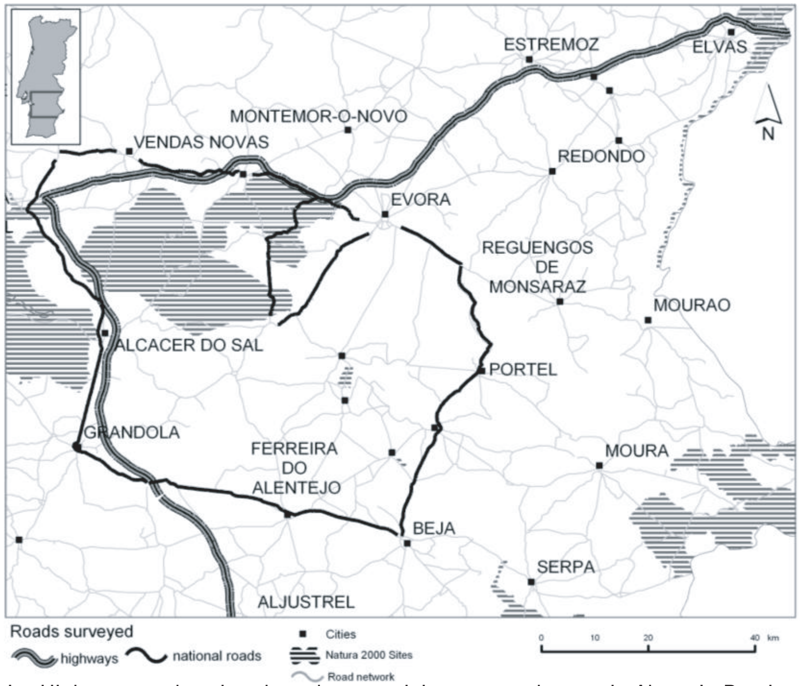



Figure 1. Major Highways and national roads comprising our study area in Alentejo Province, Portugal.

From July 2003 to December 2006, we surveyed the national roads twice a month. One observer drove 20-30km/hr on the paved roadside searching the right-hand side of the road and its verge for any carnivore fatalities, traversing the roads in both directions. Highway data on carnivore casualties were obtained by Brisa Auto-Estradas de Portugal, S.A. (private concession) database.

**Spatial Analysis**

We used Linear Nearest Neighbour Analysis (Levine & Associates 2004) to evaluate whether carnivore vehicle kill data were clustered or dispersed along road segments. The linear nearest neighbour index (NNI) is a ratio between the average distance of the nearest neighbour and the expected random distance (Levine & Associates 2004). If the observed mean distance is the same as the mean random distance, then the ratio will be 1.0. If the observed distance is smaller then the random, the NNI is < 1.0 (clustered). The data are dispersed when NNI >1.0. We hypothesized that given the heterogeneity of the landscape and the habitat preferences of carnivores that the data would be clustered.

To identify the level of risk posed by each class of variable that may influence road mortality (table 1), we divided the highways and national roads into 500m segments (n=1148). All kill data were plotted on the road network in a GIS format and the mortality rate (kills/100km/year) for each segment was calculated. Additionally, we characterized each segment according to different classes of variables.

Table 1: Variables and their description used in the analysis and range of values

| Variable name | Description |
|---|---|
| Habitat | Cork oak woodland (*Quercus suber* and/or *Quercus ilex*) |
| | Extensive agriculture (croplands and arable lands) |
| | Intensive agriculture (olive trees, vineyards and orchards) |
| | Production forest (*Pinus* sp. and *Eucalyptus* sp.) |
| Traffic volume (2005)[a)] | Daily traffic volume at the nocturnal period (vehicles/night) |
| Type of roads | Highways or national roads |
| Livestock exclusion fences | Presence or absence |
| Number of passages | Number of overpasses, underpasses, and culverts |
| Distance to streams | Distance to streams up to 1000m distant |

[a)] values ranged between 330 and 2494 vehicles/night

Except for the dichotomous variables (type of roads and presence/absence of livestock excluding fences), all variables were divided into 3 or more classes. Thus, habitat was categorized into four representative structural vegetation classes in the study area (cork oak woodland, extensive agriculture, intensive agriculture and production forest); data traffic was classified into four classes using Jenk's optimization algorithm (ESRI 1996) that minimizes the variation within each class; passages were classed into four classes (0, 1, 2, > 3 passages); and distance to streams was divided into three distance zones with biological meaning for carnivores. We used Hawth's Analysis Tools extension in ESRI® ArcGis 8.2 to select the same number of random segments for each class of variable (n=100) and we used a one-way ANOVA test to compare the means of road kill rates (Dytham 2003). When the F test was significant, we used all pair-wise comparisons using Tukey´s HSD test to identify which pairs of classes were different. If the variance was not equal we used the Games-Howell test. To remove the habitat effect on the analysis we performed the same procedure only in cork woodland areas. Spatial and statistical analyses were conducted using ArcGIS 8.2, CRIMESTAT v.3 and SPSS 14v. software.

## Results

### Carnivore Road Kill Data

A total of eight carnivores species were detected as road casualties (fig. 2). On average we found 47 vehicle-kills/100km/year; fox (*Vulpes vulpes*) had the highest mortality (20 ind./100km/year), followed by stone marten (*Martes foina*) (8 ind./100km/year), mongoose (*Herpestes ichneumon*) (6 ind./100km/year), and badger (*Meles meles*) and genet (*Genetta genetta*) (5 ind./100km/year each). Otters (*Lutra lutra*) (n=28), polecats (*Mustela putorius*) (n= 20), and weasels (*Mustela nivalis*) (n=12) were the less frequently killed over the three years. No wildcat (*Felis silvestris*), which potentially occurred in the study area, were recorded.

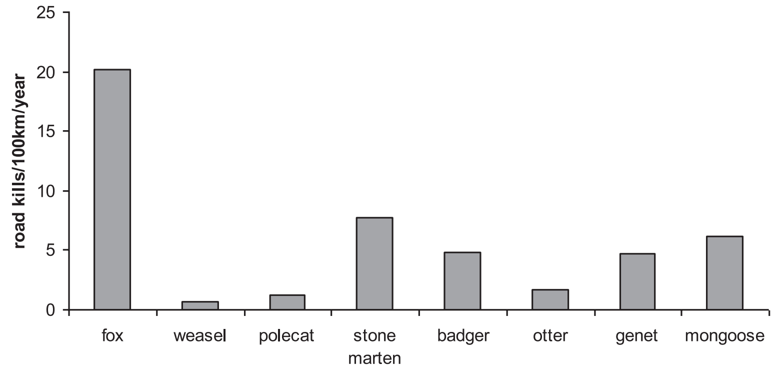



Figure 2. Yearly rate of road killed carnivores on the national roads and highways

### Spatial Analysis

Our results showed that when data for all species were lumped, road kills were dispersed along the roads (NNI>1). However, when we analysed the data separately by species, we found that only fox mortalities were dispersed; the remaining species showed clustering. Nevertheless, the t statistics related with NNI was only significant for the genet road kills distribution ($p<0.05$). The mean road kill rate was different for habitat ($F=7.9$, $df=3$, $p<0.05$), daily traffic volume ($F=6.7$, $df=3$, $p<0.05$), number of passages ($F=2.7$, $df=3$, $p<0.05$), and distance to streams ($F=3.6$, $df=2$, $p<0.05$) (fig. 3). Carcasses were found at the highest frequency in cork oak woodland and at the lowest frequency in extensive agriculture (fig. 3 (i)). The mean number of road kills increased until traffic volume reached 573-973 vehicles/night and then began to decrease (fig. 3 (ii)). Mortality increased with the number of passages (fig. 3 (v)). No significant differences were found in the rate of road kills between national roads and highways ($F=0.45$, $df=1$, $p>0.05$) (fig. 3 (iii)) or the presence/absence of livestock exclusion fences ($F=0.14$, $df=1$, $p>0.05$) (fig. 3 (iv)).

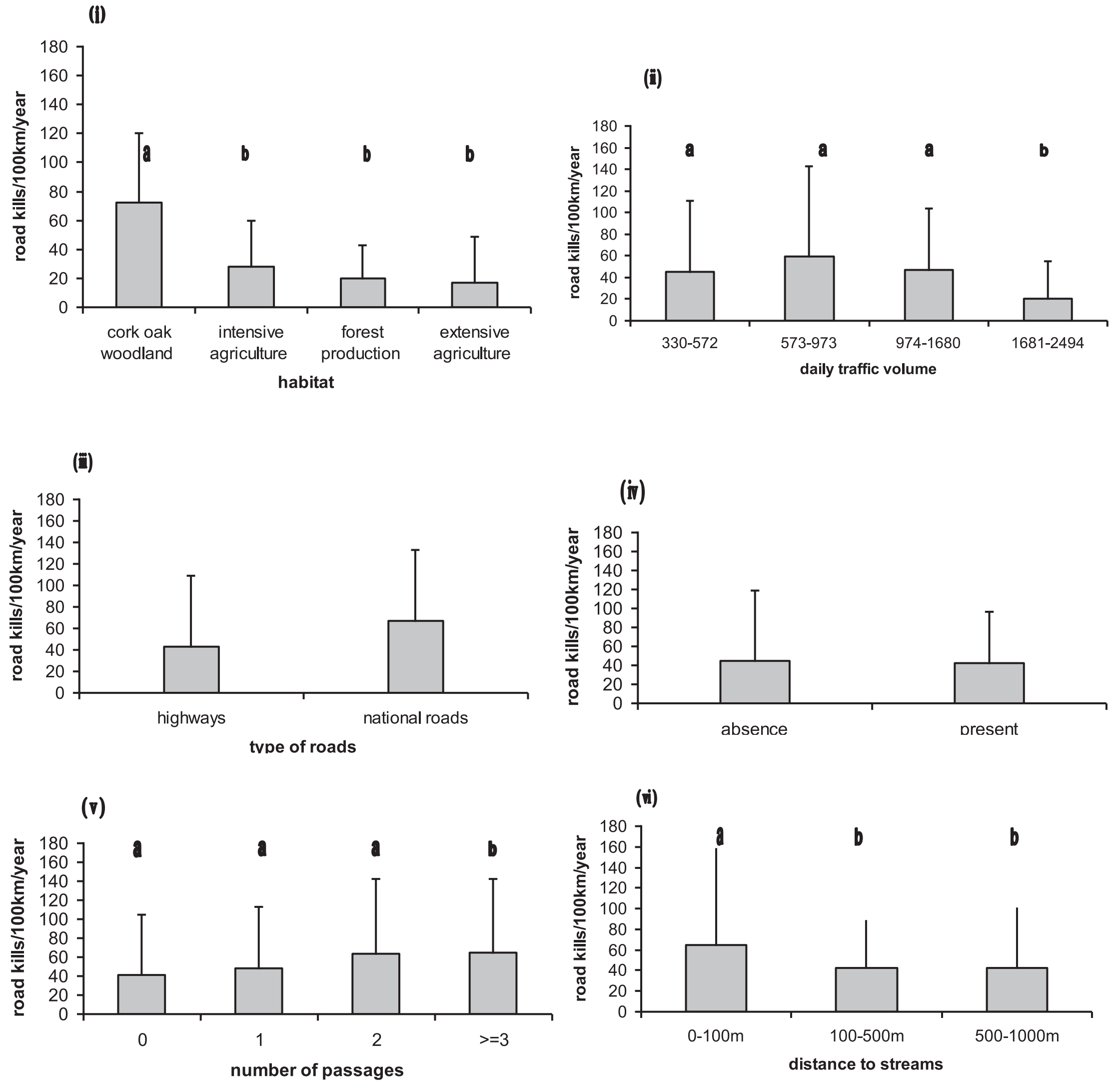



Figure 3. Mean density of road kills plotted against each explanatory variable (habitat, daily traffic volume, type of road, livestock exclusion fences, number of passages and distance to streams). Letters indicate significant differences in mean road kills rate for each class of variable.

The road segments with distance to streams less 100m had a higher mean road kill index value (fig. 3 (vi)). When we performed the same analysis by removing the habitat effect, (viz., using only segments in the cork oak woodland matrix), we found the same patterns but no significant differences among the classes of all variables (all $p>0.05$).

## Discussion

As habitat generalists and wide ranging species, carnivores are known to travel widely over different habitat types, presenting great difficulties in preventing road casualties, because crossing points are far more difficult to predict. However, our findings highlight the significance of two points: a) the incidence of road kills of the most common species; and b) the importance of habitat and traffic on fatalities.

The high number of carnivore casualties we report may be explained in part by their abundance, and also by their wide distribution in the study area, which is characterized by well managed cork oak woodlands and a low human population density. Additionally, the five most frequently killed carnivores are also the most known common species in the region (Cabral et al. 2005).

Even though the results showed that carnivore road kills taken together were dispersed: when analyzed by species, only fox casualties were dispersed. This suggests that species–specific traits of carnivores should be accounted for in these kinds of analyses to reveal if distinct differences among carnivore road kill distributions are evident.

According to our predictions, cork oak woodlands, traffic volume, and distance to streams seem to be important factors for explaining carnivore collisions. Cork oak woodland is a favored habitat for carnivores and the primary habitat where road kills occurred. The data also indicate that high traffic volume has a detrimental effect on carnivores. Nevertheless, above ~1000 vehicles/night the mortality decreased, strongly suggesting that above this threshold carnivores are discouraged from crossing roads at-grade, i.e., roads act as a barrier at higher traffic volumes. The highest carnivore mortality occurred in areas where streams were less than 100m from the road. In reality, streams function as a surrogate for riparian vegetation, the attribute that more directly influences the movement of carnivores. The landscape features associated with streams are well known as travel corridors for carnivores (Simberloff and Cox 1987), providing shelter and food and offering anti-predator cover (Virgós 2001). Livestock exclusion fences did not reduce the probability of road kills. Fences failed to prevent them from travelling over the road because these fences are not buried and have a mesh size too large to inhibit movement of small and medium sized carnivores. Contrary to our expectations, we found no differences of road kill rate between roads and highways, which we suspect is because several sections of both types of roads have similar traffic volumes. Curiously, the number of below-grade crossing structures did not appear to reduce fatalities. However, a previous study (Grilo et al., unpubl. data) showed that carnivores used underpasses and culverts regularly. We found that the number of road kills found in the vicinity of passages was significantly less than the number of times that animals crossed through the passages (Grilo, unpubl. data). It is clear that passages do provide safe passage for wildlife but do not prevent animal-vehicle collisions.

Given these results, we recommend that cork oak woodlands are prime targets for implementing mitigation measures. For example, short sections (100m on each side) of buried and small size net fences that inhibit small animal at-grade crossing and may funnel animals to underpasses or culvert openings and reduce the number of casualties. Moreover, the challenge for transportation agencies and road managers is to be aware of the road segments with high volume traffic and to take appropriate action to ensure the habitat connectivity for carnivores by providing safe passages for wildlife.

**Acknowledgements:** C. Grilo was supported by a Ph.D. grant (SFRH/BD/10600/2002) and by a project (POCTI/MGS/47435/2002) from the Fundação para a Ciência e a Tecnologia. Additional funding was provided by Brisa Auto-Estradas de Portugal S.A. Many thanks are due to Ana Filipa Ferreira, Ana Paula Rosa, Marta Pimentel, Soraia Oliveira, Hugo Tavares, Hugo Baptista, Sílvia Rosa, Dulce Ferreira, Sara Cortez, and Joaquim Pedro Ferreira who assisted road kill data collection and also the Brisa S.A. staff from Estremoz, Vendas Novas e Grândola who registered and collected the carnivore carcasses. We thank Mary Connor for providing critical comments on the manuscript.

**Biographical Sketches:** Clara Grilo is a biologist graduated in the Faculty of Sciences - University of Lisbon. She participated in a project for Iberian wolf South Douro River population conservation giving support in GIS and modelling. She is currently working on her Ph.D. at the University of Lisbon related with the impact of habitat fragmentation and linear infrastructures on small and medium sized carnivores.

Clara Silva is a biologist graduated in the University of Évora, Portugal. She has been working with owls casualties in roads of Southern Portugal since 2004. She is currently working on her master in Biological Conservation in this particular issue, in the same University.

Carla Baltazar is a biologist graduated in the Faculty of Sciences - University of Lisbon. She is currently working on her master in the same University related to model the prey density for Iberian lynx recovery in southern Portugal.

Luis Gomes is a biologist, graduated in University of Évora, Portugal, and holds a Master's degree in Conservation Biology from the same University. He is presently Ph.D. student in the Conservation Biology Unit, University of Évora. His research interests are about the behaviour and ecology of some endangered mammal species.

John A. Bissonette is Leader of the U.S. Geological Survey Utah Cooperative Fish and Wildlife Research Unit and a Professor in the Wildlands Department, College of Natural Resources, Utah State University in Logan Utah, USA. He teaches Landscape Ecology, and is currently working with roaded landscape issues. His homepage is: www.wildlifeandroads.org/john.

Margarida Santos-Reis is a Professor in the Animal Biology Department, Science Faculty, University of Lisbon, where she has teached different courses in animal diversity, biology, ecology and conservation. Being also a researcher at the Centre of Environmental Biology, a R&D centre at the same University, she is currently involved in applied research projects.

## References

Biggs J, Sherwood S, Michalak S, Hansen L & Bare C (2004). Animal related vehicle accidents at the Alamos National Laboratory, New Mexico. *The Southwestern Naturalist* 49 3 384-394.

Cabral MJ, Almeida J, Almeida PR, Dellinger T, Ferrand de Almeida N, Oliveira ME, Palmeirim JM, Queiroz AI, Rogado L, Santos-Reis M (eds) (2005). Livro Vermelho dos Vertebrados de Portugal. Instituto da Conservação da Natureza, Lisboa.

Clarke GP, White PCL & Harris S (1998). Effects of roads on badger Meles meles populations in south-west England. *Biological Conservation* 86 117-124.

Clevenger AP, Chruszcz B & Gunson K E (2003). Spatial patterns and factors influencing small vertebrate fauna vehicle-kill aggregations. *Biological Conservation* 109 15-26.

Dytham C (2003). Choosing and using statistics – a biologist's guide. 2nd edition. *Blackwell Publishing*.

Esri 1996. ArcView GIS - User's guide version 3.1. Environmental Systems Research Institute, Inc. U.S.A. 148pp.

Ferreras P, Aldama JJ, Beltrdn JF & Delibes M (1992). Rates and causes of mortality in a fragmented population of Iberian lynx Felis pardina Temminck, 1824. *Biological Conservation* 61 197-202.

Forman RTT & Alexander LE (1998). Roads and their major ecological effects. *Annual Review Of Ecology and Systematics* 29 207-231.

Forman RTT, Sperling D, Bissonette J, Clevenger A, Cutshall C, Dale V, Fahrig L, France R, Goldman C, Heanue K, Jones J, Swanson F, Turrentine T, Winter T (2003). *Road Ecology: Science and Solutions*. Island Press, Washington.

Gittleman J L, Funk S, Macdonald D & Wayne R (eds) (2001). Carnivore Conservation. *Conservation Biology* 5. The Zoological Society of London. Cambridge 675 pp.

Iuell B, Bekker GJ, Cuperus R, Dufek J, Fry G, Hicks C, HlavÁč V, Keller VB, Rossel C, Sangwine T, Torslov N, le Maire Wandall B (eds) (2003). *Wildlife and Traffic: An European Handbook for Identifying Conflicts and Designing Solutions*. KNNV publishers, UK.

Levine & Associates (2004). CRIMESTATS III a spatial statistics program for the analysis of the crime incidents. The National Institute of Justice.

Malo JE, Suárez F & Díez A (2004). Can we mitigate animal–vehicle accidents using predictive models? *Journal of Applied Ecology* 41, 701–710.

Ramp D, Caldwell J, Edwards K, Warton D & Croft DB (2005). Modelling of wildlife fatality hotspots along the Snowy Mountain Highway in New South Wales, Australia. *Biological Conservation* 126 474-490.

Simberloff D & Cox J (1987). Consequences and costs of conservation corridors. *Conservation Biology*1:63–71

Virgós E (2001). Relative value of riparian woodlands in landscapes with different forest cover for medium-sized Iberian carnivores. *Biodiversity and Conservation* 10:1039-1049

## Roads and Desert Small Mammal Communities: Positive Interaction?

**Silvia Rosa** (silviarosa2007@gmail.com) and
**John Bissonette** (435-797-2511, john.bissonette@usu.edu), USGS Utah Cooperative Research Unit,
Utah State University, Logan, UT 84322-5290 USA

### Introduction

Several indirect effects of roads on wildlife communities have been reported such as habitat quality alteration, loss in landscape connectivity, and barrier effects (Forman et al., 2003; Jaeger et al., 2005). An effect zone of up to 100m on either side of the road has been described as causing measurable impacts on ecological communities (Underhill and Anglod, 2000).

Roads can impact small mammal communities by: 1) creating an edge with different habitat characteristics (Garland and Bradley, 1984; Tyser and Worley, 1992); 2) promoting the introduction of exotic species (Getz et al., 1978; Vermeulen and Opdam, 1995; Underhill and Anglod, 2000); 3) increasing stress and reducing survival (Benedict and Billeter, 2004) through disturbance and contamination (Jefferies and French, 1972; Williamson and Evans, 1972; Quarles et al., 1974); 4) blocking movement thus causing genetic barriers and home range rearrangements (Oxley et al., 1974; Garland and Bradley, 1984; Mader, 1984; Swihart and Slade, 1984; Merriam et al., 1989; Gerlach and Musolf, 2000); and finally 5) causing direct road mortality (Wilkins and Schmidly, 1980; Ashley and Robinson, 1996; Mallick et al., 1998).

While the main focus of studies on the impact of roads on small mammals has been on road barrier effects, less attention has been given to the effect of roads on density and diversity of local communities.

Further analysis on the effect of roads on natural habitats is needed. Our objective was to assess and compare density estimators and diversity of small mammal communities in areas influenced by roads with areas having no road influence.

### Study Area

This study was conducted in the high elevation desert region of southwestern Utah, USA. It is included in the Great Basin geographic region (Durrant, 1952; Barosh, 1960; Cronquist, 1978). The study area was located near Beaver, Utah (38°16'N latitude and 112°37'W longitude) adjacent to Interstate 15 (I-15) (figure 1).

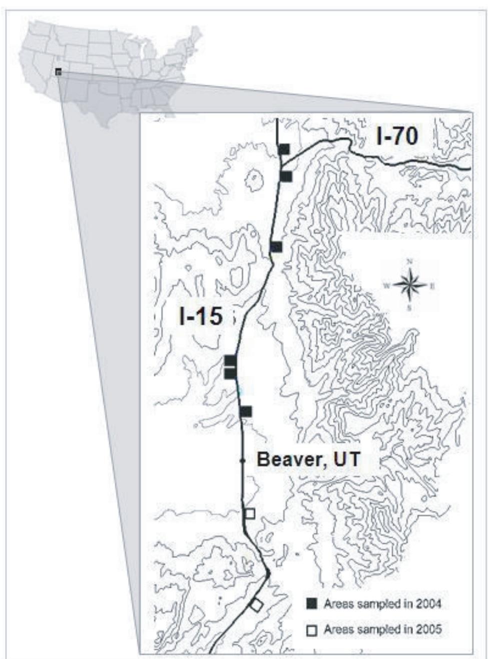



Figure 1. Study area map with trapping location in 2004 and 2005 and geographic areas (A, B, and C) used for comparison of densities in 2004 in southern Utah, USA.

### Methods

#### Field Methodology

Small mammal sampling was conducted exclusively in sagebrush habitat on both sides of the road during the summer periods of 2004 and 2005. Trapping was conducted close to and distant from the road to sample communities with and without putative road influence.

For the first year (2004), 2 trapping webs were placed on a perpendicular transect from the road at each site. In total, each web had a total of 98 traps. We used both lethal (snap traps) and non-lethal (Sherman) traps to maximize the number of species detected and to allow sampling during the diurnal period. The first webs were centered at 50 m from the road (Close) and the second webs centered on average 400 m from the road (Distant).

A different trapping design was used in 2005 to correct problems detected in the first trapping season. Trapping lines were used. Three trapping lines were placed in a perpendicular transect from the road. Trapping lines were set at increasing distances from the road verge (0m - Close, 200m - Mid, 600m - Distant).

### Data Analysis

*Diversity*

We used the Shannon-Wiener diversity index (H) to compare community diversity at different distances from the road (Begon et al., 2006). The index was calculated for each web or trap-line in all transects.

*Abundance and Density Estimation*

Analysis for 2004 web-based data employed a distance method described by Anderson et al. (1983) and accounted for first capture locations for each individual and their distances to the center. Program DISTANCE 4.1 (Buckland et al., 1993, 2001) was used to calculate densities and variance estimates. For analysis purposes, capture data in different transects were pooled in close webs and distant webs because of the low number of animals sampled in each web.

Analysis for 2005 trapping-line-based data was performed using a closed population mark-recapture method in Program MARK 4.3 (White and Burnham, 1999). Closure was assumed given that trapping occurred in a sufficiently brief interval and the removals were known and accounted for in the analysis (Williams et al., 2001). The Huggins Closed Capture estimator was used to obtain abundance estimates.

## Results

### Trapping

We completed a total of 8,406 trap nights (webs 7,056; trap-lines 1,350) and captured 484 small mammals (webs 420; trap-lines 58) comprising 13 species and 11 genera.

In 2004 we captured a total of 11 species (table 1). Two of the species, rock squirrel (*Spermophilus variegatus*) and sagebrush vole (*Lemmiscus curtatus*), were captured exclusively in areas closer to the road, and 2 other species, pinyon mouse (*Peromyscus truei*) and white-tailed antelope squirrel (*Ammospermophilus leucurus*), were captured exclusively distant from the road. The remaining 7 species were captured at both distances.

During 2005 we captured a total of 7 species (table 1). Three of the species - desert cottontail (*Sylvilagus audubonii*), jackrabbit (*Lepus californicus*) and desert woodrat (*Neotoma lepida*) - were only detected closer to the road. No unique species were detected at mid or at distant classes. The number of species decreased as distance to road increased.

During the two years of sampling we noted that some species were only detected in areas with unique micro-habitat characteristics.

Table 1: Species detected at different distances from I-15 in 2004 and 2005 in southern Utah, USA. Species (number of individual captures). * = species uniquelly detected at certain distance

| Distance to road | 2004 | 2005 |
|---|---|---|
| CLOSE | ***Peromyscus maniculatus*** **(124)**<br>***Perognathus parvus*** **(39)**<br>***Tamias minimus*** **(27)**<br>***Dipodomys microps*** **(5)**<br>***Rethrodontomys megalotis*** **(4)**<br>***Peromyscus boylii*** **(3)**<br>***Neotoma lepida*** **(2)**<br>***Lemmiscus curtatus*** **(1) ***<br>***Spermophilus variegatus*** **(1) *** | ***Perognathus parvus*** **(12)**<br>***Peromyscus maniculatus*** **(10)**<br>***Dipodomys microps*** **(8)**<br>***Tamias minimus*** **(2)**<br>***Sylvilagus audubonii*** **(2) ***<br>***Lepus californicus*** **(1) ***<br>***Neotoma lepida*** **(1) *** |
| MID | - | ***Dipodomys microps*** **(11)**<br>***Perognathus parvus*** **(4)**<br>***Peromyscus maniculatus*** **(1)**<br>***Tamias minimus*** **(1)** |
| DISTANT | ***Peromyscus maniculatus*** **(120)**<br>***Perognathus parvus*** **(54)**<br>***Tamias minimus*** **(18)**<br>***Peromyscus boylii*** **(11)**<br>***Ammospermophilus leucurus*** **(4) ***<br>***Rethrodontomys megalotis*** **(3)**<br>***Peromyscus truei*** **(2) ***<br>***Neotoma lepida*** **(1)**<br>***Dipodomys microps*** **(1)** | ***Dipodomys microps*** **(2)**<br>***Perognathus parvus*** **(2)**<br>***Peromyscus maniculatus*** **(1)** |

**Diversity Analysis**

Results of Shannon-Wiener diversity index (H) analysis showed different trends in diversity according to different sampling years. For 2004, diversity was 43.2% higher in areas distant from the road while in 2005 diversity was 57-87% lower further from the road.

**Abundance and Density Analysis**

Analysis to compare total small mammals distribution relative to road distance seems to indicate opposite trends for different years. In 2004 (figure 2), despite the fact that density was 28.9% higher at distant webs, the difference was not significant (Z = -0.49, P = 0.63). In 2005, abundance was found to be 87.3% lower at distant transects (figure 3) as compared with close distances (Z = 3.99, P < 0.001).


Figure 2. Density estimates of small mammals (and 95% Confidence Intervals) in 2004 at different distances from the road in southern Utah, USA.

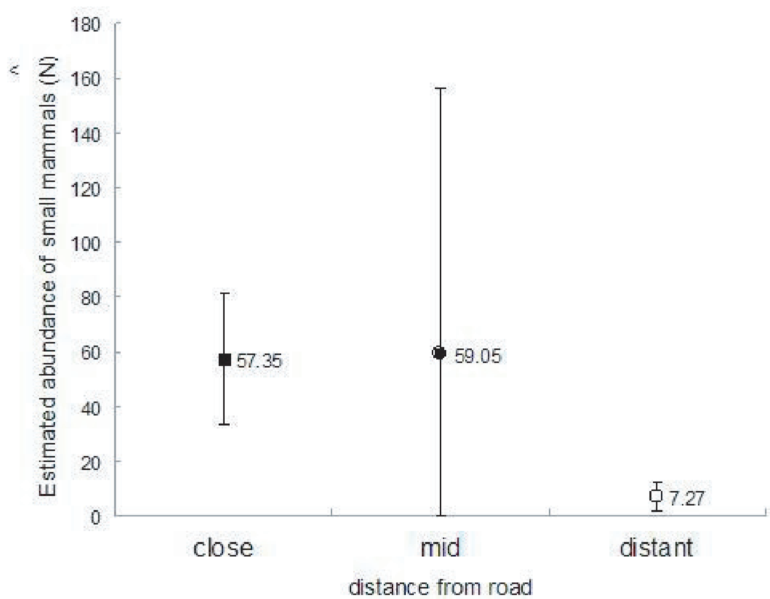



Figure 3. Abundance estimates of small mammals (and 95% Confidence Intervals) in 2005 at different distances from the road in southern Utah, USA.

When we compared densities between 3 different geographic areas, we were able to test if differences in habitat influenced density. One of the areas (area B) had significantly higher densities of all organisms (figure 4).

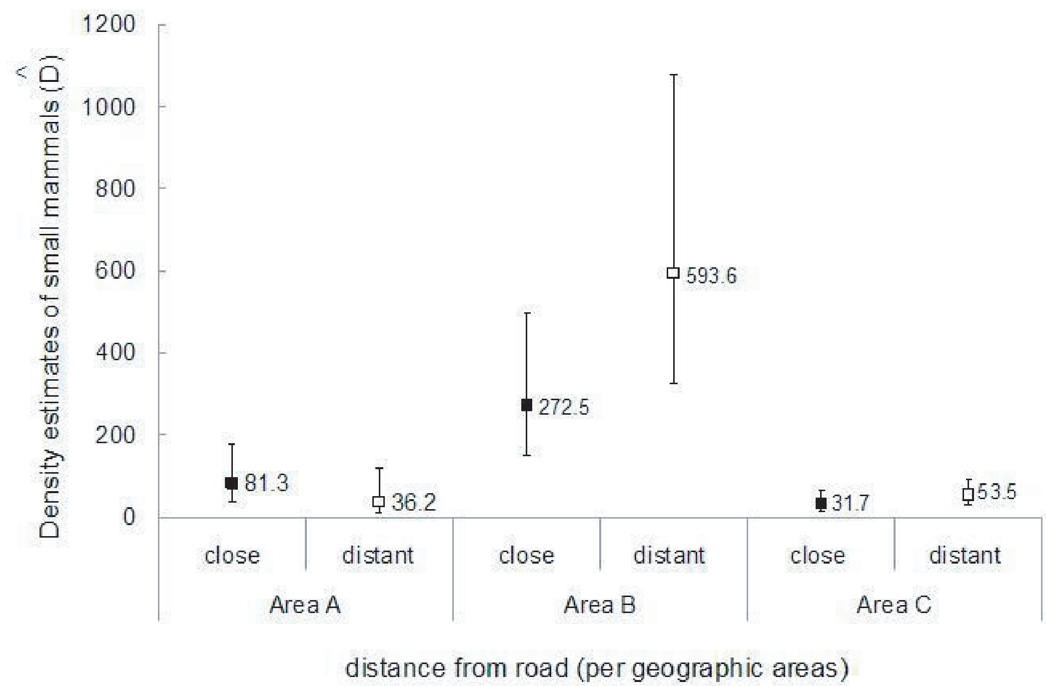



Figure 4. Density estimates of small mammals (and 95% Confidence Intervals) in 2004 at different distances from the road in three distinct geographic areas (A, B, C) in southern Utah, USA.

## Discussion

The main objective of this study was to assess if roads had any zone effects on small mammal community abundance and density. The null hypothesis was that abundance and density would not vary significantly at increasing distances from the road if the road had a no effect. We expected effects, if any, to be constant throughout the length of the study. However, the results are contradictory in different sampling years and suggest that there is no clear effect on small mammal populations relative to distance to the road.

Abundances of small mammals were similar close and distant in 2004, and higher closer to the road in 2005. Diversity was higher away from the road in 2004 and closer to the road in 2005. The road by itself did not seem to influence abundance or diversity patterns. We did not consistently detect any negative impacts. Small mammal populations did not appear to be negatively affected by the presence of the road. Roads may intervene in the landscape as distinctive structures causing barrier effects but do not appear to cause disturbance or habitat impoverishment for small mammals.

Differences in areas sampled, sampling methods, or different trapping years, could have influenced the results. Differences between areas were clearly more important than differences between close and distant trapping sites. Results show that micro-habitat highly influenced organism abundances.

Our results also suggest that the abundance and diversity of small mammals responds more markedly to habitat quality and complexity than to the presence of roads. The comparison of geographic areas in 2004 showed that higher densities of mammals existed with favorable habitat conditions (higher food and shelter availability in Area B than on other areas). Therefore, we suggest that management of roaded landscapes to increase small mammal populations would more profitably focus on roadside habitat improvement rather than on road disturbance mitigation.

This study suggests that the scientific predisposition to consider roads as negative landscape elements for all wildlife is not valid for small mammal communities.

## References

Anderson, D.R., Burnham, K.P., White, G.C., Otis, D.L., 1983. Density estimation of small-mammal populations using a trapping web and distance sampling methods. *Ecology* 64, 674-680.

Ashley, P.E., Robinson, J.T., 1996. Road mortality of amphibians, reptiles and other wildlife on the long point causeway, Lake Erie, Ontario. *The Canadian Field Naturalist* 110, 403-412.

Barosh, P.J., 1960. Beaver lake mountains, Beaver County, Utah. Their geology and ore deposits. Utah Geological and Mineralogical Survey, University of Utah Bulletin 68.

Begon, M., Townsend, C.R., Harper, J.L., 2006. Ecology: From Individuals to Ecosystems, fourth ed. Blackwell Publishing, Oxford, UK.

Benedict, R.A., Billeter, M.C., 2004. Discarded bottles as a cause of mortality in small vertebrates. *Southeastern Naturalist* 3, 371-377.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., 1993. Distance Sampling: Estimating Abundance of Biological Populations. Chapman and Hall, London.

Cronquist, A., 1978. The biota of the intermountain region in geohistorical context. Intermountain Biogeography: a symposium. Great Basin Naturalist Memoirs 2.

Durrant, S.D., 1952. Mammals of Utah - Taxonomy and Distribution. Museum of Natural History. University of Kansas publications.

Forman, R.T.T., Sperling, D., Bissonette, J.A., Clevenger, A.P., Cutshall, C.D., Dale, V.H., Fahrig, L., France, R., Goldman, C.R., Heanue, K., Jones, J.A., Swanson, F.J., Turrentine, T., Winter, T.C., 2003. *Road Ecology: Science and Solutions*. Island Press, Washington, DC, USA.

Garland, T.J., Bradley, W.G., 1984. Effects of a highway on Mojave Desert rodent populations. *American Midland Naturalist* 111, 47-56.

Gerlach, G., Musolf, K., 2000. Fragmentation of landscape as a cause for genetic subdivision in bank voles. *Conservation Biology* 14, 1066-1074.

Getz, L.L., Cole, F.R., Gates, D.L., 1978. Interstate roadsides as dispersal routes for Microtus pennsylvanicus. *Journal of Mammalogy* 59, 208-212.

Jaeger, J.A.G., Bowman, J., Brennan, J., Fahrig, L., Bert, D., Bouchard, J., Charbonneau, N., Frank, K., Gruber, B., von Toschanowitz, K.T., 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. *Ecological Modelling* 185, 329-348.

Jefferies, D.J., French, M.C., 1972. Lead concentrations in small mammals trapped on roadside verges and field sites. *Environmental Pollution* 3, 147-156.

Mader, H.-J., 1984. Animal habitat isolation by roads and agricultural fields. *Biological Conservation* 29, 81-96.

Mallick, S.A., Hocking, G.H., Driessen, M.M., 1998. Road-kills of the eastern barred bandicoot (Perameles gunnii) in Tasmania: an index of abundance. *Wildlife Research* 25, 139-145.

Merriam, G., Kozakiewicz, M., Tsuchiya, E., Hawley, K., 1989. Barriers as boundaries for metapopulations and demes of Peromyscus leucopus in farm landscapes. *Landscape Ecology* 2, 227-235.

Oxley, D.J., Fenton, M.B., Carmody, G.R., 1974. The effects of roads on populations of small mammals. *Journal of Applied Ecology* 11, 51-59.

Quarles III, H.D., Hanawalt, R.B., Odum, W.E., 1974. Lead in small mammals, plants, and soil at varying distances from a highway. *Journal of Applied Ecology* 11, 937-949.

Swihart, R.K., Slade, N.A., 1984. Road crossing in Sigmodon hispidus and Microtus ochrogaster. *Journal of Mammalogy* 65, 357-360.

Tyser, R.W., Worley, C.A., 1992. Alien flora in grasslands adjacent to road and trail corridors in Glacier National-Park, Montana (USA). *Conservation Biology* 6, 253-262.

Underhill, J.E., Angold, P.G., 2000. Effects of roads on wildlife in an intensively modified landscape. *Environmental Reviews* 8, 21-39.

Vermeulen, H.J.W., Opdam, P.F.M., 1995. Effectiveness of roadside verges as dispersal corridors for small ground-dwelling animals: a simulation study. *Landscape and Urban Planning* 31, 233-248.

White, G.C., Burnham, K.P., 1999. Program MARK: survival estimation from populations of marked animals. *Bird Study* 46, 120-138.

Wilkins, K.T., Schmidly, D.J., 1980. Highway mortality of vertebrates in southeastern Texas. *Texas Journal of Science* 32, 343-350.

Williams, B.K., Nichols, J.D., Conroy, M.J., 2001. *Analysis and Management of Animal Populations*. Academic Press.

Williamson, P., Evans, P.R., 1972. Lead: levels in roadside invertebrates and small mammals. *Bulletin of Environmental Contamination and Toxicology* 8, 280-288.

## Poster Sessions

# Ecological Effects of Road Infrastructure on Herpetofauna: Understanding Biology and Increasing Communication

**Kimberly M. Andrews** (803-725-0422, andrews@srel.edu) and **J. Whitfield Gibbons** (gibbons@srel.edu), Savannah River Ecology Laboratory, University of Georgia, Drawer E, Aiken, SC 29802, Fax: 803-725-3309 USA

**Denim M. Jochimsen** (208-885-6185, denimj@uidaho.edu), Department of Biological Sciences, University of Idaho, Room 252 Life Sciences Bldg., P.O. Box 443051, Moscow, ID 83844, Fax: 208-885-7905 USA

**Abstract:** Roads are the ultimate manifestation of urbanization, providing essential connectivity within and between rural and heavily populated areas. Roads permeate national forests and other established wilderness areas; consequently, no areas in the U.S. are protected from this expanding infrastructure. The ecological impacts roads have on herpetofauna across temporal and spatial scales are profound, beginning during the early stages of construction and progressing through to completion and daily use. Herpetofauna have the potential to be negatively influenced from roads as a consequence of urbanization, either directly from on-road mortality or indirectly as a result of a variety of ecological impacts and enabled human accessibility. The quantity and the potential severity of indirect impacts of roads and urban development on amphibians and reptiles far exceed those incurred from direct mortality of wildlife although our understanding of these indirect consequences is premature. Our objective for this presentation is to: 1) summarize the prevalence of data on direct mortality of herpetofauna, 2) to characterize the diversity of indirect effects from roads, 3) to suggest larger-scale impacts on population and community levels, and 4) to recommend areas of future research for impacts that are undocumented but for which herpetofauna are likely susceptible based on their ecological strategies. Lastly, we present approaches for resolving and preventing conflicts between wildlife and roads. While some on-road mortality can be minimized in some instances for some species with road crossings, the mitigation of indirect effects such as pollution cannot be accomplished with these measures. In light of the many indirect effects that have been identified and the many more that remain to be documented, proactive transportation planning, public education, and communication among the professional sectors of society are the most effective way to minimize and mitigate road impacts and the only effective mechanism for avoidance of road impacts.

## Introduction

Human societies, whether urban or rural in population density, depend on transportation networks to establish conduits for people and products. Mass production of vehicles in the 1900s created demand for expansion and efficiency of the road network, particularly in the United States (U.S.); currently, approximately 6.4 million km of public roads span the U.S. (Forman et al. 2003). Roads generate an array of ecological effects that disrupt ecosystem processes and wildlife movement. Road placement within the surrounding landscape is possibly the most important factor determining the severity of road impacts on wildlife because it influences roadkill locations and rates and the observed presence or absence of species.

The combined environmental effects generated by roads (e.g., thermal, hydrological, pollutants, noise, light, invasive species, human access), referred to as the "road-effect zone" (Forman 2000), extend outward from 100 m to 800 m beyond the road edge (e.g., Reijnen et al. 1995). Considered independently, each factor influences the surrounding ecosystem to varying extents and is further augmented by road type and environmental processes, including wind, water, and behavior (Forman et al. 2003). Based on a conservative assumption that effects permeate 100-150 m from the road edge, an estimated 15-22% of the nation's land area is projected to be ecologically impacted by roads (Forman and Alexander 1998), an area about 10 times the size of Florida (Smith et al. 2005). However, some effects appear to extend to 810 m (i.e., 0.5 mi), resulting in 73% of U.S. land area that would be susceptible to impacts (Riitters and Wickham 2003).

Roads enhance connectivity between rural and heavily populated areas, and consequently are the ultimate manifestation of urbanization, which occurs in progressive stages across multiple temporal and spatial scales. Between 1950 and 1990, urban land area increased more than twice as fast as population growth (White and Ernst 2003). As development sprawls outward from the city core, existing transportation corridors are supplemented to support increased traffic volumes (Forman et al. 2003). Alternatively, roads may facilitate future development of an area, increasing use of surrounding habitats by humans for hunting, collection, and observation of wildlife (Andrews 1990; White and Ernst 2003). The extension of the U.S. road system permits vehicle access to most areas, as evidenced by the fact that 82% of all land lies within only 1 km of a road (Riitters and Wickham 2003). The USBTS (2004) defines an urban area as "a municipality . . . with a population of 5,000 or more." By this definition, many national parks and wildlife refuges have daily visitation levels equivalent to populations of small urban areas and during months of peak visitation have traffic volumes comparable to some cities (National Park Service 2004). Therefore, recreational activities in these natural areas may detrimentally impact species that should otherwise be protected (Seigel 1986).

Conflicts continually arise due to the interconnectedness of issues related to roads, wildlife, and adjacent habitats. These conflicts have led experts from multiple fields (e.g., transportation planners, federal, state, and local governments, land managers, consultants, non-profit organizations, environmental action groups, engineers, landscape and wildlife ecologists) to contribute their knowledge in an effort to explain the "complex interactions between organisms and the environment linked to roads and vehicles" in the field of road ecology (Forman et al. 2003). The field continues to grow, as evidenced by the increase in scientific publication (herpetofauna; fig. 1) of reviews, bibliographies, and texts that focus on the general effects of roads on natural systems (e.g., Andrews 1990; Forman et al. 1997; Forman and Alexander 1998; Spellerberg 1998; Spellerberg and Morrison 1998; Trombulak and Frissell 2000; Forman et al. 2003; White and Ernst 2003; NRC 2005). Further, there are also brief reviews that elaborate on the specific effects that roads have on wildlife. These reviews are published online (FHWA [Federal Highway Administration] 2000), in conference proceedings (Jackson 1999; Jackson 2000), as unpublished reports (Noss 1995; Watson 2005), and in a peer-reviewed journal (Trombulak and Frissell 2000). Additionally, some of these focused reviews have dealt specifically with herpetofauna (Maxell and Hokit 1999; Ovaska et al. 2004; Smith et al. 2005); further comprehensive presentations of this information are now available (Jochimsen et al. 2004; Andrews et al. 2006 [www.parcplace.org]; Andrews et al. 2007).

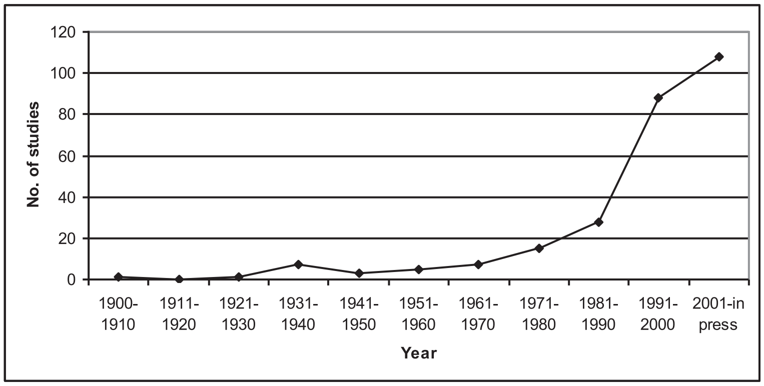



Figure 1. The number of published studies represented within this document that involve herpetofauna and road issues displayed in 10-year increments. Literature includes publications specifically on herpetofauna and road issues, vertebrate studies on roads that include herpetofauna, and herpetofaunal research that includes roads. Note that the final decade (2001-2010) includes only 6 years, yet greatly surpasses the publication rate on roads in previous decades. Figure taken from Andrews et al. (2006).

The extent to which roads are linked to the widespread decline of amphibian and reptile populations (Gibbons et al. 2000; Stuart et al. 2004) is unresolved. Nonetheless, the prospect of mitigating and, even more ideally, reducing the adverse effects that can be attributed to roads seems attainable. A better understanding of how roads affect herpetofauna and the subsequent application of this knowledge will minimize detrimental effects on these taxa. Our objective here is to discuss how roads and vehicles directly and indirectly affect amphibian and reptile individuals, populations, and communities through direct mortality, habitat loss, fragmentation, and ecosystem alterations. We present effects for which there are data in addition to identifying biological characteristics of herpetofauna that increase their susceptibility to roads and are areas in need of research. In a sister paper in this volume (Jochimsen and Andrews), we provide examples of post-construction mitigation and long-term solutions of pre-construction transportation planning and public awareness.

## Direct Mortality

Researchers have conducted surveys along roads in an effort to quantify the most conspicuous effect that roads impose on wildlife--mortality inflicted by vehicles. Direct effects involve injury or mortality that occurs during road construction (e.g., inadvertent burial or death from blasting and earth moving), or subsequent contact with vehicles associated with increased development. Direct mortality of herpetofauna has been documented since the beginning of the 20th century, the some effects of roadkill were not observed until decades later (e.g., amphibians, Puky 2006; snakes, Fitch 1999). While urban areas present obvious concerns for roadkills, road mortality has been considered the greatest non-natural source of vertebrate death in protected areas (Bernardino and Dalrymple 1992; Kline and Swann 1998).

### Amphibians (Salamanders and Anurans)

Studies investigating road effects specifically on amphibians have been conducted in Europe perhaps longer than in any other region, and mitigation efforts have been in place since the 1960s (Puky 2004; Schmidt and Zumbach 2007). The highest rates of road mortality for amphibians occur where roads located in the vicinity of a wetland or pond disrupting the spatial connectivity of essential resources and habitats across the landscape (e.g., Ashley and Robinson 1996; Smith and Dodd 2003). Mass movements triggered by rainfall and warm weather may result in excessive rates of road mortality for salamanders and anurans (e.g., Turner 1955; Clevenger et al. 2001; Ervin et al. 2001). Many species fall victim to roads in great numbers during mass migrations of breeding adults and later as emerging metamorphs. Road mortality is likely substantially higher for some species of anurans relative to most salamanders due to higher reproductive output and tendency to breed in roadside habitats. In addition, anurans possess a delicate body structure that may make them more vulnerable to the high pressure wave created by a passing vehicle, which researcher Dietrich Hummel found can result in death even without experiencing a direct hit from a vehicle (Holden 2002).

Several studies have focused strictly on the probability of individual amphibians being killed on the road. The estimated survival rate of toads crossing roads in Germany with traffic densities of 24-40 cars per hour varied from zero (Heine 1987) to 50% (Kuhn 1987). Hels and Buchwald (2001) calculated that the probability of individual mortality while crossing a road ranged from 0.34 to 0.98 across traffic volumes, depending on various attributes of a given species. Their model has been adapted to assess mortality probabilities for turtles (Gibbs and Shriver 2002; Aresco 2005a) and snakes (Andrews and Gibbons 2005). However, all are based on individual deaths presented as proportions, so the extrapolations to true population levels are equivocal.

**Reptiles (Crocodilians, Lizards, Turtles, and Snakes)**

Few road surveys have documented mortality of crocodilians and lizards, and most observations have been recorded incidentally (e.g., Klauber 1939; Fitch 1949; Dodd et al. 1989). Traffic deaths have been suggested as the major known source of mortality for some large, endangered species, including the American Crocodile (*Crocodylus acutus*; Gaby 1987; Kushlan 1988; Harris and Gallagher 1989). Crocodilians also present a safety concern for drivers and can result in human death (Associated Press 2005). Lack of evidence for high mortality of lizards could be a detection issue due to small size and rapid deterioration of road-killed specimens of many species (e.g., Kline and Swann 1998), or a lower mortality rate due to their ability to cross roads faster than other reptiles (but see Kline et al. 2001). Also, most species of lizards do not migrate seasonally and exhibit high site-fidelity within small home ranges, potentially limiting their encounters with roads (Rutherford and Gregory 2003).

Slow-moving turtles, especially species that retreat into their shells when vehicles pass, are long-lived species that likely experience irreparable population impacts when adult females are killed (Congdon et al. 1993). Studies report seasonal peaks in road mortality correlated with the migration of nesting females and hatchling dispersal (e.g., Ashley and Robinson 1996; Fowle 1996; Haxton 2000). Spatial concentrations of turtle mortalities tend to be associated with movement between wetland habitats (Dodd et al. 1989). In a seven-year census (1989-1995), Wood and Herlands (1997) reported the roadkill deaths of 4,020 Diamond-backed Terrapins (*Malaclemys terrapin*) along a road that bisects a marsh in coastal New Jersey. Along a highway dividing Lake Jackson in Tallahassee, FL, Aresco (2005a) never observed a single individual survive a road crossing, and subsequently has documented the highest turtle road mortality rate yet reported (pre-fence data; n=343; 95% killed when entering highway, remaining 5% killed in first two lanes).

The most thorough, long-term records of direct road mortality have been provided for snakes. Since the 1930s, herpetologists have driven U.S. roads to document snake occurrence and collect specimens (e.g., Klauber 1931; Scott 1938); therefore, documentation of traffic fatalities with this taxa are not novel. Reports in which the majority of specimens are already dead are not uncommon. The highest road mortality of snakes to our knowledge has been documented along U.S. Highway 441 in Paynes Prairie State Preserve in Florida (1.854 individuals/km surveyed, 623 snakes killed, 336 km surveyed, Smith and Dodd 2003). Episodic weather events may trigger mass movements of snakes that result in high levels of mortality over fine spatial and temporal scales (e.g., Hellman and Telford 1956). Movement patterns influenced by weather are not always exhibited immediately as evidenced by the summer flooding of the Mississippi River that later triggered a pulse in snake movement across a bordering highway in October (Tucker 1995).

**Summary**

Ample evidence suggests that road mortality of herpetofauna results in significant loss of individuals and in some situations threatens the sustainability of populations. Reed et al. (2004) concluded that road mortality is substantial, exceeding the damage incurred by other anthropogenic sources such as illegal collection for trade. Quantitative effects on populations have mainly been estimated using models or based on mean mortality rates determined by surveys (e.g., Rosen and Lowe 1994), estimates that must be interpreted with caution due to biases associated with road sampling (see Table 1 in Andrews et al. 2006). As the research on road impacts has been disproportionately focused on mammals and birds, we are still learning about some of the more straightforward direct effects of roads on herpetofauna. However, it is apparent that roads are unequivocally a major source of mortality for many amphibians and reptiles in many areas, and likely pose risks to population viability.

## Indirect Effects

The manifold effects of roads extend far beyond encounters between wildlife and vehicles (Andrews 1990; Forman et al. 2003); multiple effects occur across various spatial scales that extend beyond the road. Roads are designed to serve as travel corridors for humans, usually without regard for the environmental needs of wildlife. Therefore, problems may arise when wildlife use road systems for their own movement. Unlike natural corridors, roads frequently cross topographic and environmental contours, thereby fragmenting a range of habitat types (Bennett 1991) and affecting many wildlife groups that possess a diversity of ecological and life history strategies. The transformation of physical conditions on and adjacent to roads eliminates areas of continuous habitat while simultaneously creating long-lasting edge effects (Forman and Alexander 1998). When discussing indirect road effects on herpetofauna, the information base becomes sparse because indirect effects are more pervasive and more difficult to quantify than direct effects, and documenting indirect effects due to roads often requires extensive and long-term monitoring.

**The Road Zone as Habitat: For Better or Worse**

*Reproduction*

Roads and roadside areas can provide habitat for reproductive behaviors. Amphibians, especially frogs, are known to breed in roadside ditches, but successful egg and larval development may be rare (Richter 1997), as ditches often dry before larvae can metamorphose. Some anurans use water-filled tire ruts for breeding and moisture when traversing long distances (e.g., Reh and Seitz 1990), which can lead to adult and larval mortality (D. M. Jochimsen, pers. obs.). The road zone can also serve as an attractant for reproductive behaviors for reptiles (Hódar et al. 2000), an occurrence that can result in high mortality when reproductive activities coincide with peak traffic densities (Caletrio et al. 1996). Lastly, these behaviors result in differential mortality due to increased roadside exposure, as seen with roadside nesting by turtles that may result in reduced survivorship of both adult females and hatchlings (Guyot and Kuchling 1998; Aresco 2005b; Szerlag and McRobert 2006; Brisbin et al. 2007).

*Thermoregulation*

Research suggests that roadsides and road surfaces attract some reptiles for thermoregulatory purposes. Amazonian lizards may benefit from open patches created by roads, due to increased access to basking sites, which consequently improves foraging efficiency (e.g., Sartorius et al. 1999), and some snakes may be attracted to roads that serve as basking sites (e.g., Klauber 1939; Brattstrom 1965; Sullivan 1981a; but see Andrews and Gibbons 2005). Further research is needed to explore variables (e.g., species, season, and environmental conditions) that would likely be involved if thermal conditions serve to attract reptile species to roadsides and road surfaces.

*Foraging*

Secondary impacts of roads on herpetofauna can also occur when roads attract prey or predators (e.g., small mammals, Getz et al. 1978; nesting birds, Ortega and Capen 2002). Prey concentrations in roadside ditches (Franz and Scudder 1977), on shoulders, (Leighton 1903; Smith 1969), and forest edges, (Sullivan 1981b; Wells et al. 1996) can trigger an increased presence of predatory species. Terrestrial Garter Snakes (*Thamnophis elegans*) were observed foraging on Western Toad (*Bufo boreas*) tadpoles in ruts on a road in Idaho (D. M. Jochimsen, pers. obs.). Roads also provide simplified foraging opportunities for predators as they increase exposure to animals crossing the road (Vandermast, 1999). Also, dead animals attract frog, turtle, snake scavengers (e.g., Guarisco 1985; Jackson and Ostertag 1999; Jensen 1999; Morey 2005).

Clearly, some species benefit from roadside edge habitat under certain circumstances and the disturbance of urbanization in general, but ultimately this may incur increased risks. Perhaps more commonly, many herpetofaunal populations are intolerant of edge conditions generated by roads and may decrease directly, or indirectly, because of reduced prey levels resulting from reduced habitat quality surrounding roads (e.g., Haskell 2000). Therefore, assessments of indirect road impacts as a consequence of predator-prey relationships must be conducted in the context of individual species and the ecological requirements of predators and prey.

**Landscape Pollution**

*Hydrological and Microhabitat*

Hydrological changes occur beyond the immediate vicinity of roads (e.g., Jones et al. 2000). The impervious nature of roads elevates precipitation runoff, fluctuations in flow velocities, and flooding in adjacent wetlands, diminishing suitable habitat for amphibian breeding, foraging, and development (Richter 1997). Abnormal flooding cycles can lower amphibian species richness (Richter and Azous 1995) and increase the likelihood of recolonization by predatory fish in formerly fish-free isolated wetlands.

Skin permeability and vulnerability to water loss also make it difficult for amphibians to maintain optimal moisture levels. Desiccation rates increase during dispersal, particularly in altered environments that do not retain natural moisture levels (e.g., Rothermel and Semlitsch 2002) and may also be accelerated for some species when they must traverse roads in urban areas. Changes in microhabitat surrounding the road can result in reduced cover and leaf litter and therefore drier soils, which could influence the abundances of some amphibian species, particularly woodland salamanders (e.g., Marsh and Beckman 2004). These microhabitat changes are compounded by problems of chemical run-off, erosion, sedimentation, and siltation (Orser and Shure 1972; Welsh and Ollivier 1998; Semlitsch 2000; Semlitsch et al. 2007).

*Chemical*

Vehicular by-products and compounds associated with road degradation contribute to deposition of pollutants on and around roads (Hautala et al. 1995; Croteau et al. 2007). Exposure to toxic compounds may alter reproduction and have long-term lethal effects on wildlife (Lodé 2000), including endocrine disruption in amphibians that reduces reproductive abilities and survivorship (e.g., Hayes et al. 2006; Rohr et al. 2006). Mahaney (1994) found that water treatments with high petroleum contamination inhibited tadpole growth and prevented metamorphosis. Physiological (i.e., respiratory) and behavioral alterations were observed in lizards and frogs exposed to ozone (Mautz and Dohm 2004). Acid precipitation resulting from automobiles acts as an immune disruptor in adult frogs (Vatnick et al. 2006). Lead levels in soil and vegetation are negatively correlated with distance from roads (e.g., Scanlon 1979), and concentrations are positively correlated with traffic density (e.g., Goldsmith et al. 1976). Chloride from de-icing salt runoff contaminates fresh waters peripheral to road systems (Environment Canada 2001; Kaushal et al. 2005) and can be an agent in reduced survival and reproductive effort (Turtle 2000; Sanzo and Hecnar 2006; Karraker 2007). Forman and Deblinger (2000) suggested that road salts altered aquatic habitats up to 200 - 1500 m from a busy suburban highway corridor. Additionally, research has demonstrated compromised water quality and reduced amphibian survival from herbicides and dust-control agents (Kohl et al. 1994; deMaynadier and Hunter 1995; Wood 2001). Less is known about physiological effects of road-associated pollutants on reptiles. However, it is reasonable that similar issues exist with the uptake of pollutants directly from the environment or from prey items where transferred concentrations vary between sexes and among body sizes (e.g., Rainwater et al. 2005). Scanlon (1979) found higher levels of heavy metals in invertebrate-eating shrews than plant-eating rodents, suggesting that bioaccumulation could be road-related.

*Pheromonal*

Microhabitat changes may obscure olfactory or pheromonal cues. Olfaction plays a primary role in amphibian migration and orientation (e.g., Duellman and Trueb 1986), and some snakes rely extensively on scent for directional movement cues to locate mates (e.g., LeMaster et al. 2001), prey items (e.g., Chiszar et al. 1990), and ambush sites (e.g., Clark 2004). Some naïve neonate snakes trail conspecific adults to hibernacula (e.g., Cobb et al. 2005). Pheromone scent trailing, observed in a variety of species, could conceivably be altered by some contaminants, such as oil residues on roads (Klauber 1931) or road substrate type (Shine et al. 2004).

*Noise*

Vehicular traffic alters environmental conditions of habitats adjacent to roads via vibration and noise, which can modify animal behavioral and movement patterns (Bennett 1991). Effects of traffic noise and vibrations on vertebrates include hearing loss, increase in stress hormones, altered behaviors, and interference of breeding communications (Dufour 1980; Brattstrom and Bondello 1983; Forman and Alexander 1998). Road noise and ground vibration may disrupt cues necessary for orientation and navigation during migratory movements of some amphibians (e.g., breeding frogs and salamanders, Dimmitt and Ruibal 1980). Sun and Narins (2004) found that airplane and motorcycle noise reduced the calling frequency of some anuran species but increased the frequency of other species. Background noise from off-road vehicles often results in modification of calling behavior in male anurans and may impair the ability of females to discriminate among call types and to discern locations of calling males during breeding migrations (Schwartz and Wells 1983; Schwartz et al. 2001). Impacts observed in off-road environments would be exaggerated in urban environments, which present even greater noise interference.

*Light*

Artificial lighting along roads and urban areas alters foraging, reproductive, and defensive behaviors of herpetofauna (Buchanan 2006; Wise and Buchanan 2006). Exposure to artificial light can cause nocturnal frogs to suspend normal behaviors and remain motionless long after light has been removed (Buchanan 1993). More research is needed to assess the overall impacts of lighting in urban areas before informed recommendations can be made (Perry et al. 2007).

**Spatial Complexity**

*Dispersal*

Roads can serve as dispersal corridors, facilitating species expansion, an occurrence that is particularly problematic with invasive species. Roads and trail systems facilitated the expansion across Australia of introduced Cane Toads (*Bufo marinus*, Seabrook and Dettmann 1996), which have been estimated to invade new areas at a rate of over 50 km a year (Phillips et al. 2006). Phillips et al. (2003) estimated that *B. marinus* could pose a threat to as many as 30% of terrestrial Australian snake species. Additionally, fire ants (*Solenopsis invicta*) proliferate in roadside areas in the United States (Stiles and Jones 1998) and have been identified as a problematic predator on egg-laying reptiles (e.g., Allen et al. 1997; Buhlmann and Coffman 2001; Parris et al. 2002), reducing reproductive output and hatchling survivorship. Lastly, roads can enable the spread of exotic plant species that subsequently eliminate native flora and fauna (Wester and Juvik 1983; Parendes and Jones 2000) and compromise the quality and availability of habitat and prey bases (e.g., Zink et al. 1995; Maerz et al. 2005). Jochimsen (2006) found a correlation between Gopher Snakes (*Pituophis catenifer*) mortality and cover of an invasive grass species along roadsides in Idaho.

*Fragmentation*

As road density increases, species that depend on a non-fragmented landscape to complete their life cycles (e.g., Pope et al. 2000) will be in greatest jeopardy. Resources associated with refugia, mates, and prey tend to be concentrated in distinct habitats that are patchily distributed and seasonally available. When roads bisect these habitats, mortality may become concentrated spatially and seasonally (e.g., Carpenter and Delzell 1951). Landscape permeability and maintenance of movement corridors are critical to ensure metapopulation dynamics of amphibians and reptiles (Marsh and Trenham 2001). Many herpetofaunal species require not only the terrestrial habitat peripheral to wetlands, but corridor linkages with other isolated water bodies (Gibbons 2003). Depending on the mechanisms driving migratory patterns (e.g., genetic, behavioral), deterministic movement patterns and philopatric behaviors may inhibit an individual's ability to readily adapt to a road that interferes with the animal's migratory route In a modeling assessment by Jaeger and colleagues (2006), population persistence was higher if roads were spatially clustered as opposed to evenly distributed across the landscape.

**Behavioral Responses**

As landscape features that alter and fragment natural habitats, roads may impede movements of amphibians and reptiles via alteration of size, shape, or spatial arrangement of habitat patches (e.g., Fahrig and Merriam 1994). Barrier effects are defined as occurrences when 1) animals are killed on roads in numbers that functionally prevent genetic exchange between populations; 2) surrounding habitat quality is reduced such that animals cannot persist; or 3) animals behaviorally avoid roads, contributing to isolation and habitat fragmentation. Vehicles can force wildlife to adapt their behavior either by posing an impenetrable barrier, in which animals selectively avoid the road due to awareness of traffic as suggested by Klauber (1931) or through other little-understood influences on crossing behavior (Andrews and Gibbons 2005).

*Road Avoidance*

Behavioral avoidance of roads by herpetofauna is poorly documented, and species differences are less understood than is species-specific mortality on roads. Road avoidance may occur as a result of several road characteristics, such as traffic, noise, road substrate, openness, and others not yet determined. Models show that differing catalysts for avoidance can influence differing levels of vulnerability at the population level (Jaeger et al. 2005), therefore indicating a need for species-level considerations. Roads can hinder amphibian movement (e.g., Gibbs 1998), and reduced permeability can even occur on low-use forest roads (e.g., Marsh et al. 2005). Barrier effects from roads may vary depending upon the specific type of movement being made. For example, a greater proportion of natal dispersal movements occurred across roads in Maine (22.1%) than either migratory (17.0%) or home-range movements (9.2%; deMaynadier and Hunter 2000). Road avoidance has also been documented in salamanders (Madison and Farrand 1998), lizards (Klingenböck et al. 2000; Koenig et al. 2001), and tortoises (Boarman and Sazaki 1996).

A variety of researchers have noted road avoidance by snakes (e.g., Weatherhead and Prior 1992; Fitch 1999; Goode and Wall 2002; Sealy 2002; Laidig and Golden 2004; Shine et al. 2004; Plummer and Mills 2006). Avoidance rates can vary with road substrate where paved roads have typically catalyzed higher resistance (Hyslop et al. 2006). Andrews and Gibbons (2005) performed experiments that revealed significant levels of variation among species in road avoidance rates where a positive correlation was found between crossing frequency and body length, likely due to natural behaviors of smaller snakes to avoid open spaces (e.g., Klauber 1931; Dodd et al. 1989; Fitch 1999; Enge and Wood 2002). The propensity to cross roads can also vary within a species where juveniles and adults do not cross proportionately to ratios in the surrounding environment (Seigel and Pilgrim 2002) Some snakes attempt to cross, but deter and retreat (Andrews and Gibbons 2005), ultimately not crossing, a behavior that has been observed in the field (Holman and Hill 1961; Franz and Scudder 1977). Individuals that enter a road but do not cross are exposed to both direct mortality and road fragmentation.

Increasing awareness of the prevalence of behavioral avoidance of roads within and among species suggests a topic of interest from both ecological and evolutionary perspectives. Beyond considerations of road avoidance as a learned behavior, genetically-inherited avoidance of roads has not been directly documented, but if a genetic component for response to roads and traffic exists within species, behaviors that increase survival would be under selection. For instance, in areas of greater habitat connectivity, organisms that tend to avoid roads would survive and breed successfully, whereas in fragmented landscapes, organisms that risk crossing roads might be the effective breeders.

*In-Road Behaviors*

Behaviors such as movement speed and predator responses influence susceptibility to road mortality and fragmentation. Slow-moving animals, or those that cross the road at a wide angle, increase their mortality risk. Slow movements of amphibians (Hels and Buchwald 2001), turtles (Gibbs and Shriver 2002; Aresco 2005a), and snakes (Andrews and Gibbons 2005) while crossing roads have been documented. While road-crossing speeds of amphibians and turtles may be fairly consistent within and among species in each group (but see Finkler et al. 2003), crossing speeds of snakes vary significantly among species, suggesting that snakes may suffer a greater range of road mortality rates than other taxa (Andrews and Gibbons 2005). Although correlations of age, reproductive condition, or sex with road crossing speed have not been documented or studied, natural differences in speed exist (Plummer 1997). Lastly, little is published regarding crossing angles for herpetofauna. Two studies on snakes found that individuals consistently move perpendicularly across the road, taking the shortest route possible (Shine et al. 2004; Andrews and Gibbons 2005) suggesting that the road is an area that animals are simply passing through and not a selected habitat.

Immobilization behaviors that are likely derived from predator responses (Andrews and Gibbons 2005) may lead to responses to oncoming or passing vehicles that could significantly influence crossing time. Mazerolle et al. (2005) found that the strongest stimuli for immobilization behavior across six amphibian species were a combination of headlights and vibration. Andrews and Gibbons (2005) found high rates of immobilization in response to a passing vehicle among snake species that would greatly jeopardize some from successfully crossing a busy highway.

### Summary

In summary, indirect impacts from roads on herpetofauna vary considerably within and among taxonomic groups. Many indirect effects of roads are poorly understood and some have yet to be considered, posing unknown challenges for investigators to determine their ultimate impacts on herpetofauna. Potential discoveries of the indirect effects of roads on amphibian and reptile biology promise a wealth of opportunities to conduct meaningful behavioral and ecological research applicable to herpetofaunal conservation on a global scale.

## Effects on the Higher Levels of Ecological Organization

### Population-Level Impacts

The difficulty in monitoring road impacts at the population and community levels is reflected in the lack of available data, although larger scale repercussions of road impacts on herpetofauna are probably underestimated (Vos and Chardon 1998). Roads may affect population size and demography of amphibians and reptiles in a variety of ways, but understanding the full effect of roads on herpetofaunal populations may be delayed and could take decades to elucidate (Patla and Peterson 1999; Findlay and Bourdages 2000). Despite early evidence by Klauber (1939) that a California highway resulted in the local decline of snakes, documentation of amphibian and reptile population declines as a result of roads, directly or indirectly, has been limited and often speculative. In many instances, effects on population density and structure from traffic-related mortality and continued loss of individuals can only be inferred. However, declines and lower population estimates associated with increased road densities and traffic levels have been documented in frogs (e.g., Fahrig et al. 1995), turtles (Boarman and Sazaki 1996; Fowle 1996; von Seckendorff Hoff and Marlow 2002), and snakes (e.g., Rudolph et al. 1999; but see Mazerolle [2004] for amphibians and Sullivan [2000] for snakes]). Gibbs and Shriver (2002) simulated movement patterns for pond and terrestrial turtles against road density and traffic volumes that indicated mortality of >5% of the populations of land and large-bodied pond turtles, a percentage that they suggest is likely unsustainable for long-lived species.

Many amphibians and reptiles exhibit intraspecific variation in ecological requirements and strategies between sexes, across life history stages, and seasons. Variation in movement patterns and abundances may consequently result in differential road mortality rates (e.g., Rudolph and Burgdorf 1997; Titus 2006); often, mortality rates are highest in species and individuals that exhibit the greatest vagility (Bonnet et al. 1999; Carr and Fahrig 2001; Brito and Álvares 2004; Roe et al. 2006). This attribute can lead to skewed population structure in amphibians and reptiles via altered sex ratios and composition of age classes (Fukumoto and Herrero 1998). Female turtles are more likely to be killed on roads (Wood and Herlands 1997; Marchand and Litvaitis 2004; Steen and Gibbs 2004; Aresco 2005b), due in part to nesting activities (e.g., Gibbs and Steen 2005; Steen et al. 2006). Conversely, a higher proportion of male lizards (e.g., Rodda 1990) and snakes (Bonnet et al. 1999; Sealy 2002; Jochimsen 2006; Andrews and Gibbons 2007) die on roads because males disperse further than females in some species. Further, sex bias in road captures can be seasonally variable (Sherbrooke 2002; Moeller et al. 2005). Intraspecific variation in road impacts can often be linked to spatial and temporal attributes of dispersion, which can most often be correlated with mating systems. For instance, males of polygynous species are often the more risk-prone sex as they are responsible for courting and defending multiple females within a territory (Goodman et al. 2005). Further studies designed to explore the variation of sex bias in road captures driven by ecological behaviors are needed to investigate influences on population sustainability. Some long-distance movers, such as Eastern Indigo Snakes (*Drymarchon couperi*) are particularly sensitive to edge effects and therefore could be an ideal umbrella species to look at the effects of landscape fragmentation (Breininger et al. 2004).

Many herpetologists still consider road surveys valuable for monitoring amphibian and reptile occurrence despite obvious biases with this survey method (e.g., Case 1978; Enge and Wood 2002; Steen and Smith 2006). Road surveys are occasionally used to monitor the status of populations (Seigel et al. 2002; Weir and Mossman 2005); however, we urge caution in the interpretation of these data as status cannot be considered independent of the myriad impacts of roads on herpetofauna.

### Genetic Effects on Populations

Amphibian and reptile species often have restricted or patchy distributions and small effective population sizes. Roads may serve as barriers that restrict gene flow and decrease genetic diversity through a combination of direct mortality and inbreeding. In functionally-small populations, these effects may significantly increase the probability of local extinction (Rodriguez et al. 1996). Few studies have empirically documented genetic effects on herpetofauna due to roads, but those that have support the hypothesis that roads reduce gene flow and decrease genetic diversity in amphibians (e.g., Reh and Seitz 1990; Hitchings and Beebee 1998; Lesbarrès et al. 2003), especially when populations are constrained within urban areas (Hitchings and Beebee 1997; Rowe et al. 2000; Scribner et al. 2001; Vos et al. 2001).

Virtually all genetic studies of road impacts on herpetofauna heretofore have focused on amphibians, although reptiles could sustain comparable genetic impacts from roads. Further, the same life history traits such as long-life spans, low reproductive rates, and delayed maturity of many reptile species that could result in more severe genetic effects from roads than that observed with amphibians also increase the difficulty in discerning the role that road and urban fragmentation has on genetic isolation. Nonetheless, modern genetic approaches offer great potential for providing insight into how roads affect populations of both amphibians and reptiles and future research should be informative. For instance, landscape genetics is a new discipline that aims to assess population substructure at fine taxonomic levels across varying geographic scales, which is achieved by detecting genetic discontinuities (i.e., distinct genetic change within a geographic zone) as they are correlated with environmental features, including barriers such as mountains, temperature gradients, or as applicable in this discussion, roads (Manel et al. 2003). This increase in technological ability will allow for more accurate genetic investigations of populations surrounding roads, thereby permitting impact assessments within populations as applicable to an evolutionary time scale.

### Community-Level Impacts

Data on community-level impacts on herpetofauna are lacking in general, although in some instances lower species richness is correlated with road density (Dickman 1987; Halley et al. 1996; Vos and Stumpel 1996; Findlay and Houlahan 1997; Knutson et al. 1999; Lehtinen et al. 1999; Kjoss and Litvaitis 2001). Analyses of road impacts on herpetofauna at ecological scales higher than the individual or species are inherently difficult, because larger, more significant impacts on populations and communities are not instantaneous. As with populations, cumulative effects on biodiversity may take decades to become apparent. Due to natural fluctuations across spatial and temporal scales, effective analyses require long-term research. Unfortunately, long-term initiatives are typically limited by logistics (e.g., time and funding), and trade-offs between ideal experimental designs and resource availability prohibit the larger-scale or longer-term projects. Ecological modeling offers one alternative using numbers collected from short-term surveys to predict long-term effects. However, only through data collection at population and community levels will the full extent of road impacts be realized. This challenge must be met in order for our understanding of road impacts to progress, and issues of scale (both spatial and temporal) should be addressed to enable biologically valid data extrapolations.

## The Road Ahead

The formation of road ecology as a field has fostered action by scientists, conservation advocates, and agencies to design various measures to prevent, mitigate, or compensate for road impacts on surrounding habitats and wildlife (Forman et al. 2003). Many methods may be implemented once a conflict between wildlife and infrastructure is recognized, but the most common solution is the construction of crossing structures. The general function of a crossing structure is to provide safe passage for an animal across the road and to provide connectivity between habitats adjacent to the road (Forman et al. 2003). The synthesis by Jochimsen et al. (2004) provides a composite summary of the various mitigation structures based on descriptions provided by Jackson (1996), Forman et al. (2003), and the USFS website - Wildlife Crossings Toolkit (www.wildlifecrossings.info). Further, Andrews et al. (2006) present pre-construction solution assessments and a tabular presentation of post-construction mitigation projects. For a synopsis of this information, see Jochimsen and Andrews in these proceedings.

Ecologists, engineers, government officials, and the general public are increasingly aware that roads create ecological disturbances and destruction at multiple levels. The approach in the U.S. has been to alleviate traffic problems by building new roads, an action that is rarely effective, often generating new traffic instead of reducing existing volumes (e.g., Pfleiderer and Dieterich 1995). As in North America, herpetofauna throughout the world have the potential to be negatively influenced by roads as a consequence of urbanization, either directly from on-road mortality or indirectly as a result of a variety of ecological impacts, particularly increased human accessibility to the landscape.

Knowledge of road impacts on herpetofauna no longer consists only of on-road mortality. The range, quantity and, potentially, the severity of indirect impacts of roads and urban development on amphibians and reptiles far exceed those incurred from direct mortality of wildlife. Huge gaps exist in our knowledge of secondary environmental effects on wildlife. Designing controlled and replicated experiments in urban and suburban settings is challenging due to the complex spatial mosaic and political divisions of ownership and occupancy. Scientists must accept the challenge and proceed with the understanding of the complexity of road impacts and the seemingly immeasurable amount of variation inherent in diagnosing the problem and developing the solution.

Post-construction mitigation measures are being developed globally. Since the construction of the first amphibian tunnels in 1969 near Zurich, Switzerland (Puky 2004), many structures have become viable alternatives for reducing direct effects of roads for some amphibian and reptile species (Jochimsen et al. 2004). However, the minimization of indirect effects, such as pollution, cannot be accomplished with mitigation structures. Additionally, few studies adequately monitor the efficacy of road-crossing structures in reestablishing connectivity (but see Clevenger and McGuire 2001; Dodd et al. 2004), which is most often the purpose of construction. In light of the many indirect effects that have been identified and many more that remain to be documented, proactive transportation planning to maintain habitat connectivity, public education, and communication among professional sectors of society are the most effective way to minimize and mitigate road impacts and the *only* effective mechanism for avoidance of road impacts.

**Acknowledgements:** We would like to thank Palmetto Bluff Conservancy and the ICOET Conference Program for travel support to the 2007 meetings along with the SREL Education for educational support. We thank the Federal Highway Administration for their financial support in gathering this information and for an increasing interest in the effects of roads on herps. Kudos to Robin Jung and Joe Mitchell for the hectic and substantial task of creating a much-needed volume on Urban Herpetology and including a manuscript from which this paper is a synopsis. Preparation was aided by Federal Highway Administration Cooperative Agreement DTFH61-04-H-00036 between the University of Georgia and U.S. Department of Transportation and by the Environmental Remediation Sciences Division of the Office of Biological and Environmental Research, U.S. Department of Energy through Financial Assistance Award no. DE-FC09-07SR22506 to the University of Georgia Research Foundation. Lastly, we thank all of the scientists and members of society that are gaining ground on the understanding of road impacts on herpetofauna. This research supports the goals of Partners in Amphibian and Reptile Conservation (PARC).

**Biographical Sketches:** Kimberly M. Andrews, a doctoral candidate in the Institute of Ecology at the University of Georgia, conducts research on road ecology, impacts of development, and herpetology at the Savannah River Ecology Laboratory. One of her primary goals is to contribute to reptile and amphibian conservation by conducting ecological research on movement patterns and behavior in fragmented habitats and by promoting a greater understanding and appreciation of herpetofaunal ecology through public outreach and education.

Denim M. Jochimsen is currently a lecturer of the non-major's biology course at the University of Idaho and remains actively involved in environmental education throughout the Palouse region. Her education includes a B.S. in natural science (wildlife ecology major) from the University of Wisconsin–Madison (1999) and M.S. in biology from Idaho State University (2006). She has nine years of research experience with reptiles and amphibians, including survey and laboratory work. Her hope is to place road effects on herpetofauna into a broader context in terms of landscapes and communities.

Dr. J. Whitfield Gibbons, Professor of Ecology at the University of Georgia and Head of the Environmental Outreach and Education program at the Savannah River Ecology Laboratory, conducts research on life history and ecology of reptiles and amphibians. His primary research focus is to document and explain the distribution and abundance patterns of herpetofauna at the ecological and evolutionary levels, with an emphasis on conservation issues.

## References

Allen, C. R., K. G. Rice, D. P. Wojcik, and H. F. Percival. 1997. Effect of red imported fire ant envenomation on neonatal American alligators. *Journal of Herpetology* 31:318-321.

Andrews, A. 1990. Fragmentation of habitat by roads and utility corridors; a review. *The Australian Zoologist* 26:130-141.

Andrews, K. M., and J. W. Gibbons. 2005. How do highways influence snake movement? Behavioral responses to roads and vehicles. *Copeia* 2005:771-781.

Andrews, K. M. and J. W. Gibbons. 2007. Ecological attributes of snakes on roads: sex and body size are significant within and among species. In J. C. Mitchell, R. E. Jung and S. C. Walls (eds.), Urban Herpetology. Society for the Study of Amphibians and Reptiles, *Herpetological Conservation Volume 3*, Salt Lake City, UT.

Andrews, K. M., J. W. Gibbons, and D. M. Jochimsen. 2006. Literature synthesis of the effects of roads and vehicles on amphibians and reptiles. Federal Highway Administration (FHWA), U.S. Department of Transportation. Washington, D.C. 151 pp.

Andrews, K. M., J. W. Gibbons, and D. M. Jochimsen. 2007. Ecological effects of roads on amphibians and reptiles: a literature review. In J. C. Mitchell and R. E. Jung (eds.). Urban Herpetology. *Herpetological Conservation Vol. 3*, Society for the Study of Amphibians and Reptiles, Salt Lake City, UT. In press.

Aresco, M. J. 2005a. Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a north Florida lake. Journal of *Wildlife Management* 69:540-551.

Aresco, M. J. 2005b. The effect of sex-specific terrestrial movements and roads on the sex ratio of freshwater turtles. *Biological Conservation* 123:37-44.

Ashley, P. E., and J. T. Robinson. 1996. Road mortality of amphibians, reptiles and other wildlife on the Long Point Causeway, Lake Erie, Ontario. *Canadian Field Naturalist* 110:403-412.

Associated Press. 2005. Woman who wrecked after hitting alligator Tuesday dies from injuries. *The Beaufort Gazette*. 11 June 2005.

Bennett, A. F. 1991. Roads, roadsides and wildlife conservation: a review. In D. A. Saunders and R. J. Hobbs (eds.), *Nature Conservation 2: The Role of Corridors*, pp. 99-118. Surrey Beatty and Sons, London, UK.

Bernardino, Jr., F. S., and G. H. Dalrymple. 1992. Seasonal activity and road mortality of the snakes of the Pa-hay-okee wetlands of Everglades National Park, USA. *Biological Conservation* 61:71-75.

Boarman, W. I., and M. Sazaki. 1996. Highway mortality in desert tortoises and small vertebrates: success of barrier fences and culverts. In G.L. Evink, P. Garrett, D. Zeigler, and J. Berry (eds.), Trends in Addressing Transportation Related Wildlife Mortality. Proceedings of the Transportation Related Wildlife Mortality Seminar, pp. 169-173. State of Florida Department of Transportation, Tallahassee, Florida. FL-ER-58–96.

Bonnet, X., G. Naulleau, and R. Shine. 1999. The dangers of leaving home: dispersal and mortality in snakes. *Biological Conservation* 89:39-50.

Brattstrom, B. H. 1965. Body temperatures of reptiles. *American Midland Naturalist* 73:376-422.

Brattstrom, B. H., and M. C. Bondello. 1983. Effects of off-road vehicle noise on desert vertebrates. In R. H. Webb and H. G. Wilshire (eds.), *Environmental Effects of Off-Road Vehicles: Impacts and Management in Arid Regions*, pp. 167-206. Springer-Verlag. New York, NY.

Breininger, D. R., M. L. Legare, and R. B. Smith. 2004. Eastern indigo snakes (Drymarchon couperi) in Florida: influence on edge effects and population viability. In H. R. Akçakaya, M. A. Burgman, O. Kindvall, C. C. Wood, P. Sjögren-Gulve, J. S. Harfield, and M. A. McCarthy (eds.), *Species Conservation and Management: Case Studies*, pp. 299-311. Oxford University Press, New York, NY.

Brisbin, I. L., Jr., E. L. Peters, and R. A. Kennamer. 2007. A long-term study of eastern box turtles in a suburban neighborhood: survival characteristics and human-conspecific interactions. In J. C. Mitchell, R. E. Jung and S. C. Walls (eds.), Urban Herpetology. Society for the Study of Amphibians and Reptiles, *Herpetological Conservation Volume 3*, Salt Lake City, UT.

Brito, J. C., and F. J. Álvares. 2004. Patterns of road mortality in Vipera latastei and V. seoanei from northern Portugal. Amphibia-Reptilia 25:459-465.

Buchanan, B. W. 1993. Effects of enhanced lighting on the behavior of nocturnal frogs. *Animal Behavior* 45:893-899.

Buchanan, B. W. 2006. Observed and potential effects of artificial night lighting on anuran amphibians. In C. Rich and T. Longcore (eds.), Ecological Consequences of Artificial Night Lighting, pp. 192-220. Island Press, Washington, D.C.

Buhlmann. K. A., and G. Coffman. 2001. Fire ant predation of turtle nests and implications for the strategy of delayed emergence. *Journal of the Elisha Mitchell Scientific Society* 117:94-100.

Caletrio, J., J. M. Fernández, J. López, and F. Roviralta. 1996. Spanish national inventory on road mortality of vertebrates. *Global Biodiversity* 5:15-17.

Campbell, H. 1953. Observations on snakes DOR in New Mexico. *Herpetologica* 9:157-160.

Carpenter C. C., and D. E. Delzell. 1951. Road records as indicators of differential spring migrations of amphibians. *Herpetologica* 7:63-64.

Carr, L., and L. Fahrig. 2001. Effect of road traffic on two amphibian species of differing vagility. *Conservation Biology* 15:1071-1078.

Case, R. M. 1978. Interstate highway road-killed animals: a data source for biologists. *Wildlife Society Bulletin* 6:8-13.

Chiszar, D., T. Melcer, R. Lee, C. W. Radcliffe, and D. Duvall. 1990. Chemical cues used by prairie rattlesnakes (Crotalus viridis) to follow trails of rodent prey. *Journal of Chemical Ecology* 16: 79-86.

Clark, R. W. 2004. Timber rattlesnakes (Crotalus horridus) use chemical cues to select ambush sites. *Journal of Chemical Ecology* 30:607-617.

Clevenger, A. P., and T. M. McGuire. 2001. Research and monitoring the effectiveness of Trans-Canada highway mitigation measures in Banff National Park, Alberta. In *Proceedings of the Annual Conference and Exhibition of the Transportation Association of Canada*, pp. 1-16. Halifax, Nova Scotia, Canada.

Clevenger, A. P., M. McIvor, D. McIvor, B. Chruszcz, and K. Gunson. 2001. Tiger salamander, Ambystoma tigrinum, movements and mortality on the Trans-Canada Highway in southwestern Alberta. *Canadian Field-Naturalist* 115:199-204.

Cobb, V. A., J. J. Green, T. Worrall, J. Pruett, and B. Glorioso. 2005. Initial den location behavior in a litter of neonate timber rattlesnakes (Crotalus horridus). *Southeastern Naturalist* 4:723-730.

Congdon, J. D., A. E. Dunham, and R.C. van Loben Sels. 1993. Delayed sexual maturity and demographics of Blanding's turtles (Emydoidea blandingii): implications for conservation and management of long-lived organisms. *Conservation Biology* 7:826-833.

Croteau, M. C., J. Gibson, N. Gallant, D. Lean, and V. L. Trudeau. 2007. Toxicological threats to herpetofauna in urban and suburban environments. In J. C. Mitchell and R. E. Jung (eds.), *Urban Herpetology.* Society for the Study of Amphibians and Reptiles, Herpetological Conservation Volume 3, Salt Lake City, UT.

deMaynadier, P. G., and M. L. Hunter, Jr. 1995. The relationship between forest management and amphibian ecology: a review of the North American literature. *Environmental Review* 3:230-261.

deMaynadier, P. G., and M. L. Hunter, Jr. 2000. Road effects on amphibian movements in a forested landscape. *Natural Areas Journal* 20:56-65.

Dickman, C. R. 1987. Habitat fragmentation and vertebrate species richness in an urban environment. *Journal of Applied Ecology* 24:337-351.

Dimmitt, M. A. and R. Ruibal. 1980. Environmental correlates of emergence in spadefoot toads (Scaphiopus). *Journal of Herpetology* 14:21-29.

Dodd C. K., Jr., W. J. Barichivich, and L. L. Smith. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. *Biological Conservation* 118:619-631.

Dodd C. K., Jr., K. M. Enge, and J. N. Stuart. 1989. Reptiles on highways in north-central Alabama, USA. *Journal of Herpetology* 23:197-200.

Duellman, W. E., and L. Trueb. 1986. *Biology of Amphibians*. McGraw-Hill, New York, NY. 670 pp.

Dufour, P. A. 1980. Effects of noise on wildlife and other animals: review of research since 1971. U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Report No. 550/9-80-100. Washington, D.C. 70 pp.

Enge, K. M., and K. N. Wood. 2002. A pedestrian road survey of an upland snake community in Florida. *Southeastern Naturalist* 1:365-380.

Environment Canada. 2001. Priority substances list assessment report: road salts. Unpubl. Report, Minister of Public Works and Government Services. Gatineau, Québec. 186 pp.

Ervin, E. L., R. N Fisher, and K. R. Crooks. 2001. Factors influencing road-related amphibian mortality in Southern California. In G. L. Evink, P. Garrett, K. P. McDermott (eds.), *Proceedings of the 2001 International Conference on Ecology and Transportation*, pp. 43. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.

Fahrig, L., and G. Merriam. 1994. Conservation of fragmented populations. *Conservation Biology* 8:50-59.

Fahrig, L., J. H. Pedlar, S. E. Pope, P. D. Taylor, and J. F. Wegner. 1995. Effect of road traffic on amphibian density. *Biological Conservation* 73:177-182.

FHWA [Federal Highway Administration]. 2000. United States Department of Transportation, *Wildlife and highways: an overview*. http://www.fhwa.dot.gov/environment/wildlifecrossings/overview.htm. 23 July 2006.

Findlay, C. S., and J. Bourdages. 2000. Response time of wetland biodiversity to road construction on adjacent lands. *Conservation Biology* 14:86-94.

Findlay, C. S., and J. Houlahan. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. *Conservation Biology* 11:1000-1009.

Finkler, M. S., M. T. Sugalski, and D. L. Claussen. 2003. Sex-related differences in metabolic rate and locomotor performance in breeding spotted salamanders (Ambystoma maculatum). *Copeia* 2003:887-893.

Fitch, H. S. 1949. Road counts of snakes in western Louisiana. *Herpetologica* 5:87-90.

Fitch, H. S. 1999. A Kansas Snake Community: Composition and Changes Over 50 Years. Krieger Publishing Company, Melbourne, FL. 165 pp.

Forman, R. T. T. 2000. Estimate of the area affected ecologically by the road system in the United States. *Conservation Biology* 14:31-35.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207-231.

Forman, R. T. T., and R. D. Deblinger. 2000 . The ecological road-effect zone of a Massachusetts (U.S.A.) suburban highway. *Conservation Biology* 14:36-46.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road Ecology: Science and Solutions*. Island Press. Washington, D.C. 481 pp.

Fowle, S. C. 1996. Effects of roadkill mortality on the western painted turtle (Chrysemys picta belli) in the Mission Valley, western Montana. In G.L. Evink, P. Garrett, D. Zeigler, and J. Berry (eds.), Trends in Addressing Transportation Related Wildlife Mortality, Proceedings of the Transportation Related Wildlife Mortality Seminar, pp. 205-223. Florida Department of Transportation, Tallahassee, FL. FL - ER - 58 - 96.

Franz, R., and S. J. Scudder. 1977. Observations of snake movements on a north Florida highway. Unpubl. Report, Florida State Museum. University of Florida. Gainesville, FL. 13 pp.

Fukumoto, J., and S. Herrero. 1998. Observations of the long-toed salamander, Ambystoma macrodactylum, in Waterton Lakes National Park, Alberta. *Canadian Field-Naturalist* 112:579-585.

Gaby, R. 1987. Utilization of human-altered habitats by American Crocodiles in southern Florida. In R. R. Odum, K. A. Riddleberger, and J. C. Ozier (eds.), Proceedings of the 3rd Southeastern Nongame and Endangered Wildlife Symposium, pp. 128-138. University of Georgia. Athens, GA.

Getz, L. L., F. R. Cole, and D. L. Gates. 1978. Interstate roadsides as dispersal routes for Microtus pennsylvanicus. *Journal of Mammalogy* 59:208-212.

Gibbons, J. W. 2003. Terrestrial habitat: a vital component for herpetofauna of isolated wetlands. Wetlands 23:630-635.

Gibbons, J. W., D. E. Scott, T. J. Ryan, K. A. Buhlmann, T. D. Tuberville, B. S. Metts, J. L. Greene, T. M. Mills, Y. Leiden, S. Poppy, and C. T. Winne. 2000. The global decline of reptiles, dejá vu amphibians. *BioScience* 50:653–666.

Gibbs, J. P. 1998. Amphibian movements in response to forest edges, roads, and streambeds in southern New England. *Journal of Wildlife Management* 62:584-589.

Gibbs, J. P., and W. G. Shriver. 2002. Estimating the effects of road mortality on turtle populations. *Conservation Biology* 16:1647-1652.

Gibbs, J. P., and D. A. Steen. 2005. Trends in sex ratios of turtles in the United States: implications of road mortality. *Conservation Biology* 19:552-556.

Goldsmith, C. D., Jr., P. F. Scanlon, and W. R. Pirie. 1976. Lead concentrations in soil and vegetation associated with highways of different traffic densities. *Bulletin of Environmental Contamination and Toxicology* 16:66-70.

Goode, M. J., and M. D. Wall. 2002. Tiger rattlesnake ecology and management. Unpubl. Report, Nongame and Endangered Wildlife Program Heritage Report. Arizona Game and Fish Department, Phoenix, AZ. 62 pp.

Goodman, R. M., A. C. Echternacht, and F. J. Burton. 2005. Spatial ecology of the endangered iguana, Cyclura lewisi, in a disturbed setting on Grand Cayman. *Journal of Herpetology* 39:402-408.

Guarisco, H. 1985. Opportunistic scavenging by the bullfrog, *Rana catesbeiana* (*Amphibia, Anura, Ranidae*). Transactions of the Kansas Academy of Science 88: 38-39.

Guyot, G., and G. Kuchling. 1998. Some ecological aspects of populations of oblong turtles (Chelodina oblonga) in the suburbs of Perth (western Australia). In C. Miarid and R. Guyetant (eds.), Proceedings of the 9th Ordinary General Meeting of the Societas Europaea Herpetologica, pp. 173-181. Le Bourget du Lac, France.

Halley, J. M., R. S. Oldham, and J. W. Arntzen. 1996. Predicting the persistence of amphibian populations with the help of a spatial model. *Journal of Applied Ecology* 33:455-470.

Harris, L. D., and P. B. Gallagher. 1989. New initiatives for wildlife conservation the need for movement corridors. In G. Mackintosh (ed.), Defense of Wildlife: Preserving Communities and Corridors, pp. 11-34. Defenders of Wildlife, Washington, D.C.

Haskell, D. G. 2000. Effects of forest roads on macroinvertebrate soil fauna of the southern Appalachian Mountains. *Conservation Biology* 14:57-63.

Hautala, E.-L., R. Rekilä, J. Tarhanen, and J. Ruuskanen. 1995. Deposition of motor vehicle emissions and winter maintenance along roadside assessed by snow analyses. *Environmental Pollution* 87:45-49.

Haxton, T. 2000. Road mortality of snapping turtles, Chelydra serpentina, in central Ontario during their nesting period. *Canadian Field Naturalist* 114:106-110.

Hayes, T. B., P. Case, S. Chui, D. Chung, C. Haeffele, K. Haston, M. Lee, V. P. Mai, Y. Marjuoa, J. Parker, and M. Tsui. 2006. Pesticide mixtures, endocrine disruption, and amphibian declines: are we underestimating the impact? Environmental Health Perspectives 114(suppl. 1):40-50.

Heine, G. 1987. Einfach Meß- und Rechenmethode zur Ermittlung der Überlebenschance wandernder Amphibien beim überqueren von Straßen. Naturschutz und Landschaftspflege in Baden-Württemberg 41:473-479.

Hellman, R. E., and S. R. Telford, Jr. 1956. Notes on a large number of red-bellied mudsnakes, Farancia a. abacura, from northcentral Florida. *Copeia* 1956:257-258.

Hels, T., and E. Buchwald. 2001. The effect of road kills on amphibian populations. *Biological Conservation* 99:331-340.

Hitchings, S. P., and T. J. C. Beebee. 1997. Genetic substructuring as a result of barriers to gene flow in urban Rana temporaria (common frog) populations: implications for biodiversity conservation. *Heredity* 79:117-127.

Hitchings, S. P., and T. J. C. Beebee. 1998. Loss of genetic diversity and fitness in common toad (Bufo bufo) populations isolated by inimical habitat. *Journal of Evolutionary Biology* 11:269-283.

Hódar, J. A., J. M. Pleguezuelos, J. C. Proveda. 2000. Habitat selection of the common chameleon (*Chamaeleo chamaeleon*) (L.) in an area under development in southern Spain: implications for conservation. *Biological Conservation* 94:63-68.

Holden, C. 2002. Spring road peril: toad blowout. *Science* 296:43.

Holman, J. A., and W. H. Hill. 1961. A mass unidirectional movement of Natrix sipedon pictiventris. *Copeia* 1961:498-499.

Hyslop, N. L., J. M. Myers, and R. J. Cooper. 2006. Movement, survival, and habitat use of the threatened eastern indigo snake (*Drymarchon couperi*) in southeastern Georgia. Final Report to the Georgia Department of Natural Resources Nongame Endangered Wildlife Program, Forsyth, GA. 87 pp.

Jackson, D. R., and T. E. Ostertag. 1999. Gopherus polyphemus (*Gopher Tortoise*). Scavenging. *Herpetological Review* 30:40.

Jackson, S. D. 1996. Underpass systems for amphibians. In G.L. Evink, P. Garrett, D. Zeigler, and J. Berry (eds.), Trends in Addressing Transportation Related Wildlife Mortality, Proceedings of the Transportation Related Wildlife Mortality Seminar, pp. 224-227. Florida Department of Transportation, Tallahassee, FL.

Jackson, S. D. 1999. Overview of transportation related wildlife problems. In G. L. Evink, P. Garrett, D. Zeigler and J. Berry (eds.), *Proceedings of the 1999 International Conference on Wildlife Ecology and Transportation*, pp. 1-4. Florida Department of Transportation, Tallahassee, FL. FL-ER-73-99.

Jaeger, J. A. G., L. Fahrig, and K. C. Ewald. 2006. Does the configuration of road networks influence the degree to which roads affect wild-life populations? In C. L. Irwin, P. Garrett, and K. P..McDermott (eds.), *Proceedings of the 2005 International Conference on Ecology and Transportation*, pp. 151-163. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.

Jaeger, J. A. G., J. Bowman, J. Brennan, L. Fahrig, D. Bert, J. Bouchard, N. Charbonneau, K. Frank, B. Gruber, and K. T. von Toschanowitz. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. *Ecological Modelling* 185:329-348.

Jensen, J. B. 1999. Terrapene carolina carolina (Eastern Box Turtle). Diet. *Herpetological Review* 30:95.

Jochimsen, D. M. 2006. Ecological effects of roads on herpetofauna: a literature review and empirical study examining seasonal and landscape influences on snake road mortality in eastern Idaho. Unpubl. M.S. Thesis, Idaho State University, Pocatello, Idaho. 199 pp.

Jochimsen, D. M., and K. M. Andrews. What Is The Use Of Running When We Are Not On The Right Road? Guidelines to Enhanced Success Of Mitigating AND Preventing Road Effects On Herpetofauna. This ICOET Proceedings.

Jochimsen, D. M., C.R. Peterson, K.M. Andrews, and J.W. Gibbons. 2004. A literature review of the effects of roads on amphibians and reptiles and the measures used to mitigate those effects. Final Report to Idaho Fish and Game Department and the USDA Forest Service. 79 pp.

Jones, J. A., F. J. Swanson, B. C. Wemple, and K. U. Snyder. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. *Conservation Biology* 14:76-85.

Karraker, N. Impacts of road de-icing salts on amphibians and wetlands in urban and suburban environments. 2007. In J. C. Mitchell and R. E. Jung (eds.), Urban Herpetology. Society for the Study of Amphibians and Reptiles, *Herpetological Conservation Volume 3*, Salt Lake City, UT.

Kaushal, S. S., P. M. Groffman, G. E. Likens, K. T. Belt, W. P. Stack. V. R. Kelly, L. E. Band, and G. T. Fisher. 2005. Increased salinization of fresh water in the northeastern United States. *Proceedings of the National Academy of Sciences* 102:13517-13520.

Kjoss, V. A., and J. A. Litvaitis. 2001. Community structure of snakes in a human-dominated landscape. *Biological Conservation* 98:285-292.

Klauber, L. M. 1931. A statistical survey of the snakes of the southern border of California. Bulletin of the Zoological Society of San Diego 8:1-93.

Klauber, L. M. 1939. Studies of reptile life in the arid southwest, part 1. Night collecting on the desert with ecological statistics. *Bulletin of the Zoological Society of San Diego* 14:2-64.

Klauber, L. M. 1972. Rattlesnakes: Their habits, Life Histories, and Influence on Mankind. 2nd ed. University of California Press, Berkeley, CA. 1533 pp.

Kline, N. C., and D. E. Swann. 1998. Quantifying wildlife road mortality in Saguaro National Park.. In G. L. Evink, P. Garrett, D. Zeigler, and J. Berry (eds.), *Proceedings of the 1998 International Conference on Wildlife Ecology and Transportation*, pp. 23-31. Florida Department of Transportation, Tallahassee, FL.

Kline, N. C., D. E. Swann, A. Schaefer, K. Beupre, M. Pokorny. 2001. Model for estimating wildlife mortality on roads and its implication for mitigation and mortality. In G. L. Evink, P. Garrett, K. P. McDermott (eds.), *Proceedings for the 2001 International Conference on Ecology and Transportation*, p. 533. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.

Klingenböck, A., K. Osterwalder, and R. Shine. 2000. Habitat use and thermal biology of the land mullet Egernia major, a large scincid lizard from remnant rain forest in southeastern Australia. *Copeia* 2000:931-939.

Knutson, M. G., J. R. Sauer, D. A. Olsen, M. J. Mossman, L. M. Hemesath, and M. J. Lannoo. 1999. Effects of landscape composition and wetland fragmentation on frog and toad abundance and species richness in Iowa and Wisconsin, U.S.A. *Conservation Biology* 13:1437-1446.

Koenig, J., R. Shine, and G. Shea. 2001. The ecology of an Australian reptile icon: how do blue-tongued lizards (*Tiliqua scincoides*) survive in suburbia? *Wildlife Research* 28:215-227.

Kohl, R. A., C. G. Carlson, and S. G. Wangemann. 1994. Herbicide leaching potential through road ditches in thin soils over an outwash aquifer. *Applied Engineering in Agriculture* 10:497-503.

Kuhn, J. 1987. Straßentod der Erdkröte (Bufo bufo): Verlustquoten und Verkehrsaufkommen, Verhalten auf der Straße. Naturschutz und Landschaftspflege in Baden-Württemberg 41:175-186.

Kushlan, J. A. 1988. Conservation and management of the American Crocodile. *Environmental Management* 12:777-790.

Laidig, K. J., and D. M. Golden. 2004. Assessing timber rattlesnake movements near a residential development and locating new hiber-nacula in the New Jersey Pinelands. Unpubl. Report, Pinelands Commission. New Lisbon, NJ. 29 pp.

Lehtinen, R. M. S. M. Galatowitsch, and J. R. Tester. 1999. Consequences of habitat loss and fragmentation for wetland amphibian assemblages. *Wetlands* 19:1-12.

Leighton, M. D. 1903. British Lizards. George A. Morton, Edinburgh, Scotland.

LeMaster, M. P., I. T. Moore, and R. T. Mason. 2001. Conspecific trailing behavior of red-sided garter snakes, *Thamnophis sirtalis parietalis*, in the natural environment. *Animal Behaviour* 61:827-833.

Lesbarrères, D., A. Pagano, and T. Lodé. 2003. Inbreeding and road effect zone in a Ranidae: the case of the Agile frog, Rana dalmantina Bonaparte, 1840. *Comptes Rendus Biologies* 326:S68-S72.

Lodé, T. 2000. Effect of a motorway on mortality and isolation of wildlife populations. *Ambio* 29:163-166.

Madison, D. M., and L. Farrand, III. 1998. Habitat use during breeding and emigration in radio-implanted tiger salamanders (*Ambystoma tigrinum*). Copeia 1998:402-410.

Maerz, J. C., B. Blossey, and V. Nuzzo. 2005. Green frogs show reduced foraging success in habitats invaded by Japanese knotweed. *Biodiversity and Conservation* 14:2901-2911.

Mahaney, P. A. 1994. Effects of freshwater petroleum contamination on amphibian hatching and metamorphosis. *Environmental Toxicology and Chemistry* 13:259-265.

Main, M.B., and G.M. Allen. 2002. Landscape and seasonal influences on roadkill of wildlife in southwest Florida. *Florida Scientist* 65:149-158.

Manel, S., M. K. Schwartz, G. Luikart, and P. Taberlet. 2003. Landscape genetics: combining landscape ecology and population genetics. *Trends in Ecology and Evolution* 18:189-197.

Marchand, M. N., and J. A. Litvaitis. 2004. Effects of habitat features and landscape composition on the population structure of a common aquatic turtle in a region undergoing rapid development. *Conservation Biology* 18:758-767.

Marsh, D. M., and N. G. Beckman. 2004. Effects of forest roads on the abundance and activity of terrestrial salamanders. *Ecological Applications* 14:1882-1891.

Marsh, D. M., and P. C. Trenham. 2001. Metapopulation dynamics and amphibian conservation. *Conservation Biology* 15:40-49.

Marsh, D. M., G. S. Milam, N. P. Gorham, and N. G. Beckman. 2005. Forest roads as partial barriers to terrestrial salamander movement. *Conservation Biology* 19:2004-2008.

Mautz, W. J., and M. R. Dohm. 2004. Respiratory and behavioral effects of ozone on a lizard and a frog. *Comparative Biochemistry and Physiology* 139:371-377.

Maxell, B. A., and D. G. Hokit. 1999. Amphibians and reptiles. In G. Joslin and H. Youmans (eds.), Effects of Recreation on Rocky Mountain Wildlife: A Review for Montana, pp. 2.1-2.29. Committee on Effects of Recreation on Wildlife. Montana Chapter of the Wildlife Society, MT. 307 pp.

Mazerolle, M. J. 2004. Amphibian road mortality in response to nightly variations in traffic intensity. *Herpetologica* 60:45-53.

Mazerolle, M. J., M. Huot, and M. Gravel. 2005. Behavior of amphibians on the road in response to car traffic. *Herpetologica* 61:380-388.

Mendelson, J. R., III, and W. B. Jennings. 1992. Shifts in the relative abundance of snakes in a desert grassland. *Journal of Herpetology* 26:38-45.

Moeller, B. A., E. C. Hellgren, D. C. Ruthven, III, R. T. Kazmaier, and D. R. Synatzske. 2005. Temporal differences in activity patterns of male and female Texas Horned Lizards (Phrynosoma cornutum) in southern Texas. *Journal of Herpetology* 39:336-339.

Morey, S. R. 2005. Family Pelobatidae: *Scaphiopus couchii*. In M. Lannoo (ed.), Amphibian Declines: the Conservation Status of United States Species, pp. 508-511. University of California Press, Los Angeles, CA.National Park Service. 2004. www.nps.gov.

Noss, R. F. 1995. The ecological effects of roads or the road to destruction. Unpubl. report. Wildlands Center for Preventing Roads, Missoula, MT.

NRC [National Research Council]. 2005. Assessing and Managing the Ecological Impacts of Paved Roads. The National Academy Press, Washington, D.C. 294 pp.

Orser, P. N., and D. J. Shure. 1972. Effects of urbanization on the salamander Desmognathus fuscus fuscus. *Ecology* 53:1148-1154.

Ortega, Y. K., and D. E. Capen. 2002. Roads as edges: effects on birds in forested landscapes. *Forest Science* 48:381-390.

Ovaska K., L. Sopuck, C. Engelstoft, L. Matthias, E. Wind and J. MacGarvie. 2004. Best management practices for amphibians and reptiles in urban and rural environments in British Columbia. Unpubl. report. British Columbia Ministry of Water, Land and Air Protection, Biodiversity Branch, Victoria, British Columbia, Canada. 81pp.

Parendes, L. A., and J. A. Jones. 2000. Role of light availability and dispersal in exotic plant invasion along roads and streams in the H. J. Andrews Experimental Forest, Oregon. *Conservation Biology* 14:64-75.

Parris, L. B., M. M. Lamont, and R. R. Carthy. 2002. Increased incidence of red imported fire ants (Hymenoptera: Formicidae) presence in loggerhead sea turtle (*Testudines: Cheloniidae*) nests and observations of hatchling mortality. *Florida Entomologist* 85:514-517.

Patla, D. A., and C. R. Peterson. 1999. Are amphibians declining in Yellowstone National Park? *Yellowstone Science* 7:2-11.

Perry, G., B. W. Buchanan, R. N. Fisher, M. Salmon, and S. E. Wise. Effects of artificial night lighting on urban reptiles and amphibians. 2007. In J. C. Mitchell and R. E. Jung (eds.), *Urban Herpetology*. Society for the Study of Amphibians and Reptiles, Herpetological Conservation Volume 3, Salt Lake City, UT.

Pfleiderer, R. H. H., and M. Dieterich. 1995. New roads generate new traffic. *World Transport Policy and Practice* 1:29-31.

Phillips, B. L., G. P. Brown, and R. Shine. 2003. Assessing the potential impact of cane toads on Australian snakes. *Conservation Biology* 17:1738-1747.

Phillips, B. L., G. P. Brown, J. K. Webb, and R. Shine. 2006. Invasion and the evolution of speed in toads. *Nature* 439:803.

Plummer, M. V. 1997. Speed and endurance of gravid and nongravid green snakes, Opheodrys aestivus. *Copeia* 1997:191-194.

Plummer, M. V., and N. E. Mills. 2006. Natural History: Heterodon platirhinos (Eastern hognose snake). Road crossing behavior. *Herpetological Review* 37:352.

Pope, S. E., L. Fahrig, and H. G. Merriam. 2000. Landscape complementation and metapopulation effects on leopard frog populations. *Ecology* 81:2498-2508.

Puky, M. 2004. Amphibian mitigation measures in central-Europe. In C. L. Irwin, P. Garrett, and K. P. McDermott (eds.), *Proceedings of the 2003 International Conference on Ecology and Transportation*, pp. 413-471. Center for Transportation, and the Environment, North Carolina State University, Raleigh, NC.

Puky, M. 2006. Amphibian road kills: a global perspective. In C. L. Irwin, P. Garrett, and K. P.McDermott (eds.), *Proceedings of the 2005 International Conference on Ecology and Transportation*, pp. 325-338. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.

Rainwater, T. R., K. D. Reynolds, J. E. Cañas, G. P. Cobb, T. A. Anderson, S. T. McMurry, and P. N. Smith. 2005. Organochlorine pesticides and mercury in cottonmouths (*Agkistrodon piscivorus*) from northeastern Texas, USA. Environmental Toxicology and Chemistry 24:665-673.

Reed, R. N., B. S. Yang, J. W. Gibbons, R. N. Fisher, and C. Rochester. 2004. Impacts of domestic and international trade on the conservation status of snakes native to the United States. Unpubl. Report, U.S. Department of the Interior, U.S. Fish and Wildlife Service, Division of Scientific Authority, Arlington, VA. 110 pp.

Reh, W., and A. Seitz. 1990. The influence of land use on the genetic structure of populations of the common frog Rana temporaria. *Biological Conservation* 54:239-249.

Reijnen, R., R. Foppen, C. Ter Braak, and J. Thissen. 1995. The effects of car traffic on breeding bird populations in woodland. III. Reduction of density in relation to the proximity to main roads. *Journal of Applied Ecology* 32:187-202.

Richter, K. O. 1997. Criteria for the restoration and creation of wetland habitats of lentic-breeding amphibians of the Pacific Northwest. In K. B. Macdonald and F. Winmann (eds), Wetland and Riparian Restoration: Taking a Broader View, pp. 72-94. Publication EPA 910-R-97-007. USEPA, Region 10, Seattle, WA.

Richter, K. O., and A. L. Azous. 1995. Amphibian occurrence and wetland characteristics in the Puget Sound basin. *Wetlands* 15:305-312.

Riitters, K. H., and J. D. Wickham. 2003. How far to the nearest road? *Frontiers in Ecology and the Environment* 1:125-129.

Rodda, G. H. 1990. Highway madness revisited: roadkilled Iguana iguana in the Llanos of Venezuela. *Journal of Herpetology* 24:209-211.

Rodriguez, A. G. Crema, and M. Delibes. 1996. Use of non-wildlife passages across a high speed railway by terrestrial vertebrates. *Journal of Applied Ecology* 33:1527-1540.

Roe, J. H., J. Gibson, and B. A. Kingsbury. 2006. Beyond the wetland border: estimating the impact of roads for two species of water snakes. *Biological Conservation* 130:161-168.

Rohr, J. R., T. Sager, T. M. Sesterhenn, and B. D. Palmer. 2006. Exposure, postexposure, and density-mediated effects of Atrazine on amphibians: breaking down net effects into their parts. *Environmental Health Perspectives* 114:46-50.

Rosen, P. C., and C. H. Lowe. 1994. Highway mortality of snakes in the Sonoran Desert of southern Arizona. *Biological Conservation* 68:143-148.

Rothermel, B. B., and R. D. Semlitsch. 2002. An experimental investigation of landscape resistance of forest versus old-field habitats to emigrating juvenile amphibians. *Conservation Biology* 16:1324-1332.

Rowe, G., T. J. Beebee, and T. Burke. 2000. A microsatellite analysis of natterjack toad, Bufo calamita, metapopulations. *Oikos* 88:641-651.

Rudolph, D. C., and S. J. Burgdorf. 1997. Timber rattlesnakes and Louisiana pine snakes of the west Gulf Coastal Plain: hypotheses of decline. *Texas Journal of Science* 49(suppl.):111-122.

Rudolph, D. C., S. J. Burgdorf, R. N. Conner, and R. R. Schaefer. 1999. Preliminary evaluation of the impact of roads and associated vehicular traffic on snake populations in eastern Texas. In G.L. Evink, P. Garrett, D. Zeigler, and J. Berry (eds.), *Proceedings of the 1999 International Conference on Wildlife Ecology and Transportation*, pp 129-136. Florida Department of Transportation, FI-ER-73-99, Tallahassee, FL.

Rutherford, P. L., and P. T. Gregory. 2003. Habitat use and movement patterns of northern alligator lizards (*Elgaria coerulea*) and western skinks (*Eumeces skiltonianus*) in southeastern British Columbia. *Journal of Herpetology* 37:98-106.

Sanzo, D. and S. J. Hecnar. 2006. Effects of road de-icing salt (NaCl) on larval wood frogs (*Rana sylvatica*). *Environmental Pollution* 140:247-256.

Sartorius, S. S., L. J. Vitt, and G. R. Colli. 1999. Use of naturally and anthropogenically disturbed habitats in Amazonian rainforest by the teiid lizard Ameiva ameiva. *Biological Conservation* 90:91-101.

Scanlon, P. F. 1979. Ecological implications of heavy metal contamination of roadside habitats. In R. W. Dimmick, J. D. Hair, and J. Grover (eds.), Proceedings of the 33rd Annual Conference of the Southeastern Association of Fish and Wildlife Agencies, pp. 136-145. Hot Springs, AK.

Schmidt, B. R., and S. Zumbach. 2007. Amphibian road mortality and how to prevent it: A review. In J. C. Mitchell and R. E. Jung (eds.), *Urban Herpetology*. Society for the Study of Amphibians and Reptiles, Herpetological Conservation Volume 3, Salt Lake City, UT.

Schwartz, J. J., and K. D. Wells. 1983. An experimental study of acoustic interference between two species of neotropical treefrogs. *Animal Behavior* 31:181-190.

Schwartz, J. J., B. W. Buchanan, and H. C. Gerhardt. 2001. Female mate choice in the gray treefrog (Hyla versicolor) in three experimental environments. *Behavioral Ecology and Sociobiology* 49:443-455.

Scott, T. G. 1938. Wildlife mortality on Iowa highways. *American Midland Naturalist* 20:527-539.

Scribner, K. T., J. W. Arntzen, N. Cruddace, R. S. Oldham, and T. Burke. 2001. Environmental correlates of toad abundance and population genetic diversity. *Biological Conservation* 98:201-210.

Seabrook, W. A., and E. B. Dettman. 1996. Roads as activity corridors for cane toads in Australia. *Journal of Wildlife Management* 60:363-368.

Sealy, J. B. 2002. Ecology and behavior of the timber rattlesnake (*Crotalus horridus*) in the upper Piedmont of North Carolina: Identified threats and conservation recommendations. In G. W. Schuett, M. Hoggren, M. E. Douglas, and H. W. Greene (eds.), Biology of the Vipers, pp. 561-578. Eagle Mountain Publishing. Eagle Mountain, UT.

Seigel, R. A. 1986. Ecology and conservation of an endangered rattlesnake, Sistrurus catenatus, in Missouri, USA. *Biological Conservation* 35:333-346.

Seigel, R. A., and M. A. Pilgrim. 2002. Long-term changes in movement patterns of massasaugas (Sistrurus catenatus). In G. W. Schuett, M. Hoggren, M. E. Douglas, and H. W. Greene (eds.), Biology of the Vipers, pp. 405-412. Eagle Mountain Publishing. Eagle Mountain, UT.

Seigel, R. A., R. B. Smith, J. Demuth, L. M. Ehrhart, and F. F. Snelson JR. 2002. Amphibians and reptiles of the John F. Kennedy Space Cnter, Florida: a long-term assessment of a large protected habitat (1975-2000). *Florida Scientist* 65:1- 12.

Semlitsch, R. D. 2000. Principles for management of aquatic-breeding amphibians. *Journal of Wildlife Management* 64:615-631.

Semlitsch, R. D., T. J. Ryan, K. Hamed, M. Chatfield, B. Drehman, N. Pekarek, M. Spath, and A. Watland. 2007. Salamander abundance along road edges and within abandoned logging roads in Appalachian forests. *Conservation Biology* 21. In press.

Sherbrooke, W. C. 2002. Seasonally skewed sex-ratio of road-collected Texas horned lizards (*Phrynosoma cornutum*). *Herpetological Review* 33:21-24.

Shine, R., M. Lemaster, M. Wall, T. Langkilde, and R. Mason. 2004. Why did the snake cross the road? Effects of roads on movement and location of mates by garter snakes (*Thamnophis sirtalis parietalis*). Online Report. www.ecologyandsociety.org. vol. 9, iss. 1, article 9.

Smith, L.L., and C. K. Dodd, Jr. 2003. Wildlife mortality on U.S. highway 441 across Paynes Prairie, Alachua County, Florida. *Florida Scientist* 66:128-140.

Smith, L.L., K. G. Smith, W. J. Barichivich, C. K. Dodd, Jr., and K. Sorensen. 2005. Roads and Florida's herpetofauna: a review and mitigation case study. In W. E. Meshaska, Jr., and K. J. Babbitt (eds.), Amphibians and Reptiles: Status and Conservation in Florida, pp. 32-40. Krieger Publishing Company, Malabar, FL.

Smith, M. A. 1969. The British Amphibians and Reptiles. 4th Edition. *Collins New Naturalist*, London, England. 322 pp.

Spellerberg, I. F. 1998. Ecological effects of roads and traffic: a literature review. *Global Ecology and Biogeography Letters* 7: 317-333.

Spellerberg, I. F., and T. Morrison. 1998. The ecological effects of new roads – a literature review. *Science for Conservation* 84. Department of Conservation, Wellington, New Zealand.

Steen, D. A., and J. P. Gibbs. 2004. Effects of roads on the structure of freshwater turtle populations. *Conservation Biology* 18:1143-1148.

Steen, D. A., and L. L. Smith. 2006. Road surveys for turtles: an evaluation of the technique. *Herpetological Conservation and Biology* 1:9-15.

Steen, D. A., M. J. Aresco, S. G. Beilke, B. W. Compton, E. P. Congdon, C. K. Dodd, Jr., H. Forrester, J. W. Gibbons, J. L. Greene, G. Johnson, T. A. Langen, M. J. Oldham, D. N. Oxier, R. A. Saumure, F. W. Schueler, J. Sleeman, L. L. Smith, J. K. Tucker, and J. P. Gibbs. 2006. Relative vulnerability of female turtles to road mortality. *Animal Conservation* 9: 269-273.

Stiles, J. H., and R. H. Jones. 1998. Distribution of the red imported fire ant, Solenopsis invicta, in road and powerline habitats. *Landscape Ecology* 335:335-346.

Stuart, S. N., J. S. Chanson, N. A. Cox, B. E. Young, A. S. L. Rodrigues, D. L. Fishman, and R. W. Waller. 2004. Status and trends of amphibian declines and extinctions worldwide. *Science* 306: 1783-1786.

Sullivan, B. K. 1981a. Observed differences in body temperature and associated behavior of four snake species. *Journal of Herpetology* 15:245-246.

Sullivan, B. K.. 1981b. Distribution and relative abundance of snakes along a transect in California. *Journal of Herpetology* 15:247-248.

Sullivan, B. K.. 2000. Long-term shifts in snake populations: a California site revisited. *Biological Conservation* 94:321-325.

Sun, J. W. C., and P. M. Narins. 2004. Anthropogenic sounds differentially affect amphibian call rate. *Biological Conservation* 121:419-427.

Szerlag, S., and S. P. McRobert. 2006. Road occurrence and mortality of the northern diamondback terrapin. *Applied Herpetology* 3:27-37.

Titus, V. 2006. Seasonal movement patterns of the copperhead (Agkistrodon contortrix) in western Kentucky. Unpubl. M.S. Thesis, Murray State University, Murray, KY.102 pp.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18-30.

Tucker, J. K. 1995. Notes on road-killed snakes and their implications on habitat modification due to summer flooding on the Mississippi River in west central Illinois. Transactions of the Illinois State Academy of Science 88:61-71.

Turner, F. B. 1955. Reptiles and amphibians of Yellowstone National Park. Yellowstone Interpretive Series No. 5, Yellowstone Library ad Museum Association, Mammoth, WY. 40 pp.

Turtle, S. L. 2000. Embryonic survivorship of the spotted salamander (*Ambystoma maculatum*) in roadside wand woodland vernal pools in southeastern New Hampshire. *Journal of Herpetology* 34:60-67.

U.S. Bureau of Transportation Statistics (USBTS). 2004. Transtats: The Intermodal Transportation Database. www.transtats.bts.gov

Vandermast, D. B. 1999. Elaphe obsoleta (Black rat snake). Antipredator behavior. *Herpetological Review* 30:169.

Vatnick, I., J. Andrews, M. Colombo, H. Madhoun, M. Rameswaran, and M. A. Brodkin. 2006. Acid exposure is an immune disruptor in adult Rana pipiens. *Environmental Toxicology and Chemistry* 25:199-202.

von Seckendorff Hoff, K., and R. W. Marlow. 2002. Impacts of vehicle road traffic on desert tortoise populations with consideration of conservation of tortoise habitat in southern Nevada. *Chelonian Conservation and Biology* 4:449-456.

Vos, C. C., and J. P. Chardon. 1998. Effects of habitat fragmentation and road density on the distribution pattern of the moor frog Rana arvalis. *Journal of Applied Ecology* 35:44-56.

Vos, C. C., and A. H. P. Stumpel. 1996. Comparison of habitat isolation parameters in relation to fragmented distribution patterns in the tree frog (Hyla arborea). *Landscape Ecology* 11:203-214.

Vos, C. C., A. G. Antonisse-de Jong, P. W. Goedhart, and M. J. M. Smulders. 2001. Genetic similarity as a measure for connectivity between fragmented populations of the moor frog (*Rana arvalis*). *Heredity* 86:598-608.

Watson, M. L. 2005. Habitat fragmentation and the effects of roads on wildlife and habitat. Unpubl. report. Conservation Services Division, New Mexico Department of Game and Fish, Albuquerque, NM.

Weatherhead, P. J., and K. A. Prior. 1992. Preliminary observations of habitat use and movements of the eastern massasauga rattlesnake. *Journal of Herpetology* 26:447-452.

Weir, L. A., and M. J. Mossman. 2005. North American Amphibian Monitoring Program (NAAMP). In M. Lannoo (ed.), Amphibian Declines: the Conservation Status of United States Species, pp. 277-281. University of California Press, Los Angeles, CA.

Wells, M., T. Langton, L. Garland, and G. Wilson. 1996. The value of motorway verges for reptiles – a case study. In J. Foster and T. Gent (eds.), Proceedings of Reptile Survey Methods (seminar), pp. 174-181. English Nature Science No. 27. English Nature, Peterborough, England.

Welsh, Jr., H. H., and L. M. Ollivier. 1998. Stream amphibians as indicators of ecosystem stress: a case study from California's Redwoods. *Ecological Applications* 8:1118-1132.

Wester, L., and J. O. Juvik. 1983. Roadside plant communities in Mauna Loa, Hawaii. *Journal of Biogeography* 10:307-316.

White, P. A., and M. Ernst. 2003. Second Nature: Improving Transportation Without Putting Nature Second. *Defenders of Wildlife* publication, Washington, D.C. 70 pp.

Wise, S. E., and B. W. Buchanan. 2006. Influence of artificial illumination on the nocturnal behavior and physiology of salamanders. In C. Rich and T. Longcore (eds.), Ecological Consequences of Artificial Night Lighting, pp.221-251. Island Press, Washington, D.C.

Wood, R. C., and R. Herlands. 1997. Turtles and Tires: the impact of roadkills on northern diamondback terrapin, *Malaclemys terrapin terrapin*, populations on the Cape May Peninsula, Southern New Jersey, USA. In J. Van Abbema, Proceedings of the Conservation, Restoration and Management of Tortoises and Turtles – An International Conference, pp. 46-53. New York Turtle and Tortoise Society, New York, NY.

Wood, T. M. 2001. Herbicide use in the management of roadside vegetation, western Oregon, 1999-2000: effects on the water quality of nearby streams. Water-Resources Investigation Report 01-4065. U.S. Geological Survey, U.S. Department of the Interior, and Oregon Department of Transportation, Portland, OR. 34 pp.

Zink, T. A., M. F. Allen, B. Heindl-Tenhunen, and E. B. Allen. 1995. The effect of a disturbance corridor on an ecological reserve. *Restoration Ecology* 3:304-310.

# Assessing the Stone Marten's Patch Occupancy in Fragmented Landscapes and its Relation to Road-Killing Occurrences

**Fernando Ascensão** (963805043, fernandoascensao@yahoo.com),
**Clara Grilo**, and **Margarida Santos-Reis**, Centro de Biologia Ambiental, Faculdade de Ciências da Universidade de Lisboa, Campo Grande 1749-018, Lisboa, Portugal

## Abstract

Habitat loss and fragmentation is generally considered to be the greatest threat worldwide to the survival of species. Habitat fragmentation is a process generally regarded as comprising three major components: reduction in total area, increase in isolation, and reduction in average size of patches of remnant natural vegetation. Today's land use practices and road network's expansion strongly promote habitat fragmentation reducing the habitat availability and its connectivity, which is assumed to strongly influence species occurrence and population survival in fragmented landscapes. Although several studies demonstrated the negative impact of habitat fragmentation, few focused in carnivore species, and particularly in Mediterranean environments. Carnivores' position in the top of the food webs and their vulnerability to different human activities make this group especially significant in conservation and management actions. Our goal in this study was to assess the influence of human-related variables on the carnivore's probability of occurrence, according to habitat patch size and isolation, and road network characteristics. Stone marten Martes foina was selected as the model species to investigate the response to cork oak woodland fragmentation, considering that forest dependent species would show a stronger response. Marten species are known to be sensitive to forest fragmentation, although there is some evidence that their response is mainly determined by the level of forest fragmentation and the matrix quality, due to their preference for structurally complex forests to avoid competition and increase den availability.

We compared the stone marten response to scent stations located in four large and continuous forest patches (mean 36000 ha, 19 sampling sites) and in 25 smaller and isolated forest patches (mean 2.67 ha, one sampling site). For each sampling site a variable number of scent stations was used (average=11, min=7, max=17) depending on the patch size. Using the software PRESENCE we developed models that best fit stone marten probability of presence. This method parallels a closed-population mark–recapture model with an additional parameter (Phi) that represents the probability of species presence. Also, it enables the introduction of covariate information using a logistic model for Phi. Nine human and road related variables were used to develop models that best fit stone marten probability of occurrence in the smaller and isolated patches. The best models were selected using the Aikaike Information Criteria. Each variable importance was assessed by summing the AIC model weights (w) in which it was included. A data set of eighty stone marten road-kill locations and of eighty points randomly distributed along the sampled roads was used to evaluate if there were significant differences (one factor ANOVA), regarding the models' most important variables on the road casualties locations.

Results suggest that the probability of presence of stone marten in larger and continuous patches was 90%, while for the smaller and isolated patches it decreases to 60%. Nine significant models were retained. Models evidenced that the probability of presence of stone marten in isolated patches is related to cork oak density (+) (w=0.73), distance to nearest patch (-) (w=0.67), distance to nearest large patch (-) (w=0.56), distance to roads with medium/higher traffic volume (+) (w=0.37), and distance to riparian galleries (-) (w=0.12). Moreover, we detected that road kills were also significantly related to higher forest area surrounding the road ($F=7.37$, d.f.=1, $P<0.01$) and also to the proximity of nearest forest patch ($F=8.80$, d.f.=1, $P<0.01$).

According to these findings, stone marten seems to be negatively affected by habitat fragmentation being essential to promote good land management practices to guarantee a minimum area availability and well connected habitat patches through the establishment of suitable corridors for species movements. Furthermore, in road stretches close to cork oak patches, mitigation measures as wildlife passages ought to be considered in order to diminish the mortality rates. One should be aware that other forest dependent carnivores as genets Genetta genetta and wild cats Felis silvestris, the later of higher conservation concern and with decreasing density in the Iberian Peninsula, may respond stronger to habitat fragmentation than stone marten. This means that smaller and isolated habitat patches may become unoccupied, leading to species disappearance, being therefore highlighted the need to incorporate these findings in conservation action plans.

# Freshwater Mussel (*Mollusca: Unionidae*) Habitat Variability and Movement Patterns Following Relocation: A Case Study of *Potamilus Capax* (Green 1832)

**David R. Baldridge** (417-252-0614, david.baldridge@smail.astate.edu) and **Alan D. Christian**, Department of Biological Sciences, Arkansas State University, P.O. Box 1054, State University, AR 72467 USA

**Andrew J. Peck** (870-243-0095, andrew.peck@smail.astate.edu), Department of Environmental Science, Arkansas State University, 3009 A Fairview Drive, Jonesboro, AR 72401 USA

## Abstract

Relocation of freshwater mussel aggregates has been used as a mitigation strategy for nearly 30 years. Methodologies for relocation have been studied showing that identification of appropriate habitat characteristics are among the most important aspects when selecting a viable relocation site. Though relocation methodologies have been studied, little is known about the influence on behavioral patterns following relocation. This project is aimed at addressing information gaps regarding post-relocation monitoring activities which will be incorporated into the biological assessment of a proposed permit streamlining initiative between the US Fish and Wildlife Service, Federal Highway Administration, and Arkansas Transportation and Highway Department.

The focus of this initiative is the fat pocketbook, *Potamilus capax* (*Mollusca: Unionidae*), which was designated as "Endangered" in June 1976 by the USFWS in the entire range of the species. The present general distribution of *P. capax* has been reported from the upper Mississippi River on the borders of Minnesota, Wisconsin, Iowa, Illinois, and Missouri, the Ohio River System on the borders of Indiana, Illinois, and Kentucky, especially its tributary the Wabash River in Indiana and Illinois, the White River of Missouri and Arkansas, and the St. Francis River system in Arkansas. These systems typify mid-western Mississippi River drainages with areas of slow moving water and substrate ranging from shifting sand and gravel to sand, silt, and clay substrates, suitable habitat for *P. capax*. This species is further characterized as being a long-term breeder with fertilization occurring in spring and gravid females present from June to October and uses the freshwater drum (*Aplodinotus grunnies*) as its host. Though *P. capax* was at one time present in many of these systems, historical accounts indicate that it was never a predominate species within the assemblage. Though mussels, in general are considered relatively stationary, many species, including *P. capax*, have adopted a mobility trait which may yield inaccurate monitoring results.

The objectives of this study are to 1) analyze seasonal movement patterns of resident and relocated individuals and 2) relate movement to sediment characteristics at the relocation site. We hypothesize that relocated *P. capax* will show a greater displacement than resident *P. capax*. We also expect this displacement to be associated with habitat selection and/or reproduction. We have examined movement patterns of resident and relocated *P. capax* within an agricultural drainage system of the Saint Francis River system of Arkansas and Missouri. Two treatment groups have been monitored with different monitoring intervals. The first group was fitted with radio transmitters and was monitored at a maximum of one month intervals from October, 2005 to January, 2006 and July, 2006 to November, 2006 using radio telemetry. The second treatment group was monitored using mark and recapture (shell etch) techniques and positions recorded once quarterly from May, 2005 through March, 2007. Substrate composition (sand, silt, and clay), water depth, and water velocity were determined using 65 meter bank to bank transects at 10 meter intervals for the length of the 200 meter relocation reach. Substrate, depth and velocity were interpolated using krieging and spatial data analysis in GIS.

Initial movement results of the quarterly sampling show native individuals ($n = 41$) with a displacement range between 0.88 m and 151.92 m while relocated animals ($n = 13$) have displacement range between 3.44 m and 18.87 m. At the alpha = 0.10, this difference is significant ($p = 0.09$). Data for the transmitter treatment group are still being collected, but preliminary indications from the October, 2005, to January, 2006, monitoring period contradict this trend. In this time period, resident individuals ($n = 11$) had a range of total displacement from 0.60 m to 9.12 m while relocated individuals ($n = 10$) had a range of total displacement from 2.67 m to 14.90 m with a significantly greater average range as well ($p<0.10$).

Results of this study will help refine relocation monitoring methods involving freshwater mussels with a movement characteristic in their life history. Because monitoring of relocated P. capax has proven to be largely unsuccessful, better understanding their movement abilities may help to establish more appropriate monitoring methodologies for performance standard assessment. Also, a more thorough understanding of how this species uses available habitat on a seasonal basis will help refine selection criteria for potential relocation sites. This assessment information will also be used in the biological opinion by the US Fish and Wildlife Service in formulating the biological opinion of the proposed permit streamlining initiative.

# Lessons and Experiences From a Stream Restoration Project in the Piedmont of North Carolina

**Thomas Barrett** (919-858-1817, tbarrett@mulkeyinc.com), Senior Scientist/Forester, Mulkey Engineers and Consultants, Inc., 6750 Tryon Road, Cary, NC 27518 USA
**Edward Hajnos**, Design and Construction Supervisor, North Carolina Ecosystem Enhancement Program, 1652 Mail Service Center, Raleigh, NC 27699 USA

**Abstract**

Mulkey, Inc. is participating in a stream restoration study with the Ecosystem Enhancement Program in Yadkin County, North Carolina. The purpose of this study is to restore approximately 4,300 linear feet of Rocky Branch, a second order stream located in the western Piedmont of North Carolina. Stream restoration in North Carolina is generally conducted to provide compensatory mitigation for stream impacts from both highway construction and private development. Since the late 1990s, North Carolina has served at the forefront for stream restoration activities due to the state's tremendous population growth and stringent water quality standards. In an effort to provide mitigation for the state's needs in an efficient manner, the Ecosystem Enhancement Program was created in 2003 under an agreement with the North Carolina Department of Environment and Natural Resources, the North Carolina Department of Transportation, and the U.S. Army Corps of Engineers. There are approximately 400 streams and wetland restoration projects that are currently under development across 54 watersheds in North Carolina. Those resources having the greatest repair needs are prioritized and the Ecosystem Enhancement Program works with public and private organizations in an effort to restore, to enhance and to preserve wetlands, streams, and buffers, statewide. The Ecosystem Enhancement Program serves as the nucleus for consolidating and streamlining mitigation activities within the state. The project presented here is one of the many projects this program administers in an effort to meet the ever growing mitigation needs in the state.

The Rocky Branch site comprises approximately 24 acres of pasture and woodlands immediately adjacent to the Interstate 77 corridor in Yadkin County, North Carolina. The project site has a drainage area of approximately 3.1 square miles and is part of the South Yadkin River Watershed. The site was once heavily forested, but over the last 100 years has been cleared primarily for pasture and row crops. Cattle have been a significant part of the land-use since the early part of the 20th century and their impact is highly visible through compaction, erosion, and denuded vegetation along the stream. The objectives of the Rocky Branch stream restoration project were and continue to be: 1) to provide mitigation for future needs in the area, 2) to improve water quality by excluding cattle from the stream, 3) to provide a stable and functional stream channel, 4) to improve the overall quality of the stream and riparian areas and 5) to provide long-term protection of the project through a conservation easement.

The restoration of Rocky Branch's main channel and its associated tributary were completed using methods based on the work of David L. Rosgen, PhD, which emphasize the use of natural stability concepts. The stream restoration project created a new stream channel with the appropriate dimension, pattern, and profile for its specific location within the watershed. The new channel contains in-stream boulder structures which provide grade control, bank stabilization, and aquatic habitat. Boulder structures used in conjunction with this project include cross vanes, rock vanes, and j-hooks. The stream banks were stabilized using erosion control matting, native seed mixes, bare root seedlings, rootwads, and live vegetation stakes. A permanent riparian buffer was established using native vegetation specific to the region. Vernal pools were established throughout the riparian buffer to provide habitat, water storage capacity and micro-topography. To protect the project from disturbance, permanent fencing was established around the entire site.

As is true for projects of this type, an as-built report documenting stream restoration and enhancement is developed to provide a baseline for future monitoring or success criteria. A monitoring program will be implemented to document system development and progress toward achieving the success criteria as stipulated in the mitigation requirements for the project permit. Monitoring will take place over a 5-year period or until final success criteria are achieved.

# An Assessment of Field Method Efficacy to Monitor Wildlife Presence Near Interstate 70 at Vail Pass

**Paige Bonaker** (970-620-0079, mmeeko@gmail.com) and
**Len Broberg**, Ph.D., Environmental Studies Department, University of Montana, 230 Burlington Avenue, Missoula 59801 USA
**Chris Haas**, Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, CO 80523 USA

**Abstract**

The 2002 National Cooperative Highway Research Project found a need among many state transportation departments for the development of "standard analytic techniques for assessing wildlife ecology and transportation." These agencies use several methods to assess wildlife activity in areas of highway construction projects. However, there have been very few comparison studies of the different techniques and none have been conducted near a high traffic roadway. For this study, I am ascertaining the utility of various field methods to monitor wildlife near Interstate 70 at Vail Pass, Colorado.

Interstate 70 is a major east-west transportation route running through the Colorado Rockies. The associated human development that comes with this transportation corridor has resulted in varying degrees of habitat fragmentation across the region and represents a potentially significant barrier to wildlife movement. To alleviate this potential barrier effect, the Colorado Department of Transportation is proposing to build a wildlife bridge across I-70 just west of Vail Pass. The Southern Rockies Ecosystem Project (SREP) and other Colorado non-profit organizations are developing a monitoring strategy that will inform the placement of the wildlife bridge and determine baseline movement patterns and activity levels of various wildlife species before, during, and after the project. In order to gather a greater wealth of data with this strategy, a Citizen Science Wildlife Monitoring program was created in 2006 by these organizations.

My study is aimed at assessing which monitoring techniques are most effective at documenting species presence across this important wildlife linkage. In this study, "effective" is used to define any method: 1) that detects a mammal, and 2) by which the user is able to identify the mammal to the species level. This paper analyzes four sampling techniques (remote sensing digital cameras, track transect surveys, scat transect surveys, and hair snare surveys) during baited and non-baited sampling sessions. Results from this study will be used by SREP to develop a cost-effective monitoring strategy for the Vail Pass region.

In July and August 2006, eight lines were placed perpendicular to a two-lane dirt road called Shrine Pass Road (SPR) which runs relatively parallel to I-70. Each line consisted of four plots; two directly on the roadway shoulder (roadway sites) and two 100-150m (328'-492') from the road (approach sites). Each plot had a 100m (328') long x 2m (6.6') wide track and scat transect that ran as parallel as possible to SPR. At the midway point in each approach site transect, there was a hair snare station, a track bed and a camera station. The roadway sites only had a camera station at the midway point.

Two study sessions were completed. An unbaited study period ran for two weeks and included both roadway and approach stations. On day one of this session, data from all the stations and transects were collected and the survey areas were cleared. On the final day of this session, the stations and transects were again walked and all track, scat and camera data were collected. For the baited session, only the approach sites were used and the hair snares were baited with a non-rewarding scent lure. The stations and transects were sampled every day for ten consecutive days. The hair snares were re-baited every third day. All tracks, scat and hairs found were recorded and any scat and hair samples were collected. Any samples that could not be positively identified by species in the field were labeled "unknown."

Preliminary results indicate that species detection varies greatly depending on the sampling method and whether a scent lure is present. Twelve different species were positively identified by the cameras, four by scat surveys and two by track surveys. No species could be positively identified using the hair snares without genetic analysis.

Interestingly, for deer and elk, preliminary analysis indicates that detections with track surveys were significantly greater than those with camera and scat surveys. In contrast, scat was a better indicator of American marten presence compared to most other techniques. In fact, preliminary results suggest that detections of marten with scat and camera surveys are significantly greater than detections with track surveys. No difference was found between scat and camera surveys. Overall, however, scat surveys were a fairly ineffective technique without genetic analysis as several scat samples were unidentifiable in the field.

Furthermore, it seems that the baited session was more effective than the non-baited session for monitoring wildlife. For instance, all twelve species identified at camera stations were recorded during the baited session whereas only six species were recorded during the non-baited period. Non-baited cameras did not detect certain rodent species, domestic dogs, gray fox, porcupine, and American marten. In addition, scat detections for marten were significantly higher for the baited session than for the unbaited session. Finally, activity indices were higher for domestic dog, mule deer, red and gray fox, mice, chipmunks and squirrels at the baited camera stations. Comparatively, during the non-baited session, the activity index was notably higher solely for rabbits.

These results will aid in assessing what sampling methods are most appropriate for certain species given time constraints, seasonal environmental conditions, and availability of funding for monitoring equipment. The results from the field study will be reinforced by additional research on each method to evaluate their effectiveness in other studies. In the end, this study will contribute to developing an appropriate long-term monitoring strategy for the Vail Pass linkage.

# The Salmon Resource and Sensitive Area Mapping Project: Integrating a Natural Resource GIS With Field Operations Via Handheld Computer Applications

**Robert G. Carson** (503-224-3445, bcarson@masonbruce.com) and **Wendy H. Wente**, Mason, Bruce & Girard, Inc., 707 SW Washington Street, Portland, OR 97205 USA
**Milton Hill**, Oregon Department of Transportation, Transportation Data Section, 555 13th Street NE, Suite 2, Salem, OR 97301 USA

**Abstract:** The Salmon Resource and Sensitive Area Mapping (SRSAM) project was a unique effort undertaken by the Oregon Department of Transportation (ODOT) to develop a Geographic Information System (GIS) of sensitive natural resource sites integrated with high-resolution digital color infrared imagery for the entire Oregon state highway system (approximately 9,000 miles). SRSAM data allow ODOT to plan maintenance and roadway/bridge project activities with up-to-date environmental resource data by providing maintenance workers, biologists, and transportation planners with access to a current, updateable database of sensitive environmental features.

Taking full advantage of the SRSAM GIS for ODOT's transportation planning uses required development of an effective system for delivering information to individual users in the field. To this end, ODOT contracted with Mason, Bruce & Girard, Inc. (MB&G) to develop two handheld computer applications that integrate spatially referenced data, including SRSAM's sensitive resource data, with field data collection forms, thereby allowing users to view, manipulate, and enter data in the field. Use of these applications requires no specialized knowledge of GIS software, empowers users by providing access to an extensive database of environmental information, and through the use of standardized ArcPad forms for routine tasks improves the efficiency of field data collection and management.

The first application addresses ODOT's requirements for Mitigation Site Assessment, and enables biologists to spatially identify areas where maintenance or remediation is necessary. This allows a more rapid and efficient response when regulatory performance standards are not being met. The second application focuses on Environmental Scoping, the process by which ODOT identifies environmental issues likely to be associated with proposed projects. This coarse-level assessment requires numerous sources of environmental information. ODOT's Environmental Scoping Application allows users to view over 20 reference data layers, including project-site imagery, while in the field. Other data layers within the Environmental Scoping application are dynamic, allowing users to update and correct spatially referenced environmental information based on their observations. The computer-based forms for both applications obviate the need to transcribe field data collected on paper, thus eliminating a time-consuming and error-prone procedure.

Overall, SRSAM has provided a mechanism for ODOT to deliver sensitive natural resource data to maintenance crews, biologists, and transportation planners making field decisions that could impact sensitive resources. ODOT's commitment to completing the SRSAM project state-wide was a key reason that ODOT's routine road maintenance activities received a programmatic exemption under the Federal Endangered Species Act (ESA). The cost to ODOT of not obtaining the programmatic permit for maintenance activities has not been calculated, but surely would have been substantial (millions of dollars). Furthermore, the handheld computer applications, as well as the SRSAM GIS, offer a solution to a difficult ODOT challenge by standardizing data collection and storage techniques throughout the state, thereby streamlining ODOT's efforts to protect sensitive resources. In sum, the SRSAM project represents an innovative, multifaceted solution to ODOT's challenge of environmental compliance and stewardship.

## The SRSAM Project

During the late 1990s the Oregon Department of Transportation (ODOT) recognized that it could play a central stewardship role in protecting and enhancing Oregon's natural resources. ODOT also realized that attention to natural resource issues as a routine procedure during transportation-related development or maintenance activities could reduce the incidence of unnecessary negative impacts to those resources and the associated costs of mitigation or special permitting. To this end, ODOT began an effort to integrate natural resource management with its transportation system maintenance and development activities. ODOT identified two primary components that would be instrumental to its efforts: 1) a comprehensive inventory of sensitive natural resources along ODOT's transportation network, and 2) capability to produce maps, primarily to be used during maintenance activities, to indicate the locations of sensitive resources and associated restrictions.

ODOT contracted with Mason, Bruce & Girard, Inc. (MB&G), a natural resources consulting firm, to collect the desired natural resource information along ODOT's transportation corridors and develop the associated Geographic Information System (GIS) for storing and updating the statewide inventory. ODOT referred to this effort as the Salmon Resources and Sensitive Area Mapping (SRSAM) project.

To build the GIS, MB&G acquired high resolution color infrared imagery of the entire highway system across the state of Oregon. These imagery data were coupled with existing and field- verified sensitive resource data to form the basis of the SRSAM GIS (Carson et al. 2001, Carson et al. 2003). By the end of the SRSAM project development phase in 2005, MB&G had built a GIS inventory of sensitive natural resource data along all state-maintained highways in Oregon, covering approximately 9,000 roadway miles.

## Current Uses of SRSAM Data

The SRSAM data corridor extends at least 500 feet from the centerline along each side of the roadway. This corridor approach accurately captured the data needed to produce the maps ODOT originally desired for use during maintenance and project planning activities. ODOT uses the SRSAM GIS to produce two types of maps that depict: 1) Resource Areas (i.e., "RES" maps), and 2) Restricted Activity Zones (i.e., "RAZ" maps).

### Resource Area Maps

RES maps are used by ODOT biologists and project planners to identify the locations of sensitive resources (e.g., streams, wetlands, known rare plant populations, potential threatened or endangered species habitat) along the transportation corridor. These maps indicate the types of sensitive resources present along the highway in 0.01-mile increments, providing an accurate on-site resource tool that can be used when making decisions on resource management. For example, under a separate environmental resource management program, ODOT has established Special Management Areas (SMAs) designed to protect specific native plant species and their habitats in specific locations along roadways. These SMAs are included in the RES maps taken to the field by ODOT biologists and can be updated as new sensitive native vegetation and habitats are located and recorded in the field or as new management activities are implemented at already established sites.

### Restricted Activity Zone Maps

ODOT maintenance crews use the RAZ maps to identify sensitive resource sites so that their activities (e.g., mowing, pesticide applications, snow/ice removal, ditch/drainage maintenance) do not harm these resources. The color-coded RAZ maps clearly indicate zones along the roadway where specific maintenance activities are to be completed with caution or avoided entirely due to the presence of a sensitive resource. The maps are designed to require no biological training for interpretation. Through the use of the SRSAM-derived RAZ maps, ODOT actively promotes conservation of sensitive resources and habitats by providing direct knowledge of their locations to roadway maintenance crews so impacts can be avoided.

## Handheld Computer Applications

The RAZ and RES maps represent significant improvement over the previous level of natural resource data accessible to ODOT staff. However, prior to the end of the original SRSAM project, ODOT recognized a need to provide even more accurate and up-to-date natural resource data for field actions. The printed RES maps were falling short of this goal since, by necessity, they only depicted data layers chosen before the field visit was made. Important data needed in the field could therefore be inadvertently left off the maps and thus not available during the field visit. In addition, ODOT observed that the SRSAM GIS itself needs to be regularly updated to reflect changes in natural resource locations and conditions as observed in the field; otherwise the data would eventually become archaic. To address these needs, ODOT funded a pilot project and asked MB&G to develop two handheld computer applications designed to deliver information from the SRSAM GIS and other sources to individual users in the field.

To meet the needs of field data delivery, ODOT asked MB&G to focus the application development efforts on two common tasks where SRSAM data had already proven to be useful: 1) post-construction wetland and biological mitigation site monitoring, and 2) environmental scoping for transportation projects.

The hardware platform chosen by ODOT for both handheld computer applications was the Trimble GeoXT, a relatively powerful and field-rugged handheld computer with integrated global positioning system (GPS) capability (sub-meter accuracy). ODOT chose ESRI ArcPad software because of its GIS/GPS capability and its customizable data entry interface.

The handheld applications deliver GIS data and imagery to the user in the field. The user then populates ODOT-standard electronic data forms presented by the application following a standardized field survey protocol. Both applications also enable the user to collect new spatially referenced (GPS) data while in the field. The electronic forms embedded in the applications, coupled with standardized field data collection methods required by users of the applications, promote consistency and efficiency while reducing errors due to data transcription.

### Mitigation Site Assessment Application

Transportation projects in Oregon, such as bridge replacements or roadway widening efforts, often result in impacts to regulated biological or wetland resources (e.g., fish species protected by the Federal Endangered Species Act or wetlands protected by the Clean Water Act). ODOT must meet mitigation conditions included in any project-related permits they receive from regulatory agencies during the environmental permitting process. These permits frequently require ODOT to offset the expected impacts to regulated resources by constructing and maintaining mitigation sites such as created wetlands or fish habitat improvements. These mitigation efforts must be monitored over a period of time, often 5 years, to satisfy defined success criteria for providing legitimate replacement of the resource functions lost by building the project. ODOT desired a handheld computer application that would enable staff to collect the monitoring data associated with ODOT mitigation sites throughout the state.

MB&G delivered Version 1 of the Mitigation Site Assessment Application to ODOT in December, 2005. During 2006 ODOT contracted with MB&G to monitor 14 biological and wetland mitigation sites using the Mitigation Application. Overall, the application proved to be an effective tool for monitoring mitigation sites. Data collected with the Mitigation Application were used by ODOT to produce monitoring reports for submittal to the regulatory agencies involved in permitting and monitoring each project (e.g., see MB&G 2006). MB&G is currently updating and refining the Mitigation Application for state-wide use by ODOT and contractor biologists performing mitigation monitoring.

### Environmental Scoping Application

Early in the project development process, the ODOT Regional Environmental Coordinator (REC) visits a proposed project site to identify the environmental issues likely to be associated with the proposed project. This initial site reconnaissance serves to provide a coarse-level assessment of the expected environmental permitting requirements for the project. The REC typically populates a standard ODOT form designed to capture this information, and then produces a report based on the data collected during the site visit. This coarse-level assessment requires the REC to access numerous (>20) sources of environmental information (i.e. Oregon Natural Heritage Information, Hazardous Materials Sites, etc.) from the Web and from ODOT's server prior to conducting the site reconnaissance.

ODOT recognized that having the data from these databases available to the REC during the site reconnaissance would greatly increase efficiency and effectiveness. A further advantage of having the data available in the field is that the REC can record inaccuracies or omissions in the database information detected during the routine visit, thereby improving the quality of the base data. ODOT asked MB&G to design a handheld application, the Environmental Scoping Application, to meet this need. The key functionality desired by ODOT was the delivery of key environmental base data layers, ability to populate standard site reconnaissance field forms, and the ability to capture and edit spatially-referenced (via GPS) data while in the field.

MB&G delivered Version 1 of the Environmental Scoping Application to ODOT in December 2005. Version 1 displays 21 distinct data layers of environmental information for access by the REC during the site reconnaissance. In addition, this application allows the user to populate standard site reconnaissance field forms and to capture new point, line, and polygon data that are geo-referenced and associated with attribute forms. This Environmental Scoping Application has yet to be systematically field tested by ODOT, but this may occur in 2007.

## Conclusions

SRSAM has increased ODOT's efficiency with respect to environmental regulatory compliance and managing environmental resources by delivering sensitive natural resource data to personnel tasked with making decisions that could impact those resources: maintenance crews, biologists, and transportation planners. In addition, the handheld computer applications, as well as the SRSAM GIS, offer a solution to a difficult ODOT challenge by standardizing data collection and storage techniques throughout the state, thereby streamlining ODOT's efforts to protect and manage sensitive resources.

In summary, SRSAM has provided ODOT with the ability to deliver critical natural resource data to maintenance crews, biologists, and transportation planners making field decisions that could impact sensitive resources. The hand-held applications developed by ODOT and MB&G have enhanced and improved this ability, thus furthering the Agency's resource protection and stewardship goals.

**Biographical Sketches:** Bob Carson is a Principal with Mason, Bruce & Girard, Inc., and the manager of the Environmental Services Group. His 25 years of experience includes serving as environmental project manager or task leader on over 200 projects involving Endangered Species Act (ESA) and National Environmental Policy Act (NEPA) compliance and permitting, biological resource studies, and wetland delineation and mitigation. His technical expertise includes wildlife, forest, and wetland ecology and management. Bob is a Certified Wildlife Biologist and a certified Professional Wetland Scientist. He earned his Masters of Science in Wildlife Resources in 1984 from the University of Idaho, and Bachelor of Science in Forest Science in 1981 from The Pennsylvania State University.

Milt Hill is an Environmental GIS Program Manager with the Oregon Department of Transportation (ODOT). His 19 years of experience with Geographic Information Systems (GIS) in State Government encompass a broad range of activities including computer system administration, GIS analysis, GIS project management, program administration, and contract and consultant management. Prior to his employment with ODOT, Milt was the GIS Program Coordinator for the Oregon Department of Fish and Wildlife (ODFW). Milt is a certified GIS Professional (GISP) and has completed the Oregon Project Management Certification Program (OPMCP). He earned his Bachelor of Science in Geography from Portland State University in 1989.

Wendy Wente is an ecologist and project manager with Mason, Bruce & Girard, Inc. She has 13 years of experience in research design and implementation. Her professional expertise includes wildlife surveys, habitat assessments and field research designed to meet the needs of public sector clients. She specializes in federal permitting documentation primarily associated with the Endangered Species Act and the National Environmental Policy Act. Wendy earned a Bachelor of Science degree in Zoology in 1992 from Miami University in Oxford, Ohio. She completed her Ph.D. in Ecology, Evolution, and Animal Behavior at Indiana University in 2001. Prior to joining MB&G, Wendy worked as a post-doctoral researcher with the US Geological Survey, where she conducted research on problems of applied ecology including a multi-year study of regional amphibian decline and an experimental study of the effects of cattle grazing on wetland water quality.

## References

Carson, Robert, Robert Kirkman, and Jason Neil. 2001. ODOT's Salmon Resource and Sensitive Area Mapping Project: a high-tech procedure for obtaining biological resource data for resource protection and regulatory compliance. Pages 149-154 in *Proceedings of the International Conference on Ecology and Transportation*, September 24-28, Keystone, CO.

Carson, Robert, Robert Kirkman, Rick Jones, and Jason Neil. 2003. ODOT's Salmon Resource and Sensitive Area Mapping Project—application delivery of GIS biological resource data. Pages 548-551 in *Proceedings of the International Conference on Ecology and Transportation*, August 24-29, Lake Placid, NY.

Mason, Bruce & Girard, Inc. 2006. Combined 2nd And 3rd Year Compensatory Wetland Mitigation Monitoring Report (2005/2006). U.S. 26: Zigzag-Rhododendron Section, U.S. 26, Mt. Hood Highway. ODOT Key No. 07990. Clackamas County, Oregon

# Process Design for Collaboration: An Innovative Approach to Redesigning the Environmental Review Process for Transportation Projects

**Tom Crawford** (360-357-6134, tom@praxisnw.com), President, Praxis Northwest, LLC, P.O. Box 2578, Olympia, WA 98507-2578 USA

**Abstract**

Project Overview: Recent federal legislation and accompanying rules (SAFETEA-LU) require state Departments of Transportation to increase their levels of collaboration with local jurisdictions and with other state and federal environmental and resource agencies related to the environmental impact of transportation projects. At the same time, they face increased demands for reducing the time and cost associated with project environmental reviews and permitting. Some barriers to achieving these desired results, experienced by DOTs, are:

- Misunderstanding of goals, priorities and expectations among the DOT, local jurisdictions, and resource/regulatory agencies during project development.
- Items and requests passed from one agency to another getting "lost in the shuffle."
- Duplication of effort to gather and assess environmental data by the DOT, local planning agencies (MPOs), community organizations, and resource agencies.
- Important environmental or community impact considerations arising late in project development/delivery process, creating unexpected costs and schedule delays.
- Choice of a project alternative by the MPO that requires very costly and time consuming environmental studies and mitigation efforts.
- Frequent rework of environmental documents and delays in study and permit approvals.

The Language-Action Framework focuses on building commitments and coordination between customers (for example, a DOT that needs a water resource study) and performers (for example, a consultant who completes the water resource study). This approach provides a structure for improving coordination using the following key communication points:

a. Clear and specific statements of customer needs, including the motivation for the proposed effort
b. Agreement between customer and provider on cycle time, cost and quality expectations for the work, so that there is a shared understanding of and commitment to meeting these expectations.
c. Progress tracking and reporting, so that needed mid-course adjustments can be made in schedule, budget or other areas of the project
d. Interim customer feedback on project deliverables
e. Report of completed work to the customer
f. Customer review, assessment and feedback on work delivered, and recommendations for continuous quality improvement which are developed collaboratively by customer and performer.

Sample process designs have been developed, using the Language Action Framework, for three key process areas: integrating long range planning with the NEPA process, coordinating resource and regulatory agency review of environmental decisions and documents (EIS or EA), and ensuring the fulfillment of environmental commitments (including mitigation or other measures). These process designs, when adapted to the unique situation and needs of a particular agency, show potential for a wide range of tangible benefits, including:

- Reduced time and effort to produce environmental documents (EAs and EISs).
- Improved relationships between DOTs and the various resource, regulatory, and local jurisdiction agencies they collaborate with to produce and obtain approval for environmental documents.
- Increased clarity about roles and accountabilities for completing environmental studies among DOT staff, the DOT's partner agencies, and consultants/contractors.
- Improved reliability of the DOT's project schedules.
- Improved environmental outcomes, achieved through greater clarity and broad interagency commitment regarding those outcomes.

List of current/anticipated results: The Language-Action Framework has been used to design a set of sample diagrams and descriptions for typical DOT environmental streamlining processes. These process designs reflect the experience of TDOT, as well as recent AASHTO and FHWA studies of environmental streamlining and environmental management system processes within DOTs.

Recommendations for future research:

- This approach should be further tested by DOTs of various sizes and in various parts of the country, for its viability and application to meet their environmental streamlining and stewardship needs.
- The approach may also improve collaboration and coordination for specific environmental mitigations or other actions—for example, multi-agency coordination to improve aquatic resources or wildlife habitat. Additional research in this area may be useful.

**Biographical Sketch:** Tom Crawford is president and founder of Praxis Northwest, LLC, a firm which specializes in helping client organizations demonstrate outstanding results by connecting strategy with operations. Tom's work has included organizational development, process analysis and redesign, IT project planning and management, systems analysis and design and feasibility study development. Environmental agencies and processes have been a vertical market focus over the last ten years. Tom's recent work has included projects with several state Departments of Transportation and a national survey of environmental management best practices among DOTs.

# Road Decommissioning: Minimising the Adverse Ecological Effects of Roads in European Agricultural Landscapes

**Dolan, Lisa M. J.** (353879578356, l.dolan@student.ucc.ie) and
**Whelan, Pádraig M.** Department of Zoology, Ecology and Plant Science, University College Cork, Butler Building, Distillery Fields, Cork City, Cork 1234 Ireland

**Abstract**

The field of Restoration Ecology continues to provide an exciting array of new disciplines which focus on the restoration of ecological function and integrity to former habitat areas. Road Restoration Ecology (RRE) is one such discipline which is expanding the possibilities for habitat restoration beyond that which has been provided by the traditional management of roadside vegetation and landscape design.

This paper focuses on a particular aspect of RRE - that of road decommissioning. To date even though many hundreds of kilometers of forest roads have been removed in the U.S., virtually no research has addressed the impact of road removal on wildlife. Furthermore, on an international level, even less research has been committed to examining the removal of paved roads despite the fact the road development has been identified in the literature as one of the major causes of habitat fragmentation across landscapes worldwide.

In the course of new road planning and design, sections of old road pavement may be abandoned due to (1) the establishment of a new road ecosystem; (2) the realignment of an existing road; (3) the By-Pass of traffic 'hotspots'; and (4) required road closure for environmental reasons. Occasionally the extent of old road pavement is large enough to significantly extend native habitats adjacent to an old road system.

For this reason, road decommissioning can potentially: (1) restore ecological integrity, and function of semi-natural ecosystems (including soil); (2) provide compensatory habitat; (3) maintain and improve quality of existing adjacent habitat by reducing noise disturbance and human access (amongst others); (4) restore connectivity by reinforcing the ecological network of surrounding core habitat areas, and; (5) contribute to the restoration of landscape quality in the vicinity of a new road ecosystem.

It can be assumed that, where road pavement is not decommissioned and persists, it may continue to: (1) inhibit the ecological functions and services of semi-natural ecosystems, (2) pose as a barrier to the dispersal of wildlife, (3) inhibit the establishment of vegetation cover (and habitat), (4) may continue to have an adverse effect on environmental aesthetics; and (5) contribute to the release of pollutants from surface run-off. It is for one or more of these reasons that the process of road decommissioning is generally carried out.

Paved road segments on five national road schemes in Ireland were examined with a view to identifying the potential role of restored vegetation as habitat for wildlife. It has been demonstrated that native vegetation can more readily colonize former road corridors post-decommissioning, especially those roads located adjacent to existing native plant communities e.g. grasslands, hedgerows and woodlands. The resulting decommissioned sections of road generally show rapid recovery through natural recolonisation, where vegetation successional processes are shown to recapture road corridors within a few years, resulting in valuable additional habitat for wildlife, especially birds and nectar feeding invertebrates such as butterflies and bees. Various native mammal species have also been found to utilize old roads as a means of dispersal, therefore providing connectivity in an increasingly intensified agricultural landscape.

# Use of a GIS-Based Model of Habitat Cores and Landscape Corridors for VDOT Transportation Project Planning and Environmental Scoping

**Bridget M. Donaldson** (434-293-1922, bridget.donaldson@vdot.virginia.gov), Research Scientist, Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, VA 22903 USA

**Joseph T. Weber** (804-371-2545, joseph.weber@dcr.virginia.gov), GIS Projects Manager/Conservation Biologist, Virginia Department of Conservation and Recreation, Richmond, VA USA

**Abstract**

Transportation agencies across the United States are under increasing pressure to minimize or avoid impacts of transportation projects to important wildlife habitat. With new road construction and lane additions, habitat fragmentation is becoming more pronounced and its effects are increasingly evident. Transportation projects are often planned, designed, and funded before taking important habitat considerations into account, which can lead to expensive delays and lawsuits.

Wildlife linkage or corridor analyses are being conducted in an increasing number of states, and more transportation agencies are using this information during the planning of proposed road projects. The Virginia Department of Conservation and Recreation's Natural Heritage Program is creating a GIS tool, *the Virginia Natural Landscape Assessment* (VANLA) that identifies large patches of natural landcover (habitat cores) and the habitat linkages connecting these areas (landscape corridors). This mapping project can be integrated into the Virginia Department of Transportation's (VDOT) existing GIS applications for access by staff involved with transportation planning and environmental scoping activities. Analyzing a proposed project in these early stages of project development will allow VDOT to identify important natural resource areas and wildlife corridors to avoid or for which mitigation may be necessary. This can result in fewer project delays, promote collaboration between VDOT and state natural resource and regulatory agencies, and meet the directives of the new habitat conservation provision in the federal transportation legislation. In addition, basing certain project decisions on a project's location relative to a wildlife corridor can decrease the risk of animal-vehicle collisions.

# A Web-Based Approach to Compliance Reporting for Caltrans

**Ivy Edmonds-Hess** (415-243-4724, edmondshess@pbworld.com), Lead Environmental Planner/ Professional Associate, PB, 303 Second Street, Suite 700 North, San Francisco, CA 94107, Fax: 415-243-9501 USA

## Abstract

Meeting compliance reporting requirements may be relatively easy for a smaller construction project, but as the projects gets larger and longer to complete the requirements get more extensive and complicated. Following traditional techniques such as mailing hard copies of reports can become labor intensive and expensive. The following describes a web-based approach that has been successfully used for over four years by the California Department of Transportation (Caltrans) during construction of the San Francisco–Oakland Bay Bridge (SFOBB) East Span Seismic Safety Project.

The purpose of the East Span Project is to provide a seismically upgraded crossing for current and future users between Yerba Buena Island and Oakland. The construction period is approximately twelve years for construction of the new East Span and two years to remove the existing structure. Construction activities take place on land as well as in San Francisco Bay and include activities such as dredging, excavation, pile driving, construction of temporary and permanent structures, and removal of the existing bridge.

Caltrans has incorporated numerous measures to avoid, minimize and compensate for potential environmental impacts. Caltrans is performing construction monitoring for biological resources which may be affected by construction of the bridge, including birds, fish, marine mammals, eelgrass, and water quality. Additionally, Caltrans is working with multiple resource agencies to develop on-site and off-site mitigation opportunities for creation and restoration of habitat. The off-site mitigation projects are among the largest Caltrans has ever funded and are the result of many agencies and environmental interest groups working together to improve the ecosystem of the Bay.

Construction of the East Span Project began in 2002. After the biological mitigation and monitoring program had been underway for several months, Caltrans began to contemplate ways to disseminate reports and information to the permitting agencies and the public in a timelier and easier manner. While the primary objective was to meet permit compliance requirements in a cost-effective manner, it was also important to provide easy public access to the information.

In order to develop such a tool, a better understanding of the users and the functional requirements of the tool was necessary. Interviews with stakeholders were conducted to evaluate the data collection process and existing reporting mechanisms as well as to determine what functions the stakeholders would like the tool to have.

It was determined that the best approach would be to have a user-friendly website that provided information in general terms for members of the public who simply had an interest in the project as well as more specifics about the biological mitigation and monitoring program (e.g., monitoring protocols, workplans, and technical reports) for those who were interested. Distribution lists of interested parties were created for the various topics. When a report or plan related to that topic is posted to the website, the members of the distribution list are emailed along with a direct link to the report.

A website prototype was developed and an implementation planning session was conducted in which selected Caltrans and consultant staff used the prototype and provided feedback on the various components. The website was then presented to regulatory agencies staff during an interagency coordination meeting. Feedback from the permitting agencies was very favorable. Many of the staff mentioned that the website is easy to use. They also liked the fact that all documents are readily available. When needing to check on a piece of information, they don't have to search their office for a hard copy of a report, permit, or protocol.

Members of the public were first introduced to the site as a link from the overall Caltrans Bay Bridge website and a website developed by an organization representing construction workers. Use of the website started out slowly and averaged about 170 visitors per week during the first year of operation. As the website became more known, the number of visitors increased. During 2006, the website averaged about 450 visitors a week. Visitors are located in numerous countries and downloads of the permits, protocols, and weekly bird and marine mammal memos are very popular.

After four years of operation, Caltrans has determined that use of the website has been very successful. While the use of websites has been limited on other mitigation and monitoring projects, Caltrans has found this tool to be simple, user-friendly, and cost-effective. It also demonstrates Caltrans' commitment to the environment. Proponents of other projects may want to consider using a website for compliance reporting or other environmental documents, particularly as the issue of sustainability and going "paperless" becomes more prevalent.

**Biographical Sketch:** Ivy Edmonds-Hess is a Lead Environmental Planner and Professional Associate with PB. She has over 18 years of experience in environmental consulting and project management for a wide variety of projects. In her current position, she has been assisting the California Department of Transportation with environmental and permitting issues with the East Span Project for over nine years.

# Effects of a Purpose-Built Underpass on Wildlife Activity and Traffic-Related Mortality in Southern California: The Harbor Boulevard Wildlife Underpass

**David Elliott** (714-992-7113, david.elliott.m@gmail.com) and
**Paul Stapp** (714-278-2849, pstapp@fullerton.edu), Department of Biological Science, California State University, Fullerton, CA 92834-6850 USA

**Abstract**

Conservationists have advocated the construction of wildlife crossing structures for the purpose of reducing traffic mortality of wildlife and maintaining habitat connectivity in increasingly fragmented landscapes. In May 2006, construction was completed on a wildlife underpass beneath Harbor Boulevard, a four-lane road that bisects the Puente Hills, one of the few remaining large tracts of coastal sage scrub habitat in southern Los Angeles County. We monitored the frequency of road-killed wildlife and the activity of medium and large mammals at track-stations in the vicinity of the underpass before, during and after underpass construction. We also used digital remote cameras and track stations to determine wildlife use of the new underpass. Remote cameras were installed in the underpass on 26 May 2006, soon after construction was complete. Our aim was to determine whether such underpasses reduce traffic-related mortality of wildlife and improve functional connectivity of remnant coastal sage scrub and other natural habitats for wildlife populations. Cameras indicated that wildlife began using the underpass almost immediately after construction. Mule deer and coyotes were photographed using the tunnel 3 and 4 weeks, respectively, after cameras were installed. Coyotes have used the underpass fairly regularly, with a sharp increase observed in October 2006, 23 weeks after cameras were installed. Use of the underpass by deer has been less consistent, perhaps due to seasonal changes in habitat use. As of April 2007, coyotes were photographed at the underpass an average of 26.6 times per month, and deer, an average of 2.0 times per month. Additionally, one bobcat was photographed in February 2007.

Track-station surveys indicated that coyotes and striped skunks are very common across the study area, but that other rare or more secretive carnivores such as long-tailed weasels, gray foxes and bobcats are also present. Track-station activity, and the diversity of species represented, was especially high in the center of the Puente Hills study area, suggesting that wildlife activity increases as one moves east and away from more intensely urbanized areas of the county. Across the study area, rodents were the most common road-killed animals followed by, in order of abundance, striped skunks, opossums, coyotes, brush rabbits, raccoons, mule deer, and bobcats. One American badger, a species that is considered uncommon in developed parts of Los Angeles County, was also found. Incidence of road-kills increased with higher speed limits. On Harbor Boulevard, coyotes accounted for 39% of the 31 road-kills detected since surveys began in July 2004, followed by opossums (19%) and striped skunks (16%). Two bobcats (6%) were also killed by vehicles on Harbor Boulevard over this period. Incidence of road-kills was very high on Harbor Boulevard relative to the rest of the study area prior to construction; however, to date (10 months post-construction), there has been no reduction in the frequency of road-kills on Harbor Boulevard. There also has been no apparent change in the frequency of road-kills across the study area between comparable pre- and post-construction surveys. Although wildlife use of the underpass has been relatively high, the lack of any decrease in the number of road-killed animals, notably coyotes, suggests that some animals have not found or are not using the underpass, and that other measures such as fencing might be considered in the vicinity to funnel more crossings off of Harbor Boulevard and into the underpass.

The underpass was constructed at Harbor Boulevard because it represents an area of significant narrowing of the Puente Hills Wildlife Corridor by urban development, where traffic-related mortality of wildlife was suspected to be high. As such, the new underpass has the potential to facilitate movement between protected areas of the Puente Hills and other undeveloped private and public lands to the east. We hope that our project, which will monitor wildlife activity and traffic-related mortality in the vicinity of the underpass through May 2007, will add to the current body of knowledge on mitigating the negative effects of roads on wildlife. Additionally, our project may also provide information that will help to eventually create and maintain a functional wildlife corridor from the San Gabriel River to the Cleveland National Forest, of which the habitat in Puente Hills will be a critical link.

**Biographical Sketches:** David Elliott is currently a Master's student at California State University, Fullerton. His project aims to evaluate the effectiveness of a purpose-built wildlife underpass in Los Angeles County, California and measure wildlife activity in the area surrounding the underpass. Dr.

Paul Stapp is an assistant professor in the Department of Biological Science at Cal State Fullerton.

## Wildlife Mitigation and Human Safety for Sterling Highway MP 58-79, Kenai Peninsula, Alaska

**Richard Ernst**, Wildlife Biologist/Pilot (907-262-7021, rick_ernst@fws.gov), U.S. Fish and Wildlife Service, Kenai National Wildlife Refuge, P.O. Box 2139, Soldotna, AK 99669, Fax: 907-262-3599 USA

**Jeff Selinger**, Area Wildlife Biologist (907-260-2905, jeff_selinger@fishgame.state.ak.us), Alaska Department of Fish and Game, 43961 Kalifornsky Beach Road, Soldotna, AK 99669 USA

**Jim Childers**, Project Manager (907-269-0544, jim_childers@dot.state.ak.us), Alaska Department of Transportation and Public Facilities, P.O. Box 196900, 4111 Aviation Avenue, Anchorage, AK 99519 USA

**Dale Lewis**, Central Region Liaison Engineer (907-586-7429, dale.j.lewis@fhwa.dot.gov), Federal Highway Administration, Alaska Division, P.O. Box 21648, Juneau, AK 99802, Fax: 907-586-7420 USA

**Gary Olson**, President (907) 336-6673, golson@growmoremoose.org), Alaska Moose Federation, 11701 Brayton Drive, Anchorage, AK 99516 USA

**Lt. Steve Bear**, Detachment Commander (907-262-4453, steve_bear@dps.state.ak.us), Alaska Department of Public Safety, Wildlife Troopers, 44009 Kalifornsky Beach Road, Soldotna, AK 99669, Fax: 907-262-9664 USA

**Abstract**

The Sterling Highway is a paved two-lane road which links Alaska's western Kenai Peninsula, to the Seward Highway and Anchorage, the state's largest city. The Kenai National Wildlife Refuge is bisected by the Sterling Highway, which has one of the highest moose (*Alces alces*) vehicle collision rates for a rural highway in the state. The Alaska Department of Transportation and Public Facilities is planning to reconstruct a section of the Sterling Highway between MPs 58 and 79, occurring mostly within the Refuge. A working group was formed in 2005 to collect data on moose movements and review wildlife-vehicle collisions (WVC). The group consists of representatives from the Federal Highway Administration; the Alaska Departments of Transportation and Public Facilities, Fish and Game, and Public Safety; the Alaska Moose Federation (non-profit); and the U.S. Fish and Wildlife Service. The purpose of this cooperative effort is to reduce wildlife-vehicle collisions along the Sterling Highway corridor through the Kenai National Wildlife Refuge while maintaining permeability and enhancing habitat connectivity. In this paper, we describe our study design and provide interim results from 2005-06.

# Major Objectives for Road Ecology to Benefit Transportation and Society

**Richard T. T. Forman** (617-495-1930, rforman@gsd.harvard.edu), PAES Professor of Landscape Ecology, Graduate School of Design, Harvard University, Cambridge, MA 02138 USA

**Abstract:** Pinpointing major objectives as a vision for transportation and society provides a cost-effective framework for numerous detailed solutions along the road network. Three major objectives, with road ecology a central player, are highlighted: (1) improve the natural environment close to the entire road network; (2) integrate roads with a sustainable emerald network across the landscape; and (3) integrate roads with near-natural water conditions across the landscape. These are briefly described along with examples of possible key steps ahead. In effect, this big picture or vision is a cost-effective route to achievement and benefit for transportation, the environment, and society.

## Background

The world's transportation infrastructure, a remarkable engineering accomplishment, was basically built before the rise of modern ecology. Now in an era of new scientific information and new societal objectives, transportation, science and the public have all moved well ahead. Enhancing the natural environment increasingly stands alongside safety and efficiency in transport as transportation's central goal for the public.

Not surprisingly, along with this major development, the science of "Road Ecology" has emerged, focusing on plants, animals and water related to roads and vehicles (National Research Council 1997, Forman et al. 2003, Forman 2004). Decreasing the apparent drumbeat of public calls for environmental sensitivity in transportation plans and projects, planners, engineers, and managers increasingly find existing solutions, tested options, and solid ecological science readily available for application. Potential partners...transportation departments, natural resource agencies, academics, nonprofit organizations, and the informed public...are discovering common interests and opportunities for a new era of accomplishment. Project by project, countless locations along our road network ecologically improve, and environmental objectives increasingly receive emphasis in transportation plans.

Yet the big picture has yet to coalesce and capture our attention. The greatest environmental gain and the greatest cost benefit for transportation and society are achieved by keeping our eye on the big picture—the major objectives—while we work project by project, location by location, and solution by solution. Three major objectives effectively tie the detailed solutions together in context, and provide the primary gain for transportation and society (Forman 2007a). Road ecology is central to all three.

## The Three Major Objectives

1. Improve the natural environment close to the entire road network.
2. Integrate roads with a sustainable natural emerald network across the landscape.
3. Integrate roads with near-natural water conditions across the landscape.

The first objective is a flexible trajectory rather than an end point, with different solutions in different locations. The second effectively meshes road networks with the land's most-valuable large natural areas connected by major wildlife corridors to establish a combined sustainable pattern for the future. The third objective integrates road networks with the land's water-bodies, groundwater/surface-water flows, aquatic ecosystems, and fish populations, so that an effective infrastructure and relatively natural surrounding water conditions are both sustained.

The major objectives constitute a vision appealing to many potential partners and interested parties. The vision cannot be accomplished by the transportation community alone; collaboration with partners is essential, providing planning, project, policy, and public-relations values. Indeed, diverse interested parties with a common vision are an unbeatable recipe for powerful, cost-effective environmental accomplishments for transportation and society. Therefore, consider the three objectives more closely.

### Improve the Natural Environment Close to the Entire Road Network

This objective emphasizes a trajectory of improvement rather than identifying and targeting a specific end product with success or failure. The rate of improvement varies from place to place. Location-by-location solutions along a road are appropriate (Bekker et al. 1995, Trocme 2003, Iuell et al. 2003, Forman et al. 2003, van Bohemen 2005). Road-segment-by-road-segment solutions may often be more effective and cost efficient. Road-network-by-road-network approaches are likely to be especially valuable. The types of improvement stretch the imagination---habitat enhancement, vegetated stormwater-pollutant depressions, wildlife underpasses/overpasses, less-intensive mowing regimes to reduce invasive species, diverse deicing approaches, reduced air pollutants, aesthetic noise-attenuation techniques, and much more. Intriguing solutions for all of these currently operate in different nations. In essence, this objective can be accomplished with ample flexibility for transportation and great environmental gain for society.

### Integrate Roads with a Sustainable Natural Emerald Network across the Landscape

This second objective emphasizes the most important solution known to protect and sustain biodiversity in a landscape with roads and vehicles, even in the face of urbanization and anthropogenic climate change. The central component is to identify (even create) and protect emeralds, the most-valuable large natural patches or areas on land, in locations and forms undegraded by roads, traffic, and other human effects (Forman 1995, 2007b). However, significant added value is achieved by effective connections for species movement, and also walkers, among the emeralds. Highways with traffic fragment habitats and are major barriers to effective movement between natural areas. Identifying, creating in some places, and protecting major wildlife corridors emerges as the key to converting a group of large natural patches into an effective functioning emerald network, which can be sustained for the future. Planning road networks hand in hand with landscape ecology is a key to achieving this objective.

### Integrate Roads with Near-Natural Water Conditions across the Landscape

This third objective highlights water as the other major flow that crosses a landscape with roads and traffic present. Water is normally a key variable in road construction and, almost always, surrounding wetlands, streams, ponds, groundwater, other water-bodies, and especially water flows are significantly altered (Bekker et al. 1995, Forman et al. 2003, van Bohemen 2005). Thereafter culverts/bridges and roadside ditches are key determinants of water conditions in surrounding areas, and therefore are major "handles" for improvement and attaining the objective. For example, ongoing maintenance and rehabilitation/upgrading projects are cost-effective opportunities to reduce water-flow problems and the water transport of pollutants, including heat, mineral nutrients, heavy metals, and hydrocarbons from roadsides, road surfaces, and vehicles. Wide stream-corridor vegetation has double value, addressing both the second and third objectives (Forman 1995). Achieving near-natural conditions in essentially all water systems of the surrounding landscape provides many important societal benefits, from flood control and less-scarce-and-costly clean-water-supply to biodiversity, aesthetics, and happy fishermen.

The three objectives focus on the existing infrastructure on which we all depend. For new road construction, incorporating the objectives into planning can eliminate the later need to address them, an environmentally salutary and cost-effective accomplishment.

## Promising Steps Ahead

How do we get from here to there? Think big. Large areas are a surrogate for long term. Planning and improving whole landscapes and road networks is effectively long-term thinking, and is likely to produce sustainable patterns that persist. Or, achieve success in a small area, and replicate it flexibly in similar form so that it spreads widely across the road system. The first objective above is especially amenable to inexorable incremental progress, while the second and third objectives fit progressive steps logically into a framework or vision.

An array of important ecological steps is readily available for use in transportation, as the following examples emphasize (Bekker et al. 1995, Forman et al. 2003). Ongoing bridge and culvert replacement or upgrading is a cost-effective opportunity to combine benefits for water, wildlife, and other societal goals. Identify and map the major water flows and species movements across landscapes, to identify potential conflict points with the road system (Forman et al. 2003). Wildlife underpasses and overpasses are the best way for animals in major wildlife corridors to cross highways (Trocme 2003, Iuell et al. 2003, Forman et al. 2003, van Bohemen 2005). Roadside woody vegetation in distinct wildlife-crossing zones is also effective for animal crossing of roads (Forman and McDonald 2007). Determine and apply the ecologically and travel-optimum road network form and its underlying principles (Forman 2004). The road-effect zone, combining engineering and landscape ecology perspectives, is particularly valuable for transportation planning (Forman et al. 2003, van Bohemen 2005).

Indeed, appoint a respected blue-ribbon panel of transportation, engineering, ecology, planning, and other experts to critically evaluate the objectives, and outline the trajectory and timetable to success. Establish high-profile pilot projects (with monitoring) widely across the land. Continue attracting the cutting-edge scholars in road ecology, and fund high-quality scientific research (National Research Council 1997, Forman et al. 2003, Roedenbeck et al. 2007). Accomplish steps in the context of other major concerns or crises, such as greenhouse gases/climate change, urbanization-spread patterns, and water scarcity. In short, lots of promising approaches await our leadership, stepping forward to accomplish the three major objectives—the vision—for transportation, for the environment, and for society.

## References


Bekker, H., B. van den Hengel, H. van Bohemen, and H. van der Sluijs. 1995. Natuur over Wegen (Nature Across Motorways). Ministry of Transport, Public Works and Water Management, Delft, Netherlands.

Forman, R. T. T. 1995. *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge University Press, New York.

Forman, R. T. T. 2004. Road ecology's promise: what's around the bend? *Environment* 46: 8-21.

Forman, R. T. T. 2007a. Foreword. In *Getting Up to Speed*, by T. White. Defenders of Wildlife, Washington, D.C. Forthcoming.

Forman, R. T. T. 2007b. *Urban Regions: Ecology and Planning Beyond the City.* Cambridge University Press, New York. Forthcoming.

Forman, R. T. T. and R. I. McDonald. 2007. A massive increase in roadside woody vegetation: goals, pros, and cons. In *International Conference on Ecology and Transportation 2007 Proceedings*, Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina, USA. Forthcoming.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road Ecology: Science and Solutions*. Island Press, Washington, D.C.

Iuell, B., H. (G. J.) Bekker, R. Cuperus, J. Dufek, G. Fry, C. Hicks, V. Hlavac, V. Keller, C. Rosell, T. Sangwine, N. Torslow, and B. le M. Wandall. 2003. *Habitat Fragmentation due to Transportation Infrastructure: Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions*. COST 341. KNNV Publishers, Brussels.

National Research Council. 1997. *Toward a Sustainable Future: Addressing the Long-Term Effects of Motor Vehicle Transportation on Climate and Ecology*. National Academy Press, Washington, D.C.

Roedenbeck, I. A., L. Fahrig, C. S. Findlay, J. E. Houlahan, J. A. G. Jaeger, N. Klar, S. Kramer-Schadt, and E. A. van der Grift. 2007. The Rauischholzhausen agenda for road ecology. *Ecology and Society* 12(1): 11 (Online).

Trocme, M., S. Cahill, H. (J. G.) de Vries, H. Farrall, L. Folkeson, G. Fry, C. Hicks, and J. Peymen, eds. 2003. *Habitat fragmentation due to transportation infrastructure: The European review*. COST Action 341. European Commission, Brussels.

van Bohemen, H. D. 2005. *Ecological Engineering: Bridging Between Ecology and Civil Engineering: A Practical Set of Ecological Engineering Principles for Road Infrastructure and Coastal Management*. Directorate-General of Public Works and Water Management, Delft, Netherlands.

# Pre-Assessment of Wildlife Movement Patterns in a Forested Habitat Prior to Highway Development: Prioritizing Methods for Data Collection to Couple Local and Landscape Information for the Development of Statistical Models

**Kerry R. Foresman** (406-243-4492, foresman@mso.umt.edu), Professor of Biology, and
**Michael A. Krebs** (406-243-4492, michael.krebs@mso.umt.edu), GIS Analyst, Division of Biological Sciences, The University of Montana, Missoula, MT 59812, Fax: 406-243-4184 USA

## Abstract

In 2004 the Federal Highway Administration, Western Federal Lands Highway Division, presented a proposal to improve the roadway along the Thompson River in west central Montana connecting state Highway 200 east of the town of Thompson Falls and Highway 2 west of the town of Kalispell. As currently exists here, two gravel roads run, north-to-south, over a 40-mile length. This corridor supports denning wolves, has legal status as a grizzly bear corridor, has habitat which may be used by lynx, wolverine, and fisher, has large populations of elk, white-tailed and mule deer, moose, and bighorn sheep, and the river itself is a bull trout spawning tributary. Because of this, the Thompson River drainage was identified as such a significant wildlife corridor that a consortium of organizations (USDA Forest Legacy Program, USFWS Habitat Conservation Land Acquisition Program, Montana Fish, Wildlife & Parks, and Bonneville Power Administration) allocated $34 million to place a conservation easement on this region.

Initial plans were to pave this roadway to permit year-round travel and to reduce siltation of the Thompson River. Our research focus was to characterize the terrestrial wildlife populations along this corridor, to determine the most significant locations across which animal crossings occur and characterize these by local and landscape attributes, and to develop mitigation plans to deal with significant wildlife issues if improvements were to proceed. One of our primary purposes was to develop a model approach predicting wildlife activity to such studies for the FHA which could be employed in the future at other locations.

Wildlife distributions were determined through the use of remote cameras (n = 583 sites monitored with replicates; >7,600 animals detected), permanent snow-track transects (n = 52; >18,000 tracks identified), and GPS radiotelemetry (specifically bighorn sheep; n = 9; average of > 4,600 locations determined/animal). Movement patterns were further studied by identifying roadway crossing locations ("hotspots" – n = 650), backtracking a subset of these and creating GPS layers, and identifying all locations at which road mortalities (n = 33) occurred. Local (25 m radius) vegetation analyses and habitat characteristics were collected in the field at 316 locations along the roadways associated with each of these survey parameters, and various landscape level attributes within a 1 km radius of each camera location were then derived using ArcGIS 9.0 from GIS layers supplied from the USFS Northern Region Vegetation Mapping Project and Lolo National Forest coverages. These include actual surface area estimates of dominant vegetation and lifeform type, vegetation size, canopy cover, ownership, and road and stream density. A 10-meter digital elevation model (DEM) and MODIS satellite data of the study area were used to generate topographic attributes of slope and aspect and estimates of forest cover for analysis.

Using ESRI's ModelBuilder geoprocessing environment, spatial data from individual camera locations served as inputs for a data model developed for landscape-level data extraction from GIS layers and subsequent coupling of local and landscape variables. One kilometer buffer zones created around each camera location were used to intersect with GIS layers. Summary tables of model variables were generated in a geodatabase, exported to a Microsoft Access database and merged with local variables where further derivation and calculation of predictor information could be accomplished. Once complete, a final table containing both response and local and landscape predictor variables was created and exported to SPSS/S-PLUS for statistical analysis.

Three distinct regions along the 43-mile corridor were identified for separate model development. The southernmost region is largely characterized by steep, forested canyon topography; the central region consists of a broader, open, forested river valley, while the northernmost region is predominantly private agricultural land. As our primary response variable measuring animal activity along the proposed highway, we calculated the number of animal sightings recorded by each camera per 100 hours of camera time for each location (called Occurrence Index) and the number of tracks (by species) per 100 meter interval over each 1 km snow transect. Several regression modeling approaches are currently being explored including logistic, Poisson, and Ordinary Least Squares, depending on response variable distribution model fit and other procedural assumptions. Spatial correlation will also be evaluated using either ESRI's Geostatistical Analyst or S-PLUS. Models will be generated for each region and their final selection will be determined using both cross-validation and various model fit criteria. Beyond their current application in this study, it is our further goal that these models representing contrasting landscapes will have a broader inter/intra-regional application for other similar studies in the future.

# Forest Service Back Roads: Utilization of GPS/GIS Technology for Acquiring Road Infrastructure Data in the Ozark-St. Francis National Forests

**Benjamin Gentry**, GIS Technician (479-964-7200, bgentry@fs.fed.us), Ozark-St. Francis National Forest, 605 West Main St., Russellville, AR 72801 USA

**Abstract**

This presentation describes how one Forest Service unit uses GPS/GIS technology to update and maintain information regarding its road network.

The Ozark-St. Francis National Forest (OSFNF) has developed an integrated field collection and GIS process method to digitally capture spatial and tabular information about travel routes, road features, travel route conditions, and other related features, to assist in land management planning activities and environmental assessments.

The methodology draws from 5+ years of experience incurred by the Ouachita National Forest, The Nature Conservancy, and the Watershed Conservation Resource Center to inventory road locations and prioritize maintenance recommendations. These earlier activities were useful for updating Forest Service applications, or collecting variable for use in environmental prediction models such as WEPP: Road.

Currently the USFS maintains road information in an Oracle database accessed through an application known as INFRA travel routes which interfaces with an Electronic Road Log (ERL) for conducting automated updates. This tool makes available changes to tabular information fields but does not support spatial updates to GIS data layers. The methodology described in this project is manual; however the intent is an expanded amount of highly organized tabular and spatial information, collected in the field, using a standard suite of hardware/software components. These features make this methodology appropriate for dissemination to other FS units, and could easily be automated as a one-click update tool.

The OSFNF methodology uses Trimble Geoexplorer GPS units and a custom data dictionary for the collection and organization of tabular and spatial information. Post-processing methods that remove errors, correct for spatial requirements, provide QA/QC, and format the output products are clearly defined. This output is then migrated into applications such as INFRA travel routes; INFRA travel route GIS data layers, and forest specific datasets that accommodate related information. This methodology allows the OSFNF to maintain databases and GIS layers to the appropriate standards while providing an expanded dataset of road related features for land and resource management planning.

The goals of this project are to increase the spatial accuracy of road related data and to develop a tool where multi-skilled users can generate consistent outputs for this type of information. This project also seeks a method for updating tabular INFRA data and spatial GIS data layers simultaneously in order to increase the efficiency of field inventories. Ultimately, updating travel route information without ERL hardware requisites, increasing the intensity of field inventories, and achieving greater consistency will expand the OSFNF capabilities for conducting environmental assessments and opportunity analysis.

# Limited Applications of Wildlife-Vehicle Collision Analyses for Transportation Planning and Mitigation Efforts Due to Spatial Inaccuracy

**Kari E. Gunson**, Faculty of Environmental and Resource Engineering (315-375-3760, kegunson@syr.edu), State University of New York, College of Environmental Science and Forestry, 312 Bray Hall, Syracuse, NY, 13210 USA

**Anthony P. Clevenger**, Ph.D., (403-760-1371, tony.clevenger@pc.gc.ca), Western Transportation Institute, P.O. Box 174250, Montana State University, Bozeman, MT 59717 USA

## Abstract

To properly mitigate road impacts for wildlife and increase motorist safety, transportation departments need to be able to identify where particular individuals, or species are susceptible to high road-kill rates along roads. Researchers have relied on a variety of statistical methods to determine the specific explanatory factors associated with wildlife-vehicle collisions (WVC). Of particular importance in these analyses is the underlying spatial data used to describe the locations of WVCs. In this study we investigate the importance of the same WVC factors on two different datasets: one with highly accurate location data (<3 m error) representing an ideal situation and another dataset with high spatial error (+0.5 mile or 800 m), which is likely more characteristic of the average transportation agency dataset where collision locations are recorded to the closest mile marker. We used spatially accurate locations of ungulate vehicle collisions (UVC) in the Central Canadian Rocky Mountains from 1999 to 2004 to create a low accuracy dataset by shifting each location to the nearest hypothetical mile-marker on the road. We measured the same attribute at each spatially accurate UVC location and at each mile-marker location along five highways in the study area. We categorized each mile marker segment and its corresponding kills as a "high-kill" or "low-kill" zone by comparing the total number of UVCs associated with a single mile-marker segment to the average number of UVCs per mile for the same stretch of road. We measured three types of spatial variables for each high and low kill location: field measured point-specific and GIS generated proximity and proportional variables. We used univariate tests and logistic regression analyses to identify which of the attributes best predicted the likelihood of UVC occurrence for both datasets. Within the spatially accurate dataset, six of the point specific habitat and terrain variables were significant while only two of the field variables (road width and terrain) were significant for the mile-marker dataset. No proximity and one proportional measurement was significant for the mile-marker dataset. The spatially accurate regression model was significant and had more predictive ability than the low accuracy data since the majority of the variables measured were site-specific. This analysis demonstrates that WVC data collection accuracy will determine the scale and type of variables which should be measured. The application of models generated from low accuracy data is limited to a coarse landscape scale while spatially accurate models are needed to determine the fine-scale factors associated with WVCs. The particular objectives of these predictive analyses i.e. pinpointing exact locations for mitigation structures, will ultimately determine whether an agency should invest in collecting spatially accurate data as opposed to opportunistically collecting low accuracy data.

# Development of a Bald Eagle Habitat Assessment Tool and Its Application in Highway Planning

**James Hatchitt**, GIS Project Manager (352-333-8393, jim@armasi.com), ARMASI, Inc., 3966 SW 98th Dr., Gainesville, FL 32608 USA

**Abstract**

Florida has the largest population of nesting bald eagles (*Haliaeetus leucocephalus*) in the Continental US. Bald eagles are currently listed as a federal and state threatened species. The bald eagle population in Florida has recovered to the point that the US Fish & Wildlife Service (USFWS) has indicated that it no longer warrants protection under the Endangered Species Act (ESA). However the species will continue to be managed and protected by federal and state guidelines. Until recently application of management guidelines could only be based on subjective assessment of the individual nest site. Habitat management guidelines have been developed and successfully implemented to accommodate human and bald eagle habitat needs on a limited basis. Here we are describing a data based model which was used to assess each nest site in Florida based on its current and future comparative importance to the population. The results of this process are then overlaid on the Florida Intrastate Highway System (FIHS) map layer. This provides a mechanism whereby the Florida Department of Transportation (FDOT) has advanced warning of potential issues relating to bald eagle habitat.

The Florida Department of Transportation (FDOT) and FFWCC has worked cooperatively through a contract with ARMASI Inc. to develop a Bald Eagle Habitat Index of Vulnerability (BEHIV) environmental management tool. This vulnerability index evaluates each eagle nesting site in Florida to provide a quantitative assessment of the current and predicted effects of various anthropogenic and natural modifications to the long term viability of these sites. Multiple habitat aspects associated with each nest site, including land use, distance to water, and density or proximity of nest habitat areas, were systematically grouped into data layers. The various layers used in the construction of the BEHIV were incorporated into the model through a weighting process based on their relative importance to eagle nest viability (Nesbitt et al. manuscript). The weighted value assigned to each layer was developed through the review of historical data, ongoing studies, and expert opinions. The relative score compiled from the model and associated map data was used to delineate the various habitat constraints and resources associated with each of the more than 1200 nest sites in Florida. This natural setting score provides a characterization of the quality of each habitat area based on the weighted data variables compiled.

In addition to the natural setting profile an evaluation of the potential for future disruption was compiled using a Conservation Land and Future Land Use coverage with a similar weighting scheme. The amount of area for each future land use or proposed zoning land use categories contained within each habitat buffer was calculated and summarized to arrive at a potential for disruption score.

This qualitative ranking process and the database of individual component values for each nest offers a consistent means of ranking habitat areas across the state. The results of this analysis are used to determine the number of nests within a certain distance of the FIHS system along with their associated BEHIV score. We created a buffer file for each FIHS segment. The resulting buffer files were then overlain on the Eagle nest BEHIV file and the two files were then merged and summarized by FIHS segment to get a preliminary BEHIV score for each segment. Three buffer distances are used to indicate the potential for disruption of nest in proximity to the FIHS network. The buffer distances are a 750 feet Primary Alert buffer, a 1500 feet Secondary Alert buffer, and a 1 mile notification buffer (these distances are expected to be reduced once the species has been delisted).

The results of this project are intended to compliment existing information related to the FIHS maintenance and right of way development. The incorporation of the BEHIV/ASSESS into the FIHS provides a means by which FDOT personnel can be alerted to environmental concerns at an early stage in the planning process. This project and its application offers some insight to the potential for adding other environmental layers to FDOT planning areas. The results have been submitted to FDOT and the BEHIV process is currently under review by FFWCC staff for incorporation into the Bald Eagle Management Plan.

# New International Efforts for Freshwater Research, Education, and Conservation: A Report From the Society for Conservation Biology's Freshwater Working Group

**Nathaniel P. Hitt** (than@vt.edu), Department of Fisheries and Wildlife Sciences, Virginia Polytechnic Institute and State University, 100 Cheatham Hall, Blacksburg, VA 24061 USA
**Aventino Kasangaki** (aventinok@yahoo.com), Institute of Tropical Forest Conservation, Mbarara University of Science and Technology, P.O. Box 44, Kabale, Uganda
**Mordecai Ogada** (mordyogada@yahoo.com), National Museums of Kenya, Museum Hill, P.O. Box 40658, Kenya 00100
**Ken Vance-Borland** (ken.vance-borland@oregonstate.edu), Department of Forest Science, Oregon State University, Corvallis, OR 97331 USA

## Description

We provided an informational poster about the Society for Conservation Biology's Freshwater Working Group and proposed new research questions regarding the effects of transportation networks on freshwater ecosystems.

## Abstract

Freshwater ecosystems are vital for human well-being and ecological integrity but are increasingly jeopardized by habitat loss and degradation, fragmentation, water abstraction, and climate change. These threats are diverse and pervasive and thus require new thinking about conservation problems and solutions. Here, we describe the Society for Conservation Biology's Freshwater Working Group (FWWG) and invite ICOET members to join this initiative. First, we review the origins of the FWWG and briefly describe previous accomplishments. Second, we describe the international composition of the FWWG and current activities. Third, we propose new research questions regarding the effects of transportation networks on freshwater ecosystems. We explain that the landscape structure of freshwater ecosystems is distinct from terrestrial environments and that localized, direct effects of roads must be understood in the context of regional, indirect effects of landscape connectivity and other factors. We conclude that freshwater conservation requires new research across ecological scales and new collaborations across political boundaries.

# An Alternative to the Openness Ratio for Wildlife Crossing Structures Using Structure Physical Attributes and Behavioral Implications of Deer Vision and Hearing Capabilities

**Sandra Jacobson**, Wildlife Biologist (503-453-0593, sjacobson@fs.fed.us), USDA Forest Service, Pacific Southwest Research Station, Redwood Sciences Lab, 1700 Bayview Drive, Arcata, CA 95521 USA

**Abstract**

This study proposes an alternative to the current use of the "openness ratio" by investigating the contribution of the acoustical and visual proprerties as a result of structure shape and size to its effectiveness for deer.

Reed et al. (1975) coined the term "openness" to describe and measure a concept that mule deer (*Odocoileus hemionus*) prefer crossing structures with a clear view of the horizon. Since then, the concept has been extrapolated far beyond Reed's use, for all shapes of underpasses and for many species of animals, most often with no definition beyond a simplistic height x width/length. Other problems with the current use of the concept are the inconsistent use of the units (English vs metric), different terms (ratio, index or simply openness), measurements at different points on a non-square underpass, lack of differentiation between the value of height vs width, and lack of well-designed experimental studies controlling for this variable. Yet biologists intuitively know that ungulates prefer structures with good visibility, and several studies support this even without a means to clearly differentiate the contribution of openness components. This study looks at the way that different shapes and sizes of underpasses contribute to the components of an open feeling in terms of the predator avoidance adaptations of white-tailed deer (*Odocoileus virginianus*). Underpass shape, size and materials determine the acoustical signature of noises resonating within a structure. For example, an arch shape within the sizes often used for wildlife crossing structures will focus sound in the approximate location of a deer's head. As underpass size increases, resonance diminishes. Underpass length determines the amount of total light and the perception of distance to the end of the structure. White-tailed deer perceive danger through hearing, vision and smell. Their use of hearing is impaired if sounds resonating from the interior of an underpass are unknown to them and mask other normal sounds, thus causing fright and possible flight. White-tailed deer perceive movement along a horizontal plane better than focused detail, and their depth perception is lower than animals with eyes facing forward. Their vision in low light conditions is far better than humans. These factors taken together can be used to redefine the Openness concept into its important components. We propose that Openness be comprised of the following four measures. 1) Aspect Ratio measures the relationship between a structure's length and height, measured at the approximate height of a deer's head, or 1 meter. This measure considers the greater importance of horizontal visibility for predator detection from an ungulate's perspective. 2) Cross-sectional Area measures the area above a horizontal line at a 1 meter. This measure takes into account that structures of varying shape produce different perceptions of openness. 3) Brightness measures the perception of distance that varies with the length of a structure. This measure takes into account the perception of apparent distance to safety and flight distance. 4) Presence of a Ledge indicates presence or absence of a horizontal ledge whose surface is not visible from an animal inside the structure. This indicator considers the intimidating effect of a possible predator attack position on the willingness of deer to pass through an enclosed structure. Thresholds for these components will be proposed as alternative measures to the current use of the "Openness Ratio" for highway crossing structures intended for white-tailed deer, and suggested as further study for other ungulates as well.

# A Review of the Broad Effects Generated by Roads on Herpetofauna

**Denim M. Jochimsen** (208-244-1336, denim2cure@yahoo.com), School of Biological Sciences, Washington State University, P.O. Box 644236, Pullman, WA 99164-4236 USA

**Abstract**

Although, several reviews, bibliographies, and texts describing the effects of roads on natural systems have been published, amphibian and reptile taxa remain underrepresented.

An array of studies document that roads generate ecological disturbance and destruction at multiple scales across the landscape. As conflicts between roads and wildlife become increasingly common, experts seek to understand the interactions in the search for solutions. Although, several reviews, bibliographies, and texts describing the effects of roads on natural systems have been published (Andrews 1990, Forman and Alexander 1998, Trombulak and Frissell 2000, Forman et al. 2003, White and Ernst 2003) amphibian and reptile taxa remain underrepresented. The extent of the direct and indirect effects of roads on these species has been revealed in numerous studies, with excessive rates of mortality (thousands) documented, and changes in behavior, movement, survival, growth, and reproductive success of individual animals reported. Cumulatively, effects may incur population-level consequences, or influence the overall species richness and diversity in an area. The goals of this presentation are to: 1) provide examples of physiological, ecological, and behavioral traits inherent among herpetofauna that enhance their susceptibility to environmental changes associated with development and roads, 2) summarize the prevalence of direct mortality data for herpetofauna, 3) identify the diversity of indirect effects documented in the literature, 4) infer larger-scale impacts on population and community levels, 5) recommend areas of future research that are to date undocumented, but for which herpetofauna are likely susceptible, and 6) present proactive approaches for addressing conflicts.

## Effectiveness of Black Bear Crossings on I-26 in Madison County, North Carolina

**Elizabeth R. Jones** (919-515-7587, erjones@ncsu.edu), **Richard A. Lancia**, and **Phil D. Doerr**, Fisheries and Wildlife Program, Department of Forestry and Environmental Resources, North Carolina State University, Box 7646, Raleigh, NC 27695-7646 USA

**Abstract**

Roads have become an integral part of our society, but recently society has begun to realize the ecological impact that roads have on their surroundings. One major effect that roads have on large mammals is creating a barrier to movement of individuals both between and within populations. In an effort to alleviate this problem on a new interstate project, the North Carolina Department of Transportation constructed two 8' x 8' concrete box culverts on I-26 in Madison County, North Carolina, intended for use by American Black Bears (Ursus americanus). Black bears have been observed using a variety of crossing structures, and it is not known what type of design best suits their needs. To determine the effectiveness of these crossing structures, each culvert's wildlife activity is being recorded by Cuddeback digital still cameras. In addition, digital video data is being captured at one of the culverts. One crossing has been monitored since November 2005, the other since April 2006. From these data, detection probabilities and an overall estimate of wildlife use can be calculated. Wildlife crossings at other structures along the roadway will also be recorded, specifically at culverts built to carry trout streams under the interstate. Also, still cameras have been installed at a few likely crossing locations along the roadway in an attempt to capture black bear crossings. These potential crossings were selected based on the literature. Lastly, local residents are being surveyed to determine locations black bears have been seen crossing the interstate. Based on the various types of crossing data, and information from the literature, a GIS model will be constructed to predict where black bears are most likely to cross roads in the Appalachian Mountains.

At this time, no black bears have been recorded using either of the crossings, or any of the stream culverts. Bears have been recorded crossing the roadway adjacent to the crossing structure, and one bear was recorded at the entrance to the crossing structure. Several other mammal species have been recorded using the wildlife crossings, including raccoons, opossums, bobcats, groundhogs, a least weasel, a species of rat, and domestic cats. The crossings will continue to be monitored through early summer 2007. At that time, the crossings will be evaluated for effectiveness as black bear crossings, and the GIS model will be finalized.

Based on the results, transportation officials around the world will have a better understanding of how black bears, and possibly other large carnivores, interact with roads of this size.

# Summary of Strategic Agenda for Deer-Vehicle Crash Reduction: Data Collection, Research, Funding, Partnerships, and Technology Transfer

**Keith K. Knapp** (979-845-5686, k-knapp@tamu.edu), Associate Research Scientist, Texas Transportation Institute, Texas A&M University, 3135 TAMU, College Station, TX 77843-3135, Fax: 979-845-6006 USA

**Abstract**

More than 65 people (with varying backgrounds) involved with or interested in the reduction of deer-vehicle crashes (DVCs) attended the October 2005 "Deer-Vehicle Crash Reductions: Setting a Strategic Agenda" conference. At this meeting the attendees collaborated and brainstormed to identify strategic agenda action items for DVC reduction research and data collection, funding, partnership building, and technology transfer and education. Focus groups were created to discuss each of these subject areas. This poster summarizes the results of those discussions. Each of the focal groups was initially asked to identify the concerns/problems it thought should be resolved to help reduce DVCs within their subject area (and overall). They also provided goals/objectives that could be achieved within their subject area during the next three to five years, along with the strategic agenda action items that could help accomplish these goals/objectives. The focus of each group was different and in some cases their suggested strategic agenda action items were very specific. In other cases, however, similar suggestions were provided by more than one group. Four common themes or general categories were identified among the strategic agenda action items suggested. The first category includes action items that help facilitate and guide intra- and inter-agency coordination with respect to the DVC problem. The second category included action items that increase the general awareness of the DVC issue by effectively and efficiently providing the correct message to a wide range of audiences. The third group included action items to encourage the consistent collection of DVC-related data, and the fourth group of action items promotes the development, implementation, and evaluation of potential and existing DVC countermeasures. A strategic agenda document was created from the meeting activities and results. It should be used as a guide to those individuals and groups interested in advancing the reduction of DVCs. This poster summarizes the content of that strategic agenda document.

# Highway Median Impacts on Wildlife Movement and Mortality

**Angela Kociolek** (406-994-6308, angela.kociolek@coe.montana.edu), Research Associate, Western Transportation Institute at Montana State University, Bozeman, MT 59717-4250 USA
**Anthony Clevenger** (403-760-1371, tony.clevenger@pc.gc.ca), Research Ecologist, Western Transportation Institute at Montana State University, Harvie Heights, AB, T1W 2W2 Canada

**Abstract:** Linear transportation features have been shown to have a barrier effect on certain wildlife species. In the case of highway median barriers or dividers designed for safety, little research has been done to gain an understanding of how these continuous linear structures affect the movement and mortality of different taxa. This research effort was comprised of a state of the practice survey, a literature review and gap analysis, and a qualitative assessment of potential wildlife impacts based on median barrier type and taxa size. Results from this cumulative effort have produced a foundation from which to develop rigorous field studies which should ultimately yield the basis for agency standards and guidelines. This study represents the first attempt ever in North America to synthesize information about highway median barriers and wildlife.

## Background and Purpose

Transportation agencies (DOTs) regularly install solid concrete median barriers and, in some cases, incorporate mitigative designs without information on their effectiveness. Therefore a study of the interactions between vehicles, median barriers, and wildlife is needed. The continued use of concrete median barriers should be of concern where they bisect areas of ecological importance and wildlife populations. The aim of this Caltrans-sponsored project was to determine what is the current practice and knowledge in the US and Canada pertaining to potential impacts of highway median barriers on wildlife movement and mortality.

## Methods

- The literature review focused on 1.) barrier effects of roads and linear infrastructure, 2.) historical and current trends of median barrier installation and unintended/potential impacts, and 3.) the effects of median barriers on a range of wildlife species and the performance of mitigative design solutions. The gap analysis culminated in a series of unanswered questions and limitations of available information.
- Ninety-six biological/environmental and engineering specialists in DOTS in all 50 U.S. states and 13 provinces/territories in Canada were invited to participate in this online state of the practice survey. The survey addressed trends and patterns of installations, regulatory and practical issues in deployment, and agency-led research efforts to assess median barrier impacts on wildlife.
- The qualitative assessment of potential wildlife impacts followed a matrix model whereby the potential permeability and mortality risks associated with common median barrier designs were assigned (based on intuitive and available information) for each taxa group of varying sizes.

## Summary of Findings

Individually and collectively, these median barrier-wildlife research efforts confirm that a concerted study is needed in order to develop best practices for appropriate placement, design choice and mitigations to meet the needs of motorist safety while avoiding negative impacts to local wildlife populations.

### Literature Review and Gap Analysis

The literature review substantiated median barriers have an effect on a wide range of wildlife from small to large. This statement largely comes from documented anecdotal data and intuitive public concern, however, there were some supporting scientific research studies. There is general agreement that barriers can result in increased wildlife mortality and decreased wildlife movements depending on the species and/or body size. Comprehensive studies that specifically measure these impacts are lacking. The absence of WVCs in some cases may be an indication that such barriers affect how, and if, wildlife move along and/or across roadways.

### State of the Practice Survey

Thirty-four individuals representing 28 (or 45%) of DOTs in the U.S. and Canada completed the survey (figure 1). Results from the survey revealed there were few evaluations of median barriers impacts on wildlife.

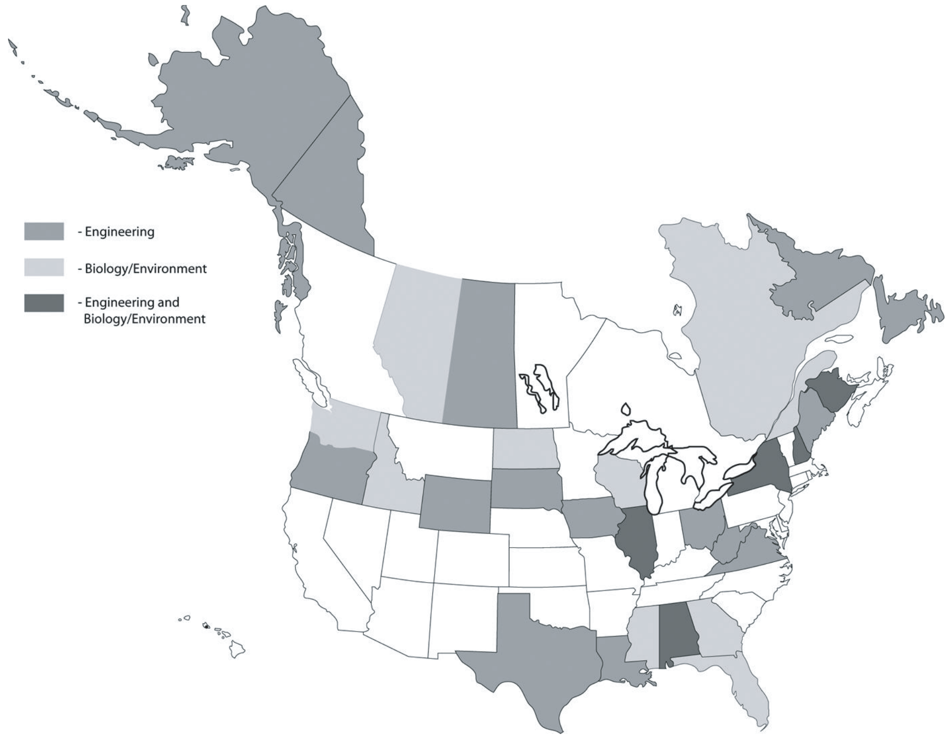



Figure 1. Survey respondent type by state, province and territory.

Few DOTs reported that they ‘employ’ or ‘consider’ mitigative designs. Of the 22 agencies that answered the following question set, results were similar; 68% rarely or never consider mitigative design solutions and 77% rarely or never employ them.

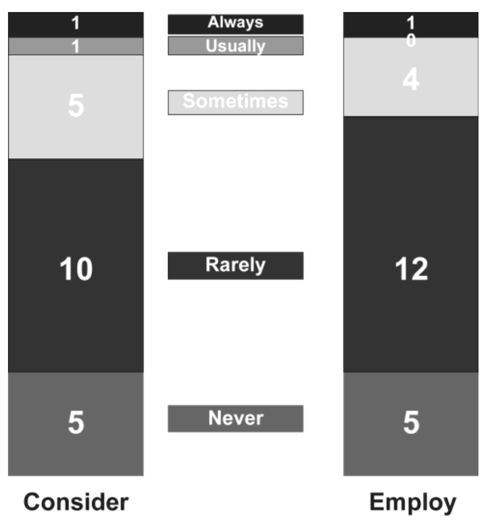



Figure 2. Number of agencies surveyed which consider or employ designs to mitigate impacts to wildlife.

No clear mandate to address wildlife and habitat connectivity concerns (other than for threatened and endangered species) and the lack of guidance for decision-making are possible explanations. But the literature review revealed that DOTs and others have attempted to address some aspect of median barrier effects on wildlife movement and/or mortality.

**Qualitative Assessment**

It is likely that animal size, median barrier dimensions, existing wildlife passages and landscape features have a collective effect on wildlife permeability and potential mortality risk on median divided roadways.

In a analysis of potential wildlife impacts, scores combining potential permeability and potential mortality risk were applied in a qualitative decision matrix for taxa relative to nine distinct median barrier types (mitigated and traditional).

Taxa groups (largely based on California fauna) were classified by general size differentiation as follows:

- A: mice, shrews/frogs, salamanders, lizards, snakes
- B: rat families, squirrels, weasels/turtles/young waterfowl and upland birds
- C: marten, fisher, mink, badger, skunk, fox, opossum
- D: coyote, bobcat, lynx, wolverine, otter, raccoon, ocelot
- E: grizzly bear, black bear, wolf, moose, elk, deer, bighorn sheep, mountain lion
    - Permeability scores were qualitatively assigned in absolute terms based on the size and physical capacity of each taxa group to overcome each barrier type.
    - Potential mortality risk was based on the extent to which a barrier might limit an animal's ability to traverse the barrier to avoid oncoming vehicles and see vehicles approaching from the opposite direction. The score also took into consideration literature that indicated a higher risk of WVC (especially deer) on undivided two-lane roads and on roads with vegetated medians.

Based on this model, small (shrew-sized) to medium (fox-sized) taxa have the highest risk with solid, concrete barrier designs. Medium taxa also have a high risk score for concrete barriers with scuppers or basal cutouts. Conversely, small and medium taxa have the lowest risk with permeable metal beam, cable, centerline rumble strips and vegetated median designs. Larger species (coyote-sized to elk- or bear-sized) have a moderate combined risk for all median (barrier) types with the exception of the Ontario Tall Wall (Table 1). This qualitative assessment is not intended to be a guideline but rather is a starting point for discussion about potential impacts.

Table 1: Combined risk score based on potential permeability and mortality risk of median barrier type for taxa of different sizes

| | Taxa Group | | | | |
|---|---|---|---|---|---|
| **Median Barrier Type** | **A** | **B** | **C** | **D** | **E** |
| **Concrete (Jersey, F-shape, Texas, etc.)** (minimum 32 in. [81 cm] high and < 8 in. [~20 cm] wide) | 2 | 2 | 3 | 5 | 5 |
| **Ontario Tall Wall** (~59 in. [150 cm] high and < 8 in. [~20 cm] wide) | 2 | 2 | 2 | 2 | 2 |
| **Concrete with gaps** (several feet spacings between panels) | 4 | 4 | 4 | 4 | 4 |
| **Concrete with scuppers** (basal openings 6 to 39 in. [15 -100 cm]) | 4 | 4 | 3 | 5 | 5 |
| **Concrete with gaps and scuppers** | 4 | 4 | 4 | 4 | 4 |
| **Metal beam** (steel, W, box, thrie, etc.) (27 to 34 in. [68.5 – 86.4 cm] high and 1 foot wide [~30 cm] or more, if doubled) | 6 | 6 | 6 | 5 | 5 |
| **Cable** (3-, 4-strand and proprietary designs) (top cable ~4 feet tall [123 cm]; lowest cable 1 to 2 feet [~3 - 6 m] above the ground) | 6 | 6 | 6 | 5 | 5 |
| **Centerline rumble strips** (negligible sized grooves cut into road surface) | 6 | 6 | 6 | 5 | 5 |
| **Vegetated median** (slightly mounded, flushed or depressed and generally tens of feet wide) | 6 | 6 | 6 | 5 | 5 |

**Legend** High Risk: 2 or 3; Moderate Risk: 4 or 5; Low Risk: 6

**Future Research**

Field research should address varying sizes of taxa and different median barrier designs (mitigated and traditional) in a variety of landscapes. The following is a recommended hierarchical research framework:

1. First and foremost, study wildlife impacts in terms of increased mortality and reduced movements.
2. Second, investigate mortality and barrier effects to individuals and populations and subsequent effects on demographics and genetics.
3. Third, ask how all of the above affects long-term persistence of focal populations.

**Acknowledgments:** The authors thank the California Department of Transportation (Caltrans) for funding this project and, specifically thank Harold Hunt for guidance and support, and Dave Hacker for initiating this work. The authors greatly appreciate the transportation agency specialists in the U.S. and Canada who participated in the survey and graciously offered their insights. For their contributions of technical, editorial, graphical and administrative assistance, the authors are grateful for staff at the Western Transportation Institute.

**Biographical Sketches:** Angela Kociolek received a M.S. in biology (Conservation emphasis) and a Master's Certificate in Interdisciplinary Studies in 1997 from Montana State University. Her thesis focused the effects of climate on ground squirrel species distribution and she has experience in avian and lichenological field research. Angela is a Returned Peace Corps Volunteer having served in the Integrated Education and Community Outreach program in northeast Thailand (1998-2000). Angela is currently a research associate at the Western Transportation Institute where she is involved in a variety of field and research/writing projects in the Road Ecology focus area.

Tony Clevenger is a research wildlife biologist Montana State University's Western Transportation Institute. His research focuses on assessing wildlife crossing performance and analyzing factors contributing to wildlife-vehicle collisions. Tony was a member of the U.S. National Academy of Sciences Committee on *Assessing and Managing the Ecological Impacts of Paved Roads* (National Academies Press, 2005). He has published over 40 articles in peer-reviewed scientific journals and has co-authored three books including, Road Ecology: Science and Solutions (Island Press, 2003). Tony is a graduate of the University of California, Berkeley, has a master's degree from the University of Tennessee, Knoxville and a Doctoral degree in Zoology from the University of León, Spain.

# Long-Term Consequences of Winter Road Management Practices to Water Quality at High-Altitude Lakes Within the Adirondack State Park (New York State)

**Tom Langen** (315-268-7933, tlangen@clarkson.edu), Associate Professor of Biology, Clarkson University, Box 5805, Potsdam, NY 13699-5805, Fax: 315-268-7118 USA

**Abstract**

The long-term impacts to water quality from the use of sodium chloride (rock salt) anti-icer and sand abrasive was evaluated at two high elevation lakes along a highway in the Adirondack Park, New York State.

Upper Cascade and Lower Cascade Lakes are two hydrologically connected water bodies in the Adirondack Park of New York State. The lakes are bordered by NYS Route 73, the primary transportation route for visitors to the tourist center of Lake Placid. The Cascade Lakes lie within a long, narrow, high elevation gorge that is notorious for some of the worst winter weather in the New York State highway system. The lakes themselves are a popular recreational destination and contain the largest population of a fish that is officially listed as endangered in New York State (round whitefish, Prosopium cylindraceum). There has been widespread concern from both governmental agencies and the general public about the impact of winter road management in this area, provoked by an apparent dieback of paper birch along the roadside and evidence of rising chloride levels in the lakes.

We have been funded by the New York State Department of Transportation (NYSDOT) to assess the impacts to soil, vegetation, lake water quality, and lake biota at the Cascade Lakes caused by use of deicing road salt (mainly sodium chloride) and sand abrasive. We also modeled future changes to lake water quality, resulting from current management practices and alternatives.

Chloride levels within soils adjacent to State Highway 73 are generally low, indicating that chloride is rapidly transported away via surface and ground water flow. Upper and Lower Cascade Lakes now have chloride levels 100 to 150 times higher than expected for a comparable Adirondack Lake. Within the last five years, there has been a 250% increase in chloride concentrations within the Cascade Lakes, which has been caused by the recent dramatic increase in road salt applications. The concentration of chloride in Chapel Pond is slightly elevated, about twice as high as the average for Adirondack

A strong concentration gradient of chloride occurs in Upper and Lower Cascade Lakes, with as much as a 57% difference in concentration between surface water (epilimnion) and bottom water (hypolimnion). Although the chloride concentrations and magnitude of the concentration gradients are within the range that results in a permanent stratification on some lakes (meromixis), Upper and Lower Cascade Lakes remain dimictic (i.e. complete turnover occurs twice a year, caused by thermal mixing). Lower Cascade Lake turns-over earlier than Upper Cascade Lake, indicating that there is little resistance to thermal mixing at present in this more heavily chloride-contaminated lake.

Twenty years of data on watershed loadings of sand and road salt at the Cascade Lakes indicate that lake chloride levels closely match loadings. Upper Cascade Lake contains 80,000 - 130,000 kg chloride, and Lower Cascade Lake contains 50,000 - 75,000 kg chloride. Seasonal changes in chloride concentrations in the lakes appear to be gradual, peaking in summer, suggesting that there is no shock elevation of concentrations associated with seasonal events (e.g. snow melt), and that sizeable input into the lakes are via groundwater discharge. Based on the mass balance model of chloride transport through the Cascade Lakes, simulated over a period of 20 years, chloride concentrations are predicted to rise over the next five years in the Cascade Lakes, with the biggest increases in the Lower Cascade hypolimnion (a 40% increase). Under present salt loadings, peak chloride concentrations in the Lower Cascade Lake hypolimnion are predicted to approach the USEPA recommended maximum limits for chronic exposure to aquatic life. Lower Cascade Lake also remains at risk of becoming meromictic. Doubling the annual salt loading will double the lakes concentrations of chloride, halving the salt loading will halve the concentration of chloride in each lake (as was empirically observed in the early 1990s). Changes in salt loadings result in a new equilibrium concentration of chloride within about seven years.

# Culvert Retrofit Testing

**Christopher May** (360-681-4556, christopher.may@pnl.gov), Senior Scientist, and
**Ron Thom** (360-681-3657, ron.thom@pnl.gov), Staff Engineer, Battelle PNNL, 1529 West Sequim Bay Road, Sequim, WA 98382, Fax: 360-681-3681 USA

**Abstract**

Road culverts located on federal, state, and private lands currently block upstream passage of juvenile salmon to thousands of miles of suitable juvenile rearing habitat. Washington State Department of Transportation (WSDOT), in cooperation with partner state and federal agencies, is currently leading a cooperative program to study juvenile salmonid passage through culverts by systematically conducting statistically designed experiments in full-scale culvert systems at the Culvert Test Bed (CTB).

The overall goal of the CTB program is to identify culvert configurations and the associated hydraulic conditions that facilitate successful upstream passage of juvenile salmonids. Previous studies have used juvenile coho salmon to examine the factors influencing passage success and leaping ability. This study begins research focused on retrofitted culverts. A retrofitted culvert is one in which the bed characteristics of an existing culvert are modified or engineered to improve fish passage. The main objectives of this study were to determine the passage success of juvenile salmon swimming through a series of configurations baffles under different culvert slopes and water flow conditions and to relate fish passage success to culvert slope, water flow, water velocity, turbulence intensity, water depth, and other hydraulic parameters for the installed retrofit design.

In 2005 and 2006, testing was conducted using a culvert-baffle configuration commonly used in Washington to enhance upstream adult salmonid passage. The primary question to be addressed is what passage success is achieved for juvenile salmon with this standard culvert-baffle configuration. The fish-passage tests evaluated passage success in a 40-ft corrugated culvert with three weir baffles at one culvert slope (1.14%) and over five flows conditions (1.5, 3, 6, 8, and 12 cfs). In addition, a full hydraulic analysis of flow conditions inside the CTB was conducted.

The relationships between natural logarithm of passage success of juvenile coho salmon (94 mm to 104 mm) and culvert discharge were statistically significant and curvilinear for all three configurations. For the configuration without baffles, passage success was about 40% at 1.5 cfs, increased to about 70% at 3 cfs, and then decreased to less than 10% at 12 cfs. The curves for configurations without baffles and with baffles and elevated backwatering condition did not differ significantly. Both these curves were significantly greater than the curve for the configuration with baffles and standard backwatering condition. Backwatering influences passage success through baffled culverts and will need to be considered as an experimental variable in future tests.

Differences between our results and other research results indicate that fish size has substantial influence on passage success and that these tests will need to be repeated for smaller juveniles. The lower passage success at 1.5 cfs relative to the higher flows both with and without baffles indicates that the lower passage success at 1.5 cfs is not a function of baffling conditions, i.e., baffles or no baffles, but rather is due to some aspect of culvert discharge. More exploratory behavior was observed at 1.5 cfs than at higher flows. The observations also suggest that consistent upstream movement may require a cue that is associated with higher flows. The nature of the cue is not known but could be related to higher velocities, greater depth, or more distinct low-velocity pathways.

Behaviors associated with successful upstream passage were more complex with baffles than without baffles. A significant quadratic relationship between the probability of passage success and the number of entries was found for all configurations at flows above 1.5 cfs. These relationships suggest that fish may be achieving the same level of passage success for less effort in the baffled configuration. The behavioral observations indicate that the fish use low-velocity pathways to accomplish passage and that these pathways differ between the baffled and unbaffled conditions and perhaps differ with flow for the baffled condition. The fish appear to be able to find and use low-velocity pathways to accomplish the passage in several different settings.

Overall, the results obtained thus far in the culvert test bed system demonstrate that the juvenile coho salmon have remarkable abilities to adapt their behavior to accomplish upstream passage in different system configurations and under different flows. The fish appear able to find and use low velocity pathways to accomplish the passage.

# Effects of a Highway Improvement Project on Florida Key Deer

**Israel D. Parker** (979-739-0679, iparker@tamu.edu), **Anthony W. Braden**, **Roel R. Lopez**, and
**Nova J. Silvy**, Department of Wildlife and Fisheries Sciences, Texas A&M University, 2258 TAMU, 006 Nagle Hall College Station, TX 77843-2258, Fax: 979-845-3786 USA
**Donald S. Davis**, Department of Veterinary Pathobiology, Texas A&M University, College Station, TX 77843 USA
**Catherine B. Owen**, Environmental Management Office, Florida Department of Transportation, Miami, FL 33172 USA

## Abstract

With an absence of predators, deer-vehicle collisions (DVCs) are the primary source of mortality for the endangered Florida Key deer (*Odocoileus virginianus clavium*). Of these collisions, >50% occur on United States Highway 1 (US 1), the primary inter-island roadway in the Florida Keys. DVCs on the 5.6-km section of US 1 on Big Pine Key (BPK) are responsible for approximately 26% of annual mortality. In 2002, a continuous 2.6-km system of 2.4-m fencing, 2 underpasses, and 4 experimental deer guards was completed on US 1 on BPK. Our objective for this project was to evaluate the effectiveness of this system in reducing DVCs. Deer heavily used the underpasses built in the fenced area all 3 post-project years (2003–2005). The fencing successfully prevented Key deer from entering the exclusion area. In spite of increasing deer population numbers, the US 1 improvement project prevented an increase in DVCs on US 1.

**Biographical Sketch:** Israel Parker is currently a Ph.D. student in the Department of Wildlife and Fisheries Sciences at Texas A&M University working on central Texas water quality issues. He received his M.S. in the Department of Wildlife and Fisheries Sciences at TAMU in 2006 focusing on Florida Key deer.

# Evaluation of a Citizen-Science Highway Wildlife Monitoring Program

**Kylie Paul** (612-910-9248, skylie101@gmail.com), **Len Broberg**, and **Christopher Servheen**, University of Montana, 1721 Phillips Street, Missoula, MT 59802
**Michael S. Quinn** (403-220-7013, quinn@ucalgary.ca), Faculty of Environmental Design, University of Calgary, 2500 University Drive NW, Calgary, Alberta T2N 1N4 Canada

**Abstract**

The Crowsnest Pass in southwestern Alberta, Canada has been highlighted as a critical area for wildlife movement. There are plans to upgrade Highway 3, which cuts through the Pass, to four lanes, with resulting increased traffic volume and speed. Currently, highway traffic volume is between 2,500 to 10,500 vehicles/day. Highway 3 may already be acting as a barrier to large carnivore and ungulate movements patterns, and wildlife mortality from animal/vehicle collisions on Highway 3 is approximately 109 large mammal deaths reported annually for a 46km stretch within the Pass. Detailed wildlife movement information in the Pass is limited.

To assist in understanding wildlife movement patterns along the highway to support decision-making for mitigation, a community based monitoring project was developed. The Alberta research institute Miistakis Institute of the Rockies created *Road Watch in the Pass* (RW), which allows local citizens to enter their wildlife observations along Highway 3 through an interactive web-based mapping tool. Over 1220 observations have been collected in over sixteen months, including 11 species of ungulates and carnivores.

This innovative approach to data collection would benefit from an analysis to determine whether the citizen reports are accurately representing visible wildlife activity along Highway 3. There are likely biases in citizen reports, based on unequal sampling effort involving location and frequency of travel. To identify and address these biases, this study compares spatial and temporal wildlife observation data from RW to a systematically gathered dataset using various statistical approaches.

We began systematic data collection in May 2006 and will continue through May 2007 to examine spatial and temporal characteristics of large mammal species movement (bighorn sheep, elk, moose, mule deer, white-tailed deer and carnivore species) along the highway. A 46-km stretch of Highway 3 was driven as a strip transect. When we observed an animal along or crossing the highway, UTM location, species, date, time, and other data were recorded. Each hour within the 24-hour period were sampled equally across a full year, allowing temporal analysis. Similar data from RW reports provided by citizens during the same period were extracted from the RW database. From May 2006 to March 2007, 395 transects were driven totaling over 395 hours of data collection and resulting in 681 wildlife observations. Spatial and temporal comparisons will be made between systematically gathered data and concurrent Road Watch data. Analysis will include examination of spatial association between the two data collection processes, comparison of spatial distribution, comparison of hourly and seasonal temporal distribution, effect of any biases on spatial or temporal distribution or species composition, and other analyses.

The Road Watch program is an important use of citizen involvement in transportation science. After analysis of RW's accuracy in representing visible wildlife activity in the Crowsnest Pass, this study will provide suggestions and stipulations to improve the scientific rigor of this unique citizen-science program.

# Roadkill and Landscape Scales on the Californian Central Coast

**Jordi Puig** (+34 948 425600 ext. 6496, jpbaguer@unav.es), University of Navarra, Department of Zoology and Ecology, E-31080 Pamplona, Fax: +34 948 425658 Spain

**Joe R. McBride** (jrm@nature.berkeley.edu), **Michael G. Herrin** (mikeherrin@berkeley.edu), and **Trevor S. Arnold** (trevarnold@yahoo.com), University of California, Berkeley, College of Natural Resources, Department of Environmental Science, Policy and Management, 137 Mulford Hall # 3114, Berkeley, CA 94720-3114 USA

**Abstract:** Roadkill data have been analyzed in a 25.6 mile-long highway stretch in the Californian central coast, in search of distribution patterns. The highway stretch was broken up into 1/10 mile sections. Roadkill data were collected along the road, mapped, and analyzed together with surrounding landscape units and landscape features defined at three different scales, namely micro-, meso-, and macro-landscape scales.

Landscape and roadkill data were arranged in such a way as to allow numerous comparisons between them at each scale. Most analyses were done by analyzing the line of best fit in X-Y plots. Linear and logarithmic comparisons were made, and t-scores (<0.05) were used to determine statistical significance.

Trends in roadkill distribution along roads have been found at different scales. Roadkill distribution patterns related to landscape features have been identified through statistical analysis even where geographical cluster does not exist. In addition the statistical analysis, new roadkill evidence found during the underpass inventory suggested the existence of an important deer pathway, operating at a larger scale than the one used in this study. Should the pathway be confirmed as such by future specific monitoring, efficient corrective measures could be successfully determined and implemented.

## Introduction

The multiple effects of roads on the surrounding environment have been studied in depth (e.g. Forman and Alexander, 1998, Jackson, 2000). Focusing on landscape fragmentation and roadkill incidence, a wide range of topics have been addressed, such as (a) the effects of landscape fragmentation on endangered species and biodiversity (e.g., Clevenger et al., 2003), (b) habitat fragmentation and habitat loss (e.g. Forman 2000, Forman and Deblinger 2000), (c) road safety (e.g. Groot-Bruinderink and Hazebroek, 1996, Romin and Bissonette, 1996), (d) the barrier effect on wildlife (e.g. Lovallo and Anderson, 1996, Gibbs, 1998), and (e) the effectiveness of wildlife under- and overpassages (e.g. Foster and Humphrey, 1995, Rodríguez et al., 1996, Clevenger and Waltho, 2000).

Roadkill clusters on existing roads (Serrano et al., 2002) provide data of particular interest. They point to dangerous driving points along roads and relevant wildlife pathways across a given landscape. When roadkill clusters exist, corrective efforts to reduce environmental impact should be stressed there. Wildlife passages are the main preventive/ corrective measure currently being implemented on fenced roads (e.g. Feldhamer et al., 1986, Romin and Bissonette, 1996). Fencing should ensure road safety without preventing road permeability to wildlife, by means of appropriate wildlife passages and other permeating structures combined together.

The aim of this study is to determine the relationship between the location of roadkills and landscape features at different scales, and to ascertain if there are any roadkill clusters along the road. Should roadkill clusters exist, they would allow the successful implementation of corrective measures to reduce roadkill rates. Should roadkill location and landscape features be related to one another, the accuracy and effectiveness of environmental impact assessments of planned roads might be improved in the future with regard to fragmentation and wildlife dynamics.

## Study Area

The road stretch under study connects Petaluma with Bodega Bay (Sonoma County, California, USA). It runs from east to west across a topographical gap in the north-south coastal range, where hilltop heights are significantly lower and woodland vegetation is scarcer than in the mountains to the north and south of the gap (figure 1). (Note: all figures are presented at the end of this paper.) The absence of rain, mild temperatures, and frequent coastal fog and inland winds are normal in this area during the long summer period. The rolling landscape is greatly dominated by fenced grassland, supporting diverse grazing intensity, and dotted by farms, housing and watering ponds. Perennial and seasonal streams run along most of the scarce spontaneous woody vegetation. Eucalyptus and pine windbreaks and groves provide wind shelter to some settlements. A coastal scrub area is located close to Bodega Bay. Three low density suburban areas may be identified along the road. Figures 2 to 7 offer an overview of the area.

## Roadkill and Landscape Data Collection

327 roadkills were registered between October 1998 and July 2002. Subsequently, the underlying relationship between roadkill location and landscape structure was examined at three different scales, namely micro-, meso- and macro-landscape scales. The 25.6 mile-long road stretch under study was broken up into 1/10 mile sections. Each one of the sections was characterised according to the surrounding landscape at every scale as follows.

Four types of macro-landscape units were defined: suburban, valley grassland, ridge grassland and coastal scrub. Valley grassland (figures 3, 7) is to be found mostly on near-flat land. Ridge grassland is usually found on rolling hills, resulting in a ridge network (figure 4). Coastal scrub (figure 6) represents an area of scattered spontaneous vegetation by the coastline, including scattered coyote brush (*Baccharis pilularis*), lupine (*Lupinus albifrons*), and poison oak (*Toxicodendron diversilobum*). Each one of the 256 sections was labelled as belonging to one of these units.

Selected meso-landscape features were (1) ridges, (2) ponds, (3) windbreaks, (4) groves, (5) ephemeral streams, and (6) perennial streams. They were identified and located on USGS maps. The distance between each of the 256 sections and each of the nearest meso-landscape features was measured to compare the roadkill location data. Ponds (figure 3), ephemeral and perennial channels were included in the study because of their potential to provide a source of food, water and shelter. Ephemeral and perennial channels were also studied because of their potential use as wildlife corridors along with ridges. Groves and windbreaks (figure 7) were considered because of their potential to provide denning sites, travel shelter and a food source.

Micro-landscape was defined as the area comprising fifteen feet from the border of the road surface to the land interior. Roughly, the entire road is lined on both sides by various types of fences. As they prevent cattle grazing, a peculiar micro-environment is created, wherein landscape features may differ from the immediate surroundings (figure 4). The micro-landscape typologies present within these spaces were: (1) groves (2) windbreaks, (3) driveway accesses, (4) shrubs and blackberry, (5) riparian environment, (6) channels, and (7) culverts. Channels, riparian vegetation, groves and windbreaks were taken into consideration again at this scale when they extend to the narrow strip next to the road. Each of the 256 sections of the road was characterized either as having or not having each one of these micro-landscape features. Channels were identified as any place where a perennial or ephemeral stream lacking shrubs and/or trees crossed the road. Driveway accesses were considered given their potential for being used as travel corridors, channeling animals to the main road, and also by their potential to attract scavengers looking for garbage. Areas containing shrubs and blackberry were considered because of their potential to provide shelter and a source of food. Culverts were considered given their potential to provide denning sites, crossing passages, and temporary shelters.

## Analysis and Findings

The mapping of roadkills along the road did not revealed geographical clustering, the kind of evidence required to quickly prompt road managers to apply preventive and corrective measures.

Data were subsequently analyzed with the JMPIN statistics program (Distributed by Duxbury Press). Data were arranged in such a way as to allow numerous comparisons between roadkills and landscape data. Most analyses were done by analyzing the line of best fit in X-Y plots. Linear and logarithmic comparisons were made utilizing the JMPIN program and t-scores (<0.05) were used to determine statistical significance.

Some data from the meso-landscape level were removed from the analysis. Because this part of the analysis was based on  distance between land features and road sections, rather than the presence or absence of a feature for every given 1/10 mile section, data would be excluded in cases where the meso-landscape feature was more than 0.5 miles  from the road. This was particularly important for ridges and ponds as in some cases the closest feature was several miles away and, hence, would have little impact on roadkill patterns. Interestingly the removal of this data only had a slight impact on our findings, and most of our statistically significant findings were for the meso-landscape level.

The relationship between opossum (*Didelphis virginiana*) roadkills and ponds at a meso-landscape level was logarithmically statistically significant (t-score = 0.0026). There were more kills when ponds were located closer to the road, and this trend exponentially drops off as ponds are farther away. Regarding stripped skunk (Mephitis mephitis) and raccoon (Procyon lotor) analyzed at a meso-landscape level, there were fewer kills where windbreaks are close to the road (t-score = 0.0104). There were also more skunk and raccoon kills when ridges were close to the road - logarithmically significant t-score (t = 0.0497) exponentially dropping of as ridges are farther away.

Finally, there were more total kills in micro-landscape riparian zones than in other zones (t-score = 0.0337). This was found to be more so for opossums than skunks and raccoons. In addition to the data collected along the road and the results confirmed by the statistical analyses, new data show a relationship between the landscape outlay and roadkill location. Several deer (*Odocoileus columbianus*) carcasses were found off the road around the tenth mile section 25.0, in the coastal scrub macro-landscape unit  (Figures. 5, 8), while walking alongside the entire length of the road to map underpasses. This finding suggests the existence of a deer pathway across the highway under study at this point.

## Discussion

As some trends in roadkill distribution have been found at micro and meso-landscape scales, increased data collection presently under way may provide extended results.

The lack of geographical roadkill clusters may be due to the relative homogeneity of the grassland landscape under study. As the relationship between landscape features and roadkill distribution has been found, roadkill clustering might be identified not in geographical areas, but in vectorial spaces which could be found through multivariable analysis covering a greater amount of data, which are currently being collected.

Opossum, raccoon and skunk display high roadkill rates, adding up to the 204 of the total 327 roadkill events. Is it due to the size of these species' populations around the highway, or to their scavenger behaviour, which would attract them to the road? May these species have learnt that this road (or roads in general) is a good place to feed on carcasses?

The fact that we have never met two roadkills in the same place and time is not enough to deny a possible attraction mechanism for scavengers to and along the highway. In any case, roadkill data must be analyzed with the species' behaviour in mind when inferences on populations are made from roadkill data.

The deer carcasses found off the road in the tenth mile section 25.0 reminds us that the data collection method overlooks some roadkills. On the other hand, some aspects of landscape dynamics may be revealed by a geographical analysis at a larger scale, complementary to those revealed by the statistical analysis already conducted. Figure 1 shows that the road runs across a topographic and vegetation gap in the coastal mountain range. Some riparian woodland remains across the gap, which is likely to support a richer wildlife activity than the grassland, as it provides shelter, food, and fresh water to wildlife. A particular riparian woodland leads directly southward towards the road (Figs. 1, 5). Its intersection with the road marks the area where the carcasses have been found. So the streambed seems to be playing a corridor role, at a larger scale than the ones intended in this study. Fencing and wider underpasses should be targeted at this point to reduce the number of collisions, if findings are confirmed by future studies undertaken to prove this hypothesis.

The absence of roadkill data at some points along the road might prove also enlightening in understanding wildlife dynamics across roads.

## Conclusions

Trends in roadkill distribution along roads have been found at different scales.

Roadkill distribution patterns related to landscape features have been identified through statistical analysis even where geographical cluster does not exist.

The use of maps and geographic analysis to interpret the recorded data proves to be a necessary tool and it supplements the statistical analysis.

Regarding the carcasses encountered off the road around the tenth of mile section 25.0, they underline the need to confirm the existence of landscape dynamics mechanisms for deer at larger scales than the ones proposed by this study from the outset. Moreover, if the high incidence of unrecorded roadkills in this spot is confirmed, it would require roadkill prevention efforts to be concentrated on this particular stretch of the road.

Preliminary studies as the one conducted here are recommended to outline the topics that should be stressed in future research. They would enable the on-going design of future research to be adjusted accordingly.

**Biographical Sketches:** Jordi Puig. Associate Professor on Environmental Impact Assessment in the University of Navarra (Pamplona, Spain) since 1996. He got his Science degree in 1990 (University of Navarra), and his PhD at the School of Forestry of the Polytechnic University, in Madrid (Spain). Visiting scholar in the UC Berkeley (2002-2003) and in the University of Manchester (2004), he has been doing research, among other topics, on roads and wildlife since 1998.

Joe R. McBride. Assistant Professor. Department of Forestry. Iowa State University (1969-70). Assistant Professor, Associate Professor, Professor. Department of Forestry and Department of Landscape Architecture. University of California. (1970-present).
Chair, Department of Forestry, University of California, (1986-89).
Chair, Department of Environmental Science, Policy, and Management, University of California, (1996-.).
Consulting experience in the fields of vegetation analysis and management and urban forestry with federal, state, county, and city governmental agencies, private landscape and land use planning firms, citizen groups, and private land owners. International consulting experience in Ecuador, China, United Kingdom, and Australia. Registered Professional Forester in California.

Michael G. Herrin. Graduate student. School of Landscape Architecture. UC Berkeley, USA.

Trevor S. Arnold. Trevor Arnold moved to the United States from Australia to attend University of California, Berkeley. He graduated in 2002 with a major in Conservation and Resource Studies and a minor in Forestry. After graduation Trevor worked as a research assistant under Joe McBride at UC Berkeley before becoming a resource manager for California State Parks. Trevor's desire to protect wildlife through research and medicine has led him to University of California, Davis School of Veterinary Medicine where he is about to begin his fourth and final year.

## References


Clevenger, A.P., Waltho, N., 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conserv. Biol.* 14, 47-56.

Clevenger, A.P., Chruszcz, B., Gunson, K.E., 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. *Biol. Conserv.* 109, 15-26.

Feldhamer, G.A., Gates, J.E., Harman, D.M., Loranger, A.J., Dixon, K.R., 1986. Effects of interstate highway fencing on white-tailed deer activity. *J. Wildlife Manage.* 50, 497-503.

Forman, R.T.T., Alexander, L.E. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics, 29, 207-231.

Forman, R.T.T., Deblinguer, R.D., 2000. The ecological road-effect zone of a Massachusetts (U.S.A.) suburban highway. *Conserv. Biol.* 14, 36-46.

Forman, R.T.T., 2000. Estimate of the area affected ecologically by the road system in the United States. *Conserv. Biol.* 14(1), 31-35.

Foster, M.L., Humphrey, S.R., 1995. Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Soc. Bull.* 23, 95-100.

Gibbs, J.P., 1998. Amphibians movements in response to forest edges, roads, and streambeds in southern New England. *J. Wildlife Manage*. 62, 584-588.

Groot-Bruinderink, G.W.T.A., Hazebroek, E., 1996. Ungulate traffic collisions in Europe. *Conserv. Biol.* 10, 1059-1067.

Jackson, S.D., 2000. Overview of transportation impacts on wildlife movement and populations, in Messmer, T.A., West B. (Eds.), Wildlife and Highways: Seeking Solutions to an Ecological and Socio-economic Dilemma. The Wildlife Society, pp. 7-20.

Lovallo, M.J., Anderson, E.M., 1996. Bobcat movements and home ranges relative to roads in Wisconsin. *Wildlife Soc. Bull.* 24(1), 71-76.

Rodríguez, A., Crema, G., Delibes, M., 1996. Use of non-wildlife passages across a high speed railway by terrestrial vertebrates. *J. Appl. Ecol.* 33, 1527-1540.

Romin, L.A., Bissonette, J.A., 1996a. Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. *Wildlife Soc. Bull.* 24, 276-283.

Serrano, M.; Sanz, L.; Puig, J., Pons, J., 2002. Landscape Fragmentation Caused by the Transport Network in Navarra (Spain). Two-scale Analysis and Landscape Integration Assessment. *Landsc. Urban. Plan.*, 58, 113-123.

## Figures

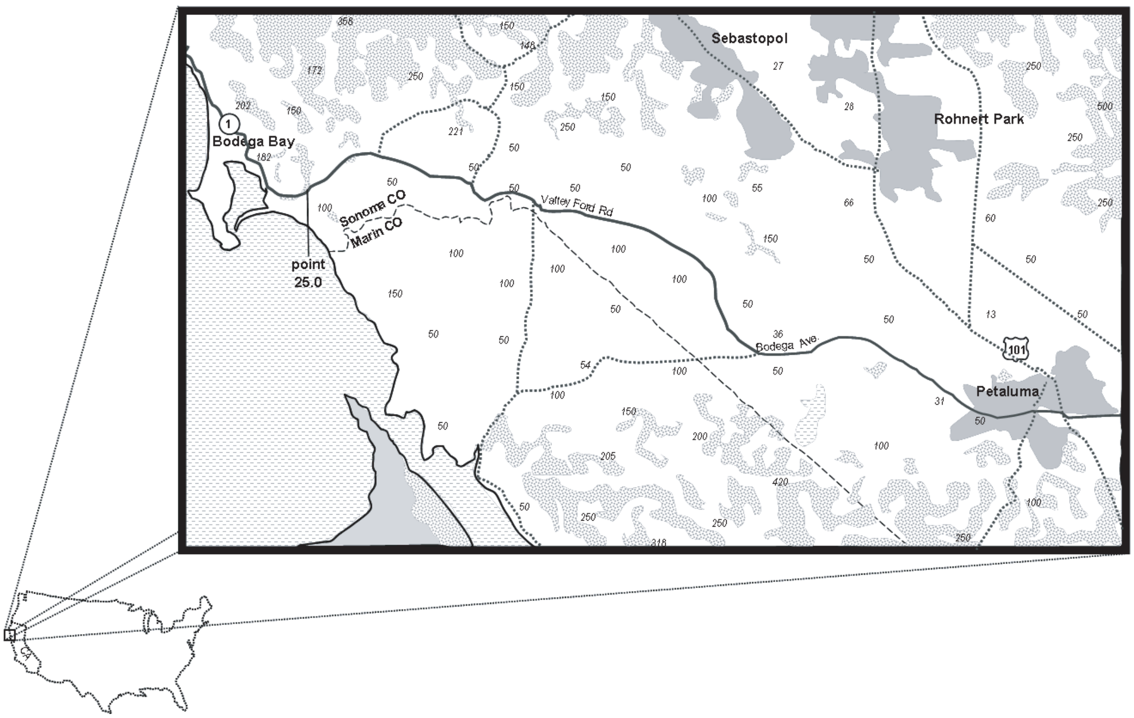



Figure 1. Study area. The road under study (unbroken line) runs across a topographical gap. Woodland and scrub patches (drawn as dotted shapes) are almost absent across the gap as well. A particular scrub unit reaches the road at 25.0 tenth of mile, close to Bodega Bay.

Figure 2. Low density suburban unit.

Figure 3. Valley grassland unit, and one of the ponds to water cattle.

Figure 4. Ridge grassland unit. See the narrow bushy strip between road and fence, defining a particular micro-landscape.

Figure 5. Coastal scrub unit, and stream crossing underneath the road. Several deer carcasses were found off the road around this point, a possible pathway for deer and other wildlife.

Figure 6. Coastal scrub next to the stream shown in Figure 4. The steepness of the slopes reinforce the possible pathway function of the stream, funneling wildlife towards it.

Figure 7. Valley grassland unit and windbreaks

Figure 8. Example of a large concrete culvert located within tenth mile section 25.0. Dimension are roughly 4 x 20 x 25 ft. During dry seasons culvert are utilized as underpasses by animals, as indicated by deer and raccoon tracks. A large female deer carcass was located on the left side of the road's shoulder (out of view). Another small deer carcass was discovered in the bush to the left.

# An Analytical Framework for Wildlife Crossing Policy in California

**Amy Pettler** (916-651-8166, amy_pettler@dot.ca.gov), Senior Endangered Species Coordinator and Wildlife Biologist, and
**Gregg Erickson** (916-654-6296, gregg_erickson@dot.ca.gov), Division of Environmental Analysis, California Department of Transportation, 1120 N Street, MS 27, Sacramento, CA 94274 USA
**James Quinn** (530-752-8027, jfquinn@ucdavis.edu),
**Robert Meese** (rjmeese@ucdavis.edu), and
**Fraser Shilling** (fmshilling@ucdavis.edu), Department of Environmental Science and Policy, University of California, Davis, CA 95695 USA

**Abstract**

This abstract reports on the results of a California joint DOT-university project to develop database, modeling, and GIS tools and to publish an electronic manual and digital library to address animal-vehicle collision reduction and connectivity issues in the state.

Despite the potentially large impacts of roads on wildlife movements and mortality, California has historically lacked standardized information tools to enable wildlife and transportation planners and managers to best identify and mitigate those impacts. These issues are being addressed by several California Department of Transportation research and development initiatives, including Animal Vehicle Collision Reduction and Connectivity Issues, Fish Passage, and Advanced Mitigation, much in collaboration with the University of California. Goals include addressing:

- Developing Useful Metrics, Standardizing Data Collection Techniques and Data Analysis Models/Tools for Assessment
- Improving Safety and Delivery in the Caltrans Planning and Project Development Process
- Strategic Outreach and Engagement
- Development of Guidance Documents and Support Tools for Analysis based on the developed Metrics, Standards, and models
- Working at a program level to optimize and leverage funding opportunities for collision reduction and connectivity issues

Elements of a new analytic framework to address this need include integrative GIS tools to identify, on both local and regional scales, locations of core wildlife populations, mapping of least-cost-path movement corridors to identify locations posing high risks of crossing mortality, a library of species-specific information on movement patterns and models, tools to develop more systematic documentation of road-related wildlife mortality, and a clearinghouse for evaluating structures, technologies and networking approaches to remotely detecting the presence of wildlife around transportation facilities, evaluating impacts, and mitigating the effects. Improved data from remote sensing and GIS clearinghouses, new methods and sensors for detecting animals and movement, emerging technologies for networking distributed and heterogeneous data, new data standards and models, and better integration with other information sources can all contribute to decreasing road impacts on animal populations and movements. Results of this project include a newly published California manual for managing wildlife crossing issues and GIS, database, and supporting digital library tools on-line at the Information Center for the Environment (http://ice.ucdavis.edu).

# Efficient Transportation Decision Public Web Site: Bridging the Gap Between Transportation Planning and the Public

**Ruth Roaza** (850-574-3197, ruth_roaza@urscorp.com), Senior Project Manager, URS Corporation, 1625 Summit Lake Drive, Tallahassee, FL 32317 USA

**Abstract**

The State of Florida has developed a new process for accomplishing transportation planning and project development for major capacity improvement projects. The goal of this process – the Efficient Transportation Decision Making (ETDM) Process - is to make transportation decisions more quickly without sacrificing the quality of the human and natural environments. The ETDM Process enables agencies and the public to provide early input to the Florida Department of Transportation (FDOT) and Metropolitan Planning Organizations (MPOs) about potential effects of proposed transportation projects.

Early in the planning process, the public and District-wide Environmental Technical Advisory Teams (ETATs) review projects for potential environmental effects. The ETAT consists of government representatives with statutory authority for issuing permits or providing environmental consultation. When they are notified to review a project, the District or MPO Community Liaison Coordinators (CLCs) inform the public that the project information is available for their review on the ETDM Web site or through the MPO or FDOT District Office. Project information includes: project details, results of GIS analyses, and resource maps. Members of the public provide comments through normal public involvement channels (for example, workshops, correspondence, telephone communication, and emails). At the end of the 45-day review period, ETDM Coordinators summarize and respond to comments in a screening summary report, which is published on the ETDM Web site and available at the FDOT District Office. The project information, ETAT comments, and summary reports continue to be available as the project progresses through subsequent phases. Updates are posted when new phases begin. A history record of the project is available as well. During Project Development, Project Managers post technical studies, environmental documents, and project-specific Web sites as they are completed. People using the site may elect to sign up to receive email notifications to keep informed about project updates in their area of interest.

One of the challenges in public involvement is providing access to information. The ETDM Web site is one means of providing that information in a timely manner. The Web site has been recently updated to comply with the American Disabilities Act (ADA) regulations. The new site was released on October 31, 2006. This interactive poster session provides an overview of the site.

**Biographical Sketch:** Ruth Roaza is a senior project manager at URS with over 15 years of experience in the technical fields of geographic information systems (GIS) and database management. For the past 7 years, she has worked under contract with the Florida Department of Transportation to support development of Florida's Efficient Transportation Decision Making (ETDM) Process. Originally, Ms. Roaza led the development of the Environmental Screening Tool (EST), an Internet application which supports the ETDM Process. Currently, she is the project manager of the ETDM consultant team. Prior to joining URS in 1998, Ms. Roaza managed the enterprise-wide GIS and Applications Development programs for the Florida Department of Environmental Protection (FDEP). Ms. Roaza received her bachelor's degree in Computer Science and Religion/Philosophy from Muskingum College. She also completed two years of graduate studies in Cross Cultural Communication at Ohio University.

# Measuring Gene Flow Across the Trans-Canada Highway and Population-Level Benefits of Road Crossing Structures for Grizzly and Black Bears in Banff National Park, Alberta

**Michael A. Sawaya**, Western Transportation Institute, Montana State University, P.O. Box 174250, Bozeman, MT 59717, USA. Email: mike.sawaya@pc.gc.ca. Phone: (403) 760-1371, 2410 Westridge Drive, Bozeman, MT, 59715, USA.

**Anthony P. Clevenger**, Western Transportation Institute, Montana State University, P.O. Box 174250, Bozeman, MT 59717, USA. Email: tony.clevenger@pc.gc.ca. Phone: (403) 760-1371, Mailing address: 138 Birch Avenue, Harvie Heights, Alberta, T1W 2W2, Canada.

**Steven T. Kalinowski**, Ecology Department, Montana State University, Bozeman, MT 59717, USA. Email: skalinowski@montana.edu. Phone: (406) 994 3232, Mailing address: Ecology Dept. Montana State University, Bozeman, MT, 59717, USA.

**Abstract**

The section of the Trans-Canada Highway (TCH) that bisects Banff National Park, Alberta supports the highest volume of traffic of any road in the North American national park system and is recognized as an important stressor to the ecological integrity of the central Canadian Rockies. Wide-ranging carnivores, such as grizzly (*Ursus arctos*) and black bears (*U. americanus*), are particularly vulnerable to road mortality and habitat fragmentation caused by roads. In order to mitigate these negative impacts on wildlife, twenty-four crossing structures have been constructed across the TCH. Over a decade of intensive study of these wildlife crossings has shown they reduce mortality and maintain wildlife movements. Track pads have recorded both bear species crossing the TCH on 1389 occasions, but the number of different individuals using the crossings, their genders and the demographic and genetic benefits of the crossings for populations remain unknown.

In 2004 and 2005, a pilot study was conducted at two of the crossing structures to evaluate the feasibility of using a barbed wire hair sampling system to determine the number of individual male and female grizzly and black bears passing through the crossings. Based on the results of that pilot study, a three-year research project was initiated in 2006 to evaluate the conservation benefits of wildlife crossing structures for grizzly and black bear populations in the Bow Valley of Banff National Park. The hair sampling system was installed at 22 of 24 of the crossing structures to determine the total number of male and female bears using the crossings and the populations of grizzly and black bears in the Bow Valley surrounding the TCH were also sampled using a combination of hair snares and rub tree surveys. The genetic information derived from the hair samples will be used to: assess the effectiveness of different types of crossing structures, estimate the population sizes for both bear species in the Bow Valley, calculate the proportion of the population using the crossings and quantify the level of movement and gene flow across the TCH.

This poster highlights our research objectives and presents some of the preliminary results from the 2006 field season. 12 grizzly bears (7 males, 5 females) and 11 black bears (7 males, 4 females) were identified from the samples collected at the crossing structures and 40 black bears (16 males, 24 females) and sixty-three grizzlies (37 males, 26 females) were identified from the samples collected from the hair snares and rub trees. These data will be analyzed using a combination of population viability analysis and landscape genetics approaches to assess the demographic and genetic benefits of wildlife crossings for bear populations in the Bow Valley. Wildlife crossings are gaining recognition as an effective method for reducing road-caused mortality and maintaining wildlife movement, but the conservation benefits of crossings for bears at the population-level has yet to be evaluated.

# Making Environmental Sustainability for Transportation Infrastructure a Reality: The Environmental Enhancement Fund in British Columbia

**Leonard Sielecki**, Environmental Issues Analyst (250-356-2255, leonard.sielecki@gov.bc.ca), British Columbia Ministry of Transportation, PO Box 9850 STN PROV GOVT, 4B - 940 Blanshard Street, Victoria, BC V8W 9T5, Fax: 250-387-7735 CANADA

**Abstract**

The award winning Environmental Enhancement Fund developed by the British Columbia Ministry of Transportation demonstrates environmentally sustainable transportation projects can be achieved through innovative private and public partnerships.

The award winning Environmental Enhancement Fund (EEF) was established by the British Columbia Ministry of Transportation (BCMoT) in 2004. The fund was conceived by the Ministry's Executive to promote environmental stewardship in the Ministry and foster partnerships with outside agencies.

EEF was initiated as a one year program in 2004, and extended in 2005. In 2006, as a result of its outstanding success and support from other government agencies and non-government organizations (NGO's), the EFF was made a permanent program by BCMoT. The EEF supports BCMoT's commitment to the British Columbia Government's goal to lead the world in sustainable environmental management, with the best air and water quality, and the best fisheries management.

The EEF is an innovative program that has helped BCMoT highway projects ensure:

1. High benchmarks for environmental stewardship are set and achieved;
2. Environmental Best Management Practices (BMP's) are more results driven and performance based;
3. Partnerships with provincial and federal agencies, First Nations and NGO's are established to ensure environmental sensitive areas and habitats are protected and/or restored, and function on a sustainable basis; and
4. Goodwill, trust and positive working relationships are established and sustained with provincial and federal agencies, First Nations, NGO's, and private landowners.

Working closely with other provincial and federal agencies, First Nations, NGO's, including the Nature Trust, Ducks Unlimited, the Pacific Salmon Foundation, the Land Conservancy of British Columbia, and private landowners, BCMoT has been involved in over 100 EEF-supported projects throughout British Columbia.

EEF projects fall under four general categories of on-ground and in-stream environmental projects that directly enhance, restore and/or protect fish and wildlife resources:

1. Fish passage improvements and restoration at highway stream crossings through culvert retrofits and replacements, enabling salmon and trout to return to their former levels in previously accessible habitat.
2. Strategic and timely acquisition of environmentally sensitive properties for conservation purposes and protection in perpetuity, with property owned and managed by non-Ministry agencies, NGO's or other organizations.
3. Fish and wildlife habitat enhancement works, in partnership with provincial and federal environmental agencies and NGO's, to: construct salmon and trout rearing habitat and spawning channels; establish water storage to create wetlands or wetted habitat and to augment low summer streamflows; increase habitat complexing and daylighting; restore highway footprint impacts; and enhance riparian areas.
4. Other fish and wildlife projects: including restoration of wild fish populations or wild fish transplants; and wildlife crash mitigation by relocating rare or endangered species, such as Roosevelt Elk, to more remote areas to establish new herds or enlarge existing ones.

Many projects have significant spin-off benefits for water and/or air quality. The projects also provide a capital environmental return and are linked directly to the BCMoT's highway infrastructure.

Since it inception, the EFF has garnered numerous accolades and awards from Federal and Provincial agencies and high profile NGO's. In 2005, Ducks Unlimited Canada awarded its most prestigious award, the Platinum Award, to BCMoT for environmental mitigation land donations associated with Ministry projects, such as the Vancouver Island Highway Project. Also in 2005, Fisheries and Oceans Canada (DFO) presented industry awards to fourteen BCMoT staff involved with highway fish passage restoration projects in the Province's northwest. In 2006, the EEF won the Transportation Association of Canada (TAC) Environmental Achievement Award. The TAC award, coveted by transportation agencies throughout Canada, provides national recognition of the importance and need of the transportation sector to continue protecting and enhancing the environment.

The EEF consistently delivers high value, tangible environmental projects linked to the highway infrastructure, in a cost-effective manner through private and public partnerships that restore and conserve British Columbia's natural resources. Given its success, the EEF model can be adopted by transportation agencies and municipalities to foster environmentally sustainable transportation projects.

## Wildlife Use of Open and Decommissioned Roads on the Clearwater National Forest, Idaho

**T. Adam Switalski** (Phone: 406-543-9551, E-mail: adam@wildlandscpr.org), Wildlands CPR, P.O. Box 7516, Missoula, MT 59807

**Len Broberg** (Phone: 406-243-, E-mail: len.broberg@mso.umt.edu), Environmental Studies Program, Rankin Hall, The University of Montana, Missoula, MT 59812-4320

**Anna Holden** (E-mail: anna.holden@grizmail.umt.edu), Environmental Studies Program, Rankin Hall, The University of Montana, Missoula, MT 59812-4320

**Abstract:** The impacts of roads on wildlife are extensive and can be especially harmful on U.S. National Forest lands where ecosystems are relatively intact. Access allowed by wildland roads can increase poaching, over-hunting, and over-trapping. Roads also increase negative edge effects, cause fragmentation, and facilitate or hinder wildlife movement. Forest Service managers are removing some roads to mitigate these impacts on wildlife, but few studies have addressed the effectiveness of this strategy.

In this study, we tested if wildlife were using decommissioned roads more than adjacent open roads. The study was conducted on the Clearwater National Forest in the Bitterroot Mountains of north-central Idaho where they have removed and revegetated more than 500 mi of roads. From May to October 2006 we monitored wildlife use on open and decommissioned roads using remotely-triggered cameras and baited track plates. Wildlife monitoring was part of a larger citizen monitoring program where a trained volunteer coordinator lead trips into the field each week to collect data on decommissioned roads. Using t-tests, we compared the number of detections and rates of detection between open and decommissioned roads.

Remotely-triggered cameras detected mammals at a higher rate on decommissioned roads than open roads for all species. However, on track plates there were about the same number of detections on open and decommissioned roads. Overall, we could not statistically distinguish the rate of detection between open and closed roads for white-tailed deer, elk, moose, and coyotes. Black bear, however, had a significantly higher rate of detection on removed roads than open roads ($p<.01$). This finding is consistent with several studies that have found that bears avoid open roads.

While the sample size was small, this study is the first to demonstrate with statistical significance that road decommissioning is restoring habitat for bears. This summer we will increase our sampling efforts to help reduce variability and test if the level of security influences rates of detection. More research is needed to fully understand the effects of road removal on wildlife and their habitat.

### Introduction

While providing many benefits to society, roads can negatively impact wildlife communities. Roads on U.S. National Forest lands can be especially harmful because of their location in relatively ecologically intact systems. Wildland roads allow access deep into forestlands increasing poaching, over-hunting, and over-trapping (Wisdom et al. 2000). Roads also increase negative edge effects, cause fragmentation, and facilitate or hinder wildlife movement (Trombulak and Frissell 2000).

Removal of some wildland roads is being used as a strategy to reduce the impacts of roads on wildlife; however, few studies have tested the effectiveness of road decommissioning (Switalski et al. 2004). Several studies have examined the effects of temporarily closing roads for elk (*Cervus canadensis*) security (e.g., Irwin and Peek 1979, Leptich and Zager 1991, Gratson et al. 2000). In a review, Rowland et al. (2005) reported that temporary road closures increase the amount of effective habitat, increase hunting opportunities, decrease damage to crops, improve diet quality, increase hunter satisfaction, and decrease vulnerability of elk during the hunting season. These studies just addressed short-term closures, with gates restricting access during the hunting season.

Road decommissioning has been recommended to improve habitat security for grizzly bears (*Ursus arctos horribilis*; Frederick 1991, USFWS 1993, Powell et al. 1996, and Mace et al. 1999), black bears (*Ursus americanus*; Boone and Hunter 1996), and rare forest carnivores (Bull et al. 2001). Reduced access for wood cutting resulting from road decommissioning has also been predicted to benefit cavity nesting birds (Bull and Wales 2001). Anecdotal evidence suggested that Western toads (Bufo boreas) were breeding on decommissioned roads in western Montana where slash created structural diversity and microhabitats (Bradley 1997).

While several studies have hypothesized that road decommissioning would improve wildlife habitat and decrease sources of mortality, there has been no formal study conducted to support or refute these ideas. In this study, we tested if wildlife were using decommissioned roads more than adjacent open roads.

### Study Area

The study was conducted on the Clearwater National Forest (CNF) in the Bitterroot Mountains of north-central Idaho. The CNF has removed and revegetated more than 500 mi of roads on the forest. Our sites were located within the Lochsa River watershed. Most sites were remote, but accessible by a paved highway (Hwy. 12) throughout the field season. Lolo and Kooskia were the closest towns and ranged from 17 mi to 57 mi from our sites.

Elevation of the study sites ranged from 3,360 ft to 4,850 ft and slopes generally exceeded 30 percent. The climate is characterized by heavy snowfall from November to March with the nearby Powell Ranger Station (3,630 ft) receiving an average annual total snowfall of 169.4 in. Rain is common in the spring and fall with slight drying in the summer. Powell Ranger Station receives an average annual total precipitation of 38.97 in with more precipitation at higher elevations. The average annual maximum temperature is 56.1 °F and the average annual minimum temperature is 29.4 °F (data from Western Regional Climate Center http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?idpowe).

The tree canopy is dominated by Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), and Englemann spruce (*Picea engelmannii*). In riparian, corridors old growth western red cedar (*Thuja plicata*) and grand fir (*Abies grandis*) are the dominant tree species. Important understory shrubs include Sitka alder (*Alnus sinuata*), Rocky Mountain maple (*Acer glabrum*), mountain ash (*Sorbus scopulina*), western thimbleberry (*Rubus parviflorus*), and blue huckleberry (*Vaccinium globulare*).

Decommissioned roads were seeded with non-persistent non-native see mixes, and some level of native plant and shrub community has returned. On many of the sites, trees have also begun to recolonize the decommissioned roads. Additionally, some non-native invasive plants are present on decommissioned roads including spotted knapweed (*Cntaurea maculosa*), St. Johnswort (*hypericum perforatum*), sulfur cinquefoil (*Ptentilla recta*), and oxeye daisy (*Crysanthemum leucanthemum*).

A complete suite of native wildlife species still thrive in the area, except grizzly bears. Most roads receive little human use, except during the hunting season. Archery season for white-tailed deer (*Odocoileus virginianus*) and elk began on August 10 and lasted the remainder of the study. Moose (*Alces alces*) were hunted with rifles from August 30 until the end of the study. Black bear hunting with dogs took place for most of the study and was allowed April 1 until June 30 and then again from August 30 until the end of the study. Coyotes (*Canis latrans*) were managed as predatory wildlife and could be shot on sight. Trapping was generally not allowed during our study.

## Methods

From May to October 2006 we monitored wildlife use on open and decommissioned roads using remotely-triggered cameras and baited track plates. Wildlife monitoring was part of a larger citizen monitoring program where a trained volunteer coordinator lead trips into the field each week to collect data on decommissioned roads.

Using GIS, we calculated the "local road density" of each site for an average female black bear home range (12 $km^2$; Reynolds and Beecham 1980) around each study site (table 1). We also recorded the amount of human use on open and decommissioned roads, aspect, and the amount of cover on decommissioned roads (table 2).

Table 1: Study site characteristics

| Study Site | Distance to paved road (mi) | Distance from closest town (mi) | Local road density ($mi/mi^2$)* |
|---|---|---|---|
| Shotgun | 6.5 | 44 (Lolo, MT) | 8 |
| Doe | 6 | 57 (Lolo, MT) | 2.8 |
| Pete King | 6 | 17 (Kooskia, ID) | 7.3 |

* Calculated using an average female black bear home range (12$km^2$; Reynolds and Beecham 1980) buffer; ground truthing will be necessary because not all decommissioned roads have been removed from the Forest Service inventory

Table 2: Study site characteristics for open and decommissioned roads

| | *Open road sites* | | *Decommissioned road sites* | | | |
|---|---|---|---|---|---|---|
| Study Site | Amount of use | Aspect | Year of decomm | Degree of Cover | Amount of use | Aspect |
| Shotgun | low | NE | ~1990 | high | none | NE |
| Doe | low | creek bottom | 2000 | low | low | creek bottom |
| Pete King | high | SE | 2003 | low | low | ridgetop |

### Sampling Design

Our study design consisted of three paired monitoring sites on open and decommissioned roads. One set of a remotely-triggered camera and a track plate were placed on an open road near the beginning of the decommissioned road. A second camera and track plate was set 0.3 mi back on the decommissioned road. A third camera was placed 1 mi back on the decommissioned road to test if increased security (i.e., increased distance from an open road) influenced wildlife use. In order to minimize the amount of variability, sites were located at similar elevation and between 6 and 7 mi from a paved road (table 1).

### Sampling Methods

StealthCam© remotely-triggered film and digital cameras were used to record large mammal use. Remotely-triggered cameras have been used successfully for many years to detect wildlife and have been commercially available since the early 1990s (e.g., Kucera and Barret 1993). They contain a passive infrared sensor which triggers the camera using heat and motion. Cameras were mounted on trees adjacent to open and decommissioned roads. On decommissioned roads, cameras were next to existing wildlife trails on the former location of the road prism. Camera stations automatically photograph animals that interrupt the infrared "trip" beam. At night, a visible flash allowed animals to be identified. Cameras were programmed to take three consecutive photos with a 60-second delay between triggers. The camera tagged each photo with the date on each photo. Cameras were checked once a week to ensure they were functioning properly.

Track plates were used to record small and medium size mammals. We employed similar tracking methods as developed by Fowler and Golightly (1994). Track plates consisted of a 24 in x 36 in piece of sheet metal covered by an aluminum roof. In the center of the track plate, a 12 in x 18 in piece of white contact paper was placed sticky side up and affixed with double-sided tape. The remainder of the track plate was covered with a tracking medium consisting of Sight Black©. The track plate was baited with a small can of cat food. Each week, the contact paper with tracks was removed and kept as a permanent record.

**Statistical Analysis**

For analysis, the total number of detections on open and decommissioned roads from remotely-triggered cameras and track plates were summarized. For remotely-triggered cameras, each trigger was counted as an individual unless it was apparent that the same animal was repeatedly triggering the camera. We had different levels of sampling effort because of camera malfunctions, stolen cameras, and to account for an additional camera on decommissioned roads. In order to accommodate for this disparity of effort, we calculated the rate of detection for each species on open and decommissioned roads dividing the number of individuals of a species by the number of days of sampling (fig. 1). We conducted t-tests to identify if there was a significant difference in the means of the rates of detection between open and decommissioned roads (Zar 1999).

For track plates, there was generally the same amount of sampling effort on each site, so we used raw data for analysis. Multiple tracks of the same species during one sampling period were counted just once. For track plate data, we conducted t-tests to identify if there was a significant difference in the means of the amount of detections between open and decommissioned roads (Zar 1999).

## Results

We recorded 11 mammalian species, 1 avian species, and people on open and decommissioned roads. We had a total of 505 camera days which recorded 154 wildlife detections and people (vehicles on open roads; hunters and Agency personnel on decommissioned roads; fig.1). Track plates were checked a total of 38 times resulting in 135 individual detections (fig. 2).

The amount of use on open roads appeared to correspond with distance from the closest town. The closest site to a town (Pete King) had the most use. The amount of use on decommissioned roads appeared to be related to the degree of cover and/or year decommissioned. Shotgun Creek which did not have any human use had been decommissioned for almost 20 years and had dense spruce and alder covering much of the old roadbed.

Overall, remotely-triggered cameras detected mammals at a higher rate on decommissioned roads than open roads for all species (fig. 1). Deer were the most frequently detected species on open and decommissioned roads (10% and 22%, respectively). Coyotes were only detected on decommissioned roads. The one avian species detected, turkey, was only found on open roads.

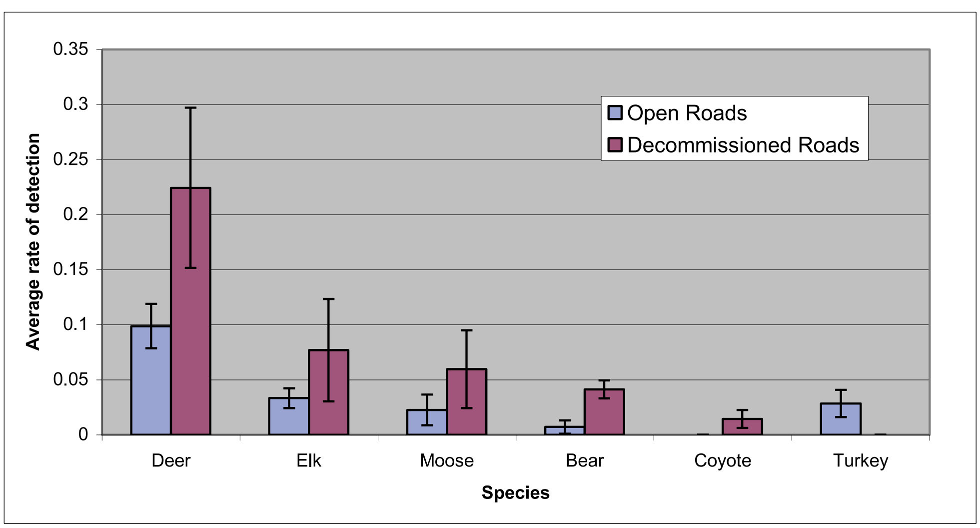



Figure 1. Average rate of detection (number of species/number of camera days) by remotely-triggered cameras on three open and decommissioned roads in the Powell Ranger District of the Clearwater National Forest (May 2006 through October 2006). Error bars are ± one standard error.

On track plates, there were about the same number of detections on open and decommissioned roads (66 and 69, respectively; fig. 2). However, bear tracks were found more on decommissioned roads than open roads. Mice (*Peromyscus* spp.) and voles (*Microtus* spp.) were detected the most and were found on almost every track plate. We could not distinguish these species by their tracks, so they were grouped together. Other species detected on track plates included jumping mouse (*Zapus princips*) , chipmunk (*Tamias* spp.), red squirrel (*Tamiasciurus hudsonicus*), short-tailed weasel (*Mustela erminea*), and American marten (*Martes americana*).

Statistical analysis of camera data found that black bear were detected at a significantly higher rate on decommissioned roads than on open roads ($p<.01$; fig. 1). There were high levels of variability between sites for most other species and thus there wasn't a statistical difference in detection between open and decommissioned roads.

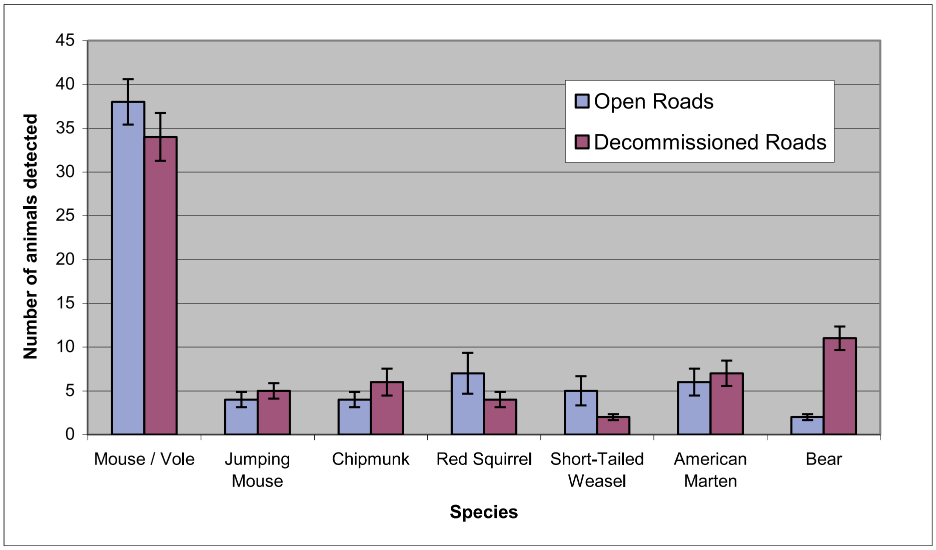



Figure 2. Number of species detected by track plates on three open and decommissioned roads in the Powell Ranger District of the Clearwater National Forest (May 2006 through October 2006). Error bars are ± one standard error.

## Discussion

Overall, we could not statistically distinguish the rate of detection between open and closed roads for white-tailed deer, elk, moose, and coyotes. Black bear, however, had a significantly higher rate of detection on removed roads than open roads ($p<.01$). This is consistent with the scientific literature that suggests that bears avoid roads. Numerous studies have found avoidance of open roads by grizzly bears (e.g., McLellan and Shakleton 1988, Mace et al. 1996, 1999) and black bears (e.g., Brody and Pelton 1989, Kasworm and Manley 1990, Powell et al. 1996). On open roads, these animals are susceptible to poaching and increased hunting pressure. The result of bears avoidance of roads leads to decreased habitat in areas with high road density.

Bear hunters with dogs were documented on open roads during the study and it is likely that bears would avoid these areas to reduce mortality risk, especially during the hunting season. Only on two of our open road sites did we once detect bears. And we never detected bears on roads during the spring or fall hunting season. While Powell et al. (1996) suggested road decommissioning as a critical management scheme to protect hunted populations of black bears; this is the first study to show that this may be the case.

There were high levels of variability due to our small sample size. The Doe Creek site only recorded elk on an open road and had more deer on an open road. Doe Creek was decommissioned in 2000 and has not had much time for vegetation to become established. The low number of detections of ungulates on Doe Creek decommissioned road site could be due to their preference for hiding cover. This site had a low degree of cover and several long lines of sight. Distance to cover was found to be a significant factor determining use of crossing structures by wildlife in Banff National Park, Canada (Clevenger and Waltho 2005).

The management implications of these findings could be very important both in the Clearwater National Forest and beyond. For example, six of eight species of bears around the world are experiencing significant declines in their populations (Servheen 1989). While black bear populations are generally stable, isolated populations in the southern U.S. have been in decline. Additionally, black bears could be a surrogate for the more endangered grizzly bear that are expected to naturally reoccupy the Selway-Bitterroot ecosystem. Considering that black bears tend to be less wary of humans than grizzly bears, they likely would respond similarly to road decommissioning efforts. The Flathead National Forest (MT) has decommissioned more than 300 miles of roads for grizzly bear security, yet little is know if this program is effective. Our study may provide supporting evidence that decommissioned roads provide more security for bears and use them more than open roads.

Our track plates did not find any statistical difference between open and decommissioned roads. This could be due to the lack of structural complexity on recently decommissioned roads. Recently decommissioned roads resemble clearcuts or open roads, and it may take many years for small mammal habitat to return. Many small mammals will avoid and in some occasions not cross open roads (Wisdom et al. 2000). Recently, Semlisch et al. (2007) examined road effects on a woodland salamander (Plethodon metcalfi) in the southern Appalachian Mountains. In addition to finding lower salamander abundance adjacent to forest roads, they also found lower abundance on old (80 years), abandoned overgrown logging roads. Thus, the effects of road building may persist for generations.

## Conclusion and Next Steps

While the sample size was small, this study is the first to demonstrate with statistical significance that road decommissioning is restoring habitat for bears. While more research is needed to fully understand the effects of road removal on bears, this is a first step. This summer, we will be increasing our sample size to include two more study sites. We also hope to increase our sampling effort by monitoring sites more than once a week. Checking on our cameras and track plates twice a week would increase the amount of data collected and reduce the amount of data lost due to camera malfunctions. By increasing our sample size, we hope to reduce variability and gain greater insight into the impacts of increased levels of security on wildlife use of decommissioned roads.

**Acknowledgements:** We thank Rachel Kalenberg, Sam Rogers, Coleman Whitney, Denver Henderson, and Gini Porter for their help summarizing our data and conducting data analysis.

**Biographical Sketches:** Adam Switalski has been Wildlands CPR's Science Coordinator since 2002. Adam received his M.S. in wildlife ecology from Utah State University. He is a faculty affiliate at the University of Montana and sits on the Board of the Montana Chapter of the Society for Conservation Biology. Recently, Adam organized an Organized Oral Session on road removal research for the 2007 ESA/SER conference in San Jose, CA. He currently is coordinating road removal research projects in Idaho and Montana.

Len Broberg is Professor and Director of the Environmental Studies Program at the University of Montana. He received his J.D. at Wayne State University and a Ph.D. in Biology from the University of Oregon. Len teaches courses in conservation biology and environmental law and policy. He has also published work on transboundary conservation, land use planning, restoration, and wildlife ecology.

Anna Holden is an Environmental Studies graduate student at the University of Montana. Previously she has worked with the University of Montana's Wilderness Institute as a field instructor. Anna was also a recipient of the Doris Duke Conservation Fellowship.

## References

Boone, R.B., and M.L. Hunter. 1996. Using diffused models to simulate the effects of land use on grizzly bear dispersal in the Rocky Mountains. *Landscape Ecology* 11(1): 51-64.

Bradley, K. 1997. An evaluation of two techniques for the utilization of logging residues: organic mulch for abandoned road revegetation and accelerated decomposition in small chipped piles. M.S. thesis. Missoula, MT: University of Montana. 58p.

Brody, A.J., and M.R. Pelton. 1989. Effects of roads on black bear movements in western North Carolina. *Wildlife Society Bulletin* 17: 5-10.

Bull, E. L., B. C. Wales. 2001. Effects of disturbance on birds of conservation concern in eastern Oregon and Washington. *Northwest Science* 75 Special Issue 166-173.

Bull, E. L., K. B. Aubry, B. C. Wales. 2001. Effects of disturbance on forest carnivores of conservation concern in eastern Oregon and Washington. *Northwest Science* 75 Special Issue 180-184.

Clevenger, A.P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation* 121: 453-464.

Fowler, C.H. and R.T. Golightly, Jr. 1994. Fisher and marten survey techniques on the Tahoe National Forest. Report for U.S. Forest Service. Contract No. PSW-90-0034CA. 64 pp.

Frederick, G.P. 1991. Effects of forest roads on grizzly bears, elk, and gray wolves: a literature review. USDA Forest Service – Kootenai National Forest, Libby MT. Publication number R1-91-73. 53p.

Gratson, Michael W., and Craig L. Whitman. 2000. Road closures and density and success of elk hunters in Idaho. *Wildlife Society Bulletin* 28(2): 302-310.

Irwin, L.L., and J.M. Peek. 1979. Relationship between road closure and elk behavior in northern Idaho. In North American elk: ecology, behavior, and management. Editors MS Boyce, and LD Hayden-Wing, 199-205. Laramie, Wyoming, USA: Univerity of Wyoming.

Kasworm, W.F., and T.L. Manley. 1990. Road and trail influences on grizzly bears and black bears in northwest Montana. In Bears – their Biology and Management: Proceedings of the 8th International Conference on Bear Research and Management, February 1989, Victoria, B.C. Edited by L.M. Darling and W.R. Archibald. Bear Biology Association, University of Tennessee, Knoxville. Pp. 79-84.

Kucera, T.E., and R.H. Barrett. 1993. The Trailmaster camera system for detecting wildlife. *Wildlife Society Bulletin* 21: 505-508.

Leptich, D.J., and P. Zager. 1991. Road access management effects on elk mortality and population dynamics. In Proceedings of the elk vulnerability symposium, compilers A.G. Christensen, L.J. Lyon, and T.N. Lonner, 126-31 Bozeman, Montana: Montana State University.

McLellan, B.N., and D.M. Shackleton. 1988. Grizzly bears and rsource-extraction industries: effects of roads on behavior, habitat use, and demography. *Journal of Applied Ecology* 25: 451-460.

Mace, R.D., J.S. Waller, T.L. Manley, L.J. Lyon, and H. Zuuring. 1996. Relationships among grizzly bears, roads and habitat in the Swan Mountains, Montana. *Journal of Applied Ecology* 33: 1395-1404.

Mace, R.D., J.S. Waller, T.L. Manley, K. Ake, and W.T. Wittinger. 1999. Landscape evaluation of grizzly bear habitat in western Montana. *Conservation Biology* 13(2): 367-377.

Powell, J.W., J.W. Zimmerman, D.E. Seaman, and J.F. Gilliam. 1996. Demographic analysis of a hunted black bear population with access to a refuge. *Conservation Biology* 10(1): 224-234.

Reynolds, D.G., and J.J. Beecham. 1980. Home range activities and reproduction of balck bears in west-central Idaho. In: Martinka, C.J., McArthur, K.L. (eds.) Bears-their biologu and management. Bear Biology Association Conference Series 3. U.S. Government Printing Office, Washington, D.C. pp.181-190.

Rowland, M.M., M. Wisdom, B.K. Johnson, and M. A. Penninger. 2005. Effects of roads on elk: Implications for management in forested ecosystems. Pages 42-52 in Wisdom, M.J., technical editor, The Starkey Project: a synthesis of long-term studies of elk and mule deer. Reprinted from 2004 Transactions of the North American Wildlife and Natural Resources Conference, Alliance Communications Group, Lawrence, KS.

Semlitsch, R.D., T.J. Ryan, K. Hamed, M. Chatfield, B. Brehman, N. Pekarek, M. Spath,and A. Watland. 2007. Salamander abundance alon road edges and within abandoned logging roads in Appalachian forests. *Conservation Biology* 21: 159-167.

Servheen, C. 1989. The status and conservation of the bears of the world. International Conference on Bear Research and Management. Monograph Series 2: 1-32.

Switalski, T.A., J.A. Bissonette, T.H. DeLuca, C.H. Luce, and M.A. Madej. 2004. Benefits and impacts of road removal. *Frontiers in Ecology and the Environment* 2(1): 21–28.

Trombulak, S.C., and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14: 18-30.

US Fish and Wildlife Service (USFWS). 1993. Grizzly bear recovery plan. Missoula, MT. 181p.

Wisdom, M.J., R.S. Holthausen, B.C. Wales, C.D. Hargis, V.A. Saab, D.C. Lee, W.J. Hann, T.D. Rich, M.M. Rowland, W.J. Murphy, and M.R. Eames. 2000. Source habitats for terrestrial vertebrates of focus in the interior Columbia basin: broad-scale trends and management implications. Volume 1 – Overview. Gen. Tech. Rep. PNW-GTR-485. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Zar, J.H. Biostatistical Analysis. 1999. Prentice Hall, Inc. Upper Saddle River, New Jersey

# An Overview of Recent Deer-Vehicle Collision Research in Arkansas

**Philip A. Tappe** (Phone: 870-460-1352, Email: tappe@uamont.edu),
**Michael C. Farrell** (Phone: 719-524-5297, Email: mike.farrell2@us.army.mil), and
**Donald I.M. Enderle** (Phone: 770-270-7678, Email: denderle@photoscience.com), Arkansas Forest Resources Center and School of Forest Resources, University of Arkansas, Monticello, AR 71656.

## Abstract

An expanding human population combined with a growing white-tailed deer (*Odocoileus virginianus*) population has resulted in an escalation of the number of deer-vehicle collisions in Arkansas. In response to this increase, we initiated research to help understand the scope of the problem and to investigate factors contributing to deer-vehicle collisions (DVCs) on Arkansas highways.

In Arkansas, vehicle accident reports filed with the Arkansas State Police are currently the most extensive and reliable source of information on DVCs. We used these reports to gather data on DVCs over a 4-year period, 1998 – 2001. A total of 5,858 reports of DVCs were obtained and used to document mean vehicle-damage estimates, mean numbers of human injuries and deer deaths, mean numbers of collisions by time of day and month, and proportions of bucks and does involved in collisions by month.

The same 5,858 DVC reports were used to conduct an examination of the influence of county-level factors on the density (no. /1000 km) of reported DVCs in Arkansas. Principal components (PCA) and regression analyses were used to evaluate the importance of county-level factors, such as human population densities/urbanization, landcover composition and arrangement, timber harvest levels, deer density indices, and highway densities and characteristics.

Of the 5,858 DVC reports, 3,170 were spatially referenced to specific locations on highways, thus allowing for an evaluation of site-specific factors that may influence the locations of DVC occurrences in Arkansas. We used logistic regression analyses to evaluated the importance of landcover patterns, landcover characteristics, and number of stream/highway intersections within 400, 800, and 1200 m of collision sites; landcover crossing types and maximum topographic relief within 100 m of collision sites; and distances to nearest forest and to nearest water. Furthermore, we developed models for each physiographic region of the state, as well as a state-wide model, to identify high risk areas along Arkansas highways.

Collisions were documented in all months, but we found most (>50%) occurred during October – December with a peak in November. The number of collisions was greatest between 5:30 p.m. and midnight with a smaller peak occurring between 5:00 - 7:00 a.m. Most deer (67.5%) were killed as a result of the collisions; 32.5% were injured and fled the collision site. We do not know the ultimate fate of these animals. Overall, 48.3% of the collisions were with bucks and 51.7% were with does. However, we found this proportion varied by month, ranging from 24.1% bucks and 75.9% does in June to 64.7% bucks and 35.3% does in November (Fig. 3). Annually, the human injury rate averaged 0.7%. Reported, estimated damage to individual vehicles averaged almost $2.7 million/year with a mean of $1,926 per collision. Based on an assumed reporting rate of approximately 17%, we estimated that Arkansas could potentially have up to 18,000 DVCs annually with a loss of almost $35 million in vehicle damage.

We found that deer-vehicle accident occurrence in Arkansas counties was influenced more by roadway features, level of urbanization, and human population densities than by deer densities or landscape characteristics. PCA indicated two important components contributing to DVC densities in Arkansas counties. Component 1 represented a predominantly forested matrix with high edge density and contrast. Component 2 described an urban environment, with high road densities, human population densities, and average daily traffic counts. These 2 components were strongly related to DVCs ($r^2 = 0.55$, $P < 0.001$), with Component 2 explaining the most variation (71.4%).

Landcover characteristics of DVC sites were useful in predicting site-specific probabilities of deer-vehicle collisions. Based on 31 site-specific variables, correct classification rates of predictive models (DVC sites vs. non-DVC sites) ranged from 62% - 70%. Five groups of factors strongly correlated with DVC locations were the: (1) presence and amount of water; (2) presence of a diverse association of land cover types; (3) amount and size of urban area; (4) amount and size of forested area; and (5) density of pastures and agricultural crops.

Information derived from these studies can aid land managers, agencies, and policy makers in making informed decisions related to DVC mitigation. Additionally, our results provide a foundation for future research targeted at increasing our knowledge of interactions between wildlife and roads, and for further research into DVC mitigation strategies.

**Biographical Sketch:** Philip A. Tappe is a professor of wildlife ecology and management, Associate Director of the Arkansas Forest Resources Center, University of Arkansas Division of Agriculture; and Associate Dean of the School of Forest Resources, University of Arkansas at Monticello. He received his B.S. and M.S. from Stephen F. Austin State University, and his Ph.D. from Clemson University.

# Bats and Bridges: Promoting Species Conservation Through Early Multi-Agency Planning

**Zak Toledo**, Natural Resources Specialist (503-383-8265, zak.toledo@hdrinc.com), HDR Engineering, Inc., 1165 Union Street, NE, Suite 200, Salem, OR 97301, Fax: 503.587.2929 USA

**Abstract**

The purpose of this process is to promote species conservation and environmental enhancements for the OTIA III State Bridge Delivery Program. Bat habitat enhancements applied in the field throughout the state will be presented as an example of these efforts.

The OTIA III State Bridge Delivery Program is part of the Oregon Department of Transportation's 10-year, $3 billion Oregon Transportation Investment Act program. OTIA funds will repair or replace hundreds of bridges, pave and maintain city and county roads, improve and expand interchanges, add new capacity to Oregon's highway system, and remove freight bottlenecks statewide. About 17 family-wage jobs are sustained for every $1 million spent on transportation construction in Oregon. Each year during the OTIA program, construction projects will sustain about 5,000 family-wage jobs.

Oregon Bridge Delivery Partners (OBDP) is a private-sector firm that has contracted with the Oregon Department of Transportation to manage the $1.3 billion state bridge program. OBDP, a joint venture formed by HDR Engineering Inc. and Fluor Enterprises Inc., will ensure quality projects at least cost and manage engineering, environmental, financial, safety, and other aspects of the state bridge program.

OBDP has developed a framework to integrate the myriad of tools developed for the Program, including environmental performance standards, a joint batched-programmatic biological opinion, environmental and engineering baseline reports, and a web-based GIS. The purpose of this framework is to identify environmental concerns early in the project development process and communicate these concerns to design teams and regulatory agencies to promote environmental stewardship through impact avoidance and minimization.

Innovative and creative use of technology has been a keystone to the framework. Environmental professionals input the relevant environmental data for a project in a comprehensive, on-line Pre-Construction Assessment (PCA). The data are used to identify project challenges (e.g., archaeological sites or wetlands within the project footprint) and compile electronic reports to the regulatory agencies. Environmental metrics, such as exempted T&E species take and wetland fill quantities, are tracked using the GIS database. One framework meets the needs of many stakeholders.

Now with over two and a half years of execution, we have some great successes and lessons learned to share. The focus of this presentation will be on our species conservation and environmental enhancement identification process with bat habitat presented as a case study. Through early planning and coordination with our regulatory and resource agency partners, OBDP has integrated enhancement opportunities into project design. This enhancement request process has been developed to work with both of the dominant project delivery methods: design-bid-build and design-build.

Through this process, regulatory and resource agency liaisons are sent a pre-field information packet so they can solicit input from their agency cohorts. A group field visit is then facilitated by an OBDP environmental coordinator. All comments collected from the field and the inquiries are uploaded into a tracking database. The enhancement requests are screened and classified for future actions, such as accept without change to scope, schedule, or budget or request additional scope, schedule, or budget. Those requests that are approved are integrated into the project contract, whereas those that denied are passed on to alternative groups, such as the ODOT region, maintenance district, or headquarters for future potential action.

To date, all requests have been collected, entered into the database, and classified. This presentation will focus on the bat habitat elements integrated into the bridge design. More than a half-dozen bridges have had various bat habitat elements incorporated into their designs. None of the 15 bats in Oregon are listed as threatened or endangered these efforts are strictly enhancements with the hope of avoiding the need for future listing. Many bats, including the Townsends big-eared bat (*Corynorhinus townsendii*; endangered in Washington, sensitive in Oregon), have been known to use ODOT bridges for both day and night roosts as well as maternal colonies. We will present the process we have developed, the environmental performance standard that directs the designers, and the final product integrated into actual bridges.

# Riparian Restoration Plan for Stormwater Flow Control Management

**Carl Ward**, Biology Program Manager (360-570-6706, wardc@wsdot.wa.gov), Washington State Department of Transportation, PO Box 47417, Olympia, WA 98504-7417, Fax: 360-570-6697 USA

**Abstract**

WSDOT is proposing riparian restoration as an alternative to the construction of large stormwater detention facilities for the State Route 167 Extension Project.

WSDOT is proposing riparian restoration as an alternative to the construction of large stormwater detention facilities for the State Route 167 Extension Project. Buildings, roads, culverts, and other infrastructure will be removed and the land use will be converted back to a riparian forest. Within the 189 acres proposed for riparian restoration: approximately 30 acres of existing impervious surface will be removed; 63 acres of existing wetlands will be restored; 19 stream crossings will be removed or improved; fill materials in the floodplain will be removed; 13,000 feet of stream channel will be protected; 9,350 feet of stream channel will be created; and the area will be replanted with native vegetation.

The RRP is expected to prevent property damage caused from flooding by removing buildings, roads, and infrastructure from flood prone areas. Project implementation with the RRP is predicted to reduce future flooding impacts by 48 percent compared to future conditions without the project. The RRP is expected to provide water quality treatment above and beyond any wet ponds or similar treatment facilities required under the Highway Runoff Manual by removing sediment and nutrients from surface runoff.

The RRP is expected to result in considerable benefits to streams by reestablishing vegetated riparian buffers which increase shade to maintain cooler water temperatures. Establishing woody vegetation increases bank stability and helps form habitat for fish and wildlife, and improves water quality. The RRP will also reduce the amount of inlet structures and drainage piping required to maintain flow control, while at the same time increasing the channel migration area. As the future large woody debris recruitment forces channel migration, the abandoned stream channels will develop into wetlands and off-channel rearing habitats for fish. The RRP includes the restoration of upland habitat within the riparian buffers, and also provides wildlife habitat and migration corridors, and will provide improved wetland buffer functions.

A Net Environmental Benefits Analysis was performed to quantitatively estimate and compare the relative ecological losses and gains between the use of conventional stormwater treatment ponds and the RRP approach. Project wide, the RRP approach was found to have 57 percent greater environmental benefit than the conventional treatment approach.

# A Summary of the 2006 Linking Conservation and Transportation Workshops

**Patricia White**, Director, Habitat & Highways Campaign (202-772-0236, twhite@defenders.org), Defenders of Wildlife, 1130 Seventeenth Street, NW, Washington, DC 20036-4604, Fax: 202-682-1331

**Abstract**

To improve the linkage between conservation and transportation planning, emphasize the use of information, tools and methods that can be shared between the transportation, resource and regulatory agencies.

**Project Description**

In 2006, the Federal Highway Administration (FHWA), NatureServe and Defenders of Wildlife teamed up to organize three state-based workshops to improve linkages between conservation and transportation planning. Host states included the ICOET 2007 host state, Arkansas,* as well as Colorado and Arizona. Approximately 150 people participated in the workshops, from the executive to the field level. Each workshop emphasized the information, tools and methods that can be shared among transportation planners, wildlife and resource agencies and the regulators to better inform the planning process. In addition to improved inter-agency relationships and increased stewardship, integration can save money and time by streamlining transportation projects. Following presentations on transportation planning, conservation data sources and available technology, workshop participants discussed opportunities to integrate and collaboratively developed a work plan.

Each workshop included:

- an overview of transportation planning in their state, from local to state level and from long-range to project level
- major conservation planning approaches in use, including natural heritage methods and State Wildlife Action Plans
- software tools for comprehensive planning, including NatureServe VISTA, Community Viz and Quantm
- discussion and strategy building

**Current or Anticipated Results**

This presentation will summarize the lessons learned from the workshop series, to include:

- In order to gauge interest and importance of the subject matter, participants were asked for input prior to and following the workshop. For example, â€œWhat would be most helpful towards integrating conservation planning into the transportation planning process?â€ These responses will be compiled and categorized for consistencies across states and across disciplines.
- Compiled and categorized lists of obstacles and opportunities for comprehensive planning, as identified by workshop participants
- Finished work plans from each workshop, with progress updates as of May 2007
- Recommendations for other states from workshop participants
- *As Arkansas hosted both a workshop and ICOET, Arkansas workshop participants will be asked to join us for this session and answer questions on their own progress

**Recommendations for Future Research**

- Addressing identified obstacles to integrated planning
- Continued monitoring of integrated planning efforts
- Quantify conservation gains from integrated planning efforts

# Relating Vehicle-Wildlife Crash Rates to Roadway Improvements

**Rhonda Young** (Phone: 307-766-2184, Email: rkyoung@uwyo.edu), Assistant Professor, Department of Civil and Architectural Engineering, University of Wyoming, Laramie, Wyoming 82071, Fax 307-766-2221
**Steven Vander Giessen** (Phone: 307-766-3427, Email: zzyzx@uwyo.edu) and
**Chris Vokurka** (Phone: 307-766-3427, Email: cvokurka@uwyo.edu), Graduate Research Assistants, Department of Civil and Architectural Engineering, University of Wyoming, Laramie, Wyoming 82071

**Abstract:** Animal-Vehicle Crashes are a growing trend in America, and Wyoming in particular. The focus of this research effort is to determine the effect of road reconstruction on the number of animal-vehicle crashes using changes in the reported animal-vehicle crash rates. Using GIS tools, the entire Wyoming highway system was analyzed using 10 years of reported crash data to determine both the frequency and crash rate of animal-vehicle crashes on each roadway segment. Seven reconstruction projects were selected for the study. Statistical analyses were performed with a focus on crash rates. The seven sections were analyzed as an aggregate data set, and it was determined that wild animal-vehicle crash rates experienced increases following reconstruction. During this same period, those crash rates not associated with animal-vehicle crashes, as well as the overall crash rate, were generally observed to decrease. An analysis of changes in roadway design attributes was performed, and the only attribute observed to have a statistically significant impact on the animal-vehicle crash rate was design speed.

## Background and Purpose

There lack of information concerning the geometric design of roads and the effect on animal-vehicle crashes. There have been few attempts to correlate changes in road design, and these are primarily concerned with the addition of lanes of traffic to a highway. None of these have been concerned with the addition of lane and shoulder width or changes to the horizontal or vertical curvature of a roadway. The main objective of this research effort is to determine what features of a reconstructed highway may have an effect on the number of animal-vehicle crashes.

## Methods

The research effort collected background data on seven reconstruction projects in the state of Wyoming including geometric features (lane widths, shoulder width, curve radii, superelevation, and bridge and culvert structures), traffic volumes, wildlife population estimates, speeds (current, before speeds in available, and estimated change in speeds) and crash records. The before and after crash frequencies and crash rates were calculated for each project. A crash rate that accounted for wildlife population number was also calculated.

Three types of analyses were performed on the data set. A general analysis comparing before and crash after rates for the aggregated data set, a analysis on the aggregated dataset that considered project attributes such as design speed, lane width, shoulder width, and pavement width, and individual analyses of the project segments. The general analysis performed paired t-test to determine if there was a statistically significant change in crash rates for animal-vehicle crashes, animal-vehicle crashes accounting for changes in animal populations, non-animal-vehicle crashes, and total crashes.

For the aggregate analysis with project attribute variables, a single variable regression analysis was performed on each of the six project variables (animal population density, design speed, lane width, shoulder width, pavement width, and design speed with estimated speed reductions). A model that combined the significant attributes was then generated using stepwise regression.

The last analysis that was performed was using the individual segments before and after crash rates assuming a Poisson distribution. Each of the seven projects were analyzed separately to determine if the crash rates has a significant increase or decrease in crash rates.

### Preliminary Results

The general analysis comparing before and after crash rates of the aggregated data found that there was a statistically significant increase in the animal-vehicle crash rates at the 97% confidence level. When the animal population values were accounted for there was still a significant increase in the animal-vehicle crash rates at the 96% confidence level. The non-animal-vehicle crash rate was observed to decrease at the 95% confidence level. The total crash rate was observed to decrease at the 87% confidence level.

The aggregate analysis with project attribute variables the important attributes were determined to be animal density of the herds and the design speed of the project. The final model that included the animal density and design speed variables has a $R^2$ value of 0.55, suggesting that significant variation remained unexplained.

Due to small sample size issues the individual analyses were less conclusive than the aggregate analyses. All seven projects showed an increase in animal-vehicle crash rates, although only one of these increases was statistically significant. Five of the seven projects showed a decrease in non-animal-vehicle crash rates, although only three of these decreases were statistically significant. The total crash rate results were the most varied with four of the seven showing decreased crash rates. Two of these were statistically significant decreases. None of the increased rates were found to be statistically significant.

**Next Steps**

The next step to this research effort is to apply the empirical bayes methodology to the data set utilizing a rural two-lane highway safety prediction algorithm. The use of this methodology will correct for regression-to-the-mean bias and improve the precision of the statistical analyses.

# Simulation-Optimization Framework to Support Sustainable Watershed Development by Mimicking the Pre-Development Flow Regime

**Dr. Emily Zechman**, Research Assistant Professor (919-513-7920, emzechma@ncsu.edu), Department of Civil, Construction, and Environmental Engineering, North Carolina State University, Campus Box 7908, Raleigh, NC 27695-7908, Fax: 919-515-7908 USA

## Abstract

A new approach is presented to achieve a more aggressive sustainability objective for designing transportation infrastructure and land use planning: to design BMPs to continuously mimic the natural flow regime and ensure that ecosystems downstream of development would not be adversely affected.

As the land uses are changed for development of urban areas and transportation infrastructure, ecosystems in receiving water bodies are significantly affected by the changes in duration, peak, and minimum flows. Though Best Management Practices (BMPs) are typically designed to not exceed some peak flow during a design storm and perhaps maintain a minimum flow at low-flow periods, downstream conditions are altered, potentially harming ecosystems. A new approach is presented to achieve a more aggressive sustainability objective: to design BMPs to continuously mimic the natural flow regime and ensure that ecosystems downstream of development would not be adversely affected. This objective may not be achievable through the implementation of a single detention pond at a watershed outlet; a system of BMPs strategically placed throughout the watershed may be required. Several BMPs exist as options for treatment, such as detention/retention ponds, constructed wetland systems, infiltration systems (i.e., porous pavement), and vegetative filtrations systems. As each system chosen for implementation must be specified by a set of design decisions and placement location, an efficient mechanism of optimization is needed to handle the large array of decisions. In addition, a comprehensive modeling framework is needed to simulate a collection of BMPs simultaneously. A quantitative analysis framework is described and illustrated for coupling BMP and watershed models with optimization techniques.

## Reconciling Conservation and Transportation Planning on a Regional Scale: A Symposium of the Society for Conservation Biology North American Section

The North American Section of the Society for Conservation Biology served as a co-sponsor of ICOET 2007 and conducted its annual meeting in conjunction with the conference. This meeting included a half-day symposium on "Reconciling Conservation and Transportation Planning on a Regional Scale." Abstracts of the presentations from the symposium are provided below, along with contact information for the key speakers.

### An Approach to Integrating Transportation and Conservation Planning: Examples From Florida

**Daniel J. Smith, Ph.D.** (406-994-6114, dan.smith@coe.montana.edu), Research Scientist, Western Transportation Institute, Montana State University, Bozeman, MT USA

**Reed F. Noss, Ph.D.** (407-823-5769, rnoss@mail.ucf.edu), Davis-Shine Professor of Conservation Biology, University of Central Florida, Orlando, FL USA

An important objective of conservation planning and reserve design is the provision for functional landscape connectivity. For instance, a well-connected network of reserves might support viable populations or metapopulations of species that might not be supported within single, isolated reserves. Roads present significant obstacles to achieving this objective. Recent research on the ecological effects of roads has demonstrated the range and intensity of impacts to landscapes and biodiversity. Results from four separate studies in Florida are discussed. We employed a broad approach to examine the overall effects of roadways on landscape connectivity for wildlife. Methods included road-kill and track surveys, mark-recapture and telemetry studies, and GIS models. Different taxa (e.g., carnivores, ungulates, selected herpetofauna, and small mammals) were used to examine effects of roads at multiple scales. This multi-species approach was used to determine presence/absence, movement patterns, and landscape use in proximity to roads. Empirical data and landscape models for different taxonomic groups suggest distinctly different types of sensitivity to traffic, roads, and road-related habitat fragmentation; hence, they require different conservation planning strategies. This research approach can provide transportation planners with the information needed to minimize negative impacts of roads on native biodiversity, landscape patterns, and ecological processes, such as fire and hydrology.

### Effects of Roads and Traffic on Populations of Small Animals: Implications for Transportation Planning

**Lenore Fahrig** (613-520-2600, lenore_fahrig@carleton.ca), Geomatics and Landscape Ecology Research Laboratory, Department of Biology, Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S 5B6 Canada

I summarize our research on the impacts of roads and traffic on populations of small animals – amphibians and small mammals – and provide recommendations for transportation planning based on the results. Traffic density within a landscape has large effects on population sizes of several amphibian species. These effects are of the same order of magnitude and often larger than the landscape-scale effects of habitat loss. Traffic density affects amphibian population sizes up to distances of at least 2 km. Small mammals avoid crossing roads, with the result that roads limit small mammal movements across landscapes. However, there is a positive net effect of increasing road density within the landscape on small mammal population abundances. We hypothesize that this is due to negative effects of road density on predators of small mammals. I conclude with some suggestions for road design and regional planning.

### Applications of Local-Scale Research for Planning and Evaluating Measures Designed to Restore Regional Landscape Connectivity

**Anthony P. Clevenger** (403-760-1371, tony.clevenger@pc.gc.ca), Wildlife Biologist, Western Transportation Institute, Montana State University, P.O. Box 174250, Bozeman, MT 59717 USA

Historically, planning of surface transportation generally considered a one-dimensional, linear zone along the highway. Thus, the engineering and design dimensions were the primary concern for planners. In the past, we also find that mitigation for transportation impacts tended to be site-specific, with little consideration of how the project fits into the context of the surrounding ecosystem. Because of the broad landscape context of road systems, it is essential to incorporate landscape patterns and processes in the planning and construction process. Federal and state transportation agencies have recognized now that ecosystem approaches and early stakeholder involvement in identifying issues and areas of concern are essential if their projects are to be environmentally sustainable, streamlined, and garner public support. Partnering and collaborative approaches are essential when developing ecosystem and habitat conservation initiatives. Transportation agencies today need sound science-based information to guide the planning and design process. Like any developing or nascent area of applied science though, initial concepts arrive from theoretical investigations. The strength and validity of these concepts are tested and compared with results from empirical research that help to incrementally refine the concepts and form basic principles. These concepts and principles are generally the basis from which managers and practitioners evaluate their objectives and goals, and ultimately make

their decisions regarding a specific project or management scheme. Our presentation will address some practical guidelines for integrating transportation planning and landscape-scale conservation management. Learning through an adaptive management process and long-term monitoring research are ways that transportation and land management agencies can utilize science-based information to guide future projects and make them more cost-effective. We draw upon examples from 25 years of incremental highway mitigation projects in Banff National Park, Alberta, and the developing Interstate 90 Snoqualmie Pass project in Washington State. Practical management questions that relate to pre-construction data requirements, monitoring intensity, performance goals, and ecological indicators of mitigation performance in a landscape context are discussed. Last, we present a framework for developing practical guidelines to meet variable transportation standards and performance goals that range from the lowest level of genes/individuals to higher levels of populations and ecosystem concerns.

## Effects of Roads on Carnivore Behavior and Ecology in Southern California: Movements, Mortality, and Gene Flow

**Seth P.D. Riley** (805-370-2358, seth_riley@nps.gov), Wildlife Ecologist, National Park Service, and Adjunct Professor, UCLA-EEB; and

**R. M. Sauvajot, J. P. Pollinger, E. C. York, S. Ng, and R. K. Wayne**, Department of Ecology and Evolutionary Biology, UCLA, Santa Monica National Recreation Area, 401 W. Hillcrest Drive, Thousand Oaks, CA 91360 USA

Mammalian carnivores range over large areas and exist at low densities, so they can be particularly vulnerable to the effects of habitat loss and fragmentation. Southern California is one of the country's most heavily developed regions, including an extensive road network and many wide and heavily traveled freeways. We have been studying the effects of urban development and roads on the behavior and ecology of bobcats, coyotes, and mountain lions since 1996. Freeways represent a significant barrier to movement for carnivores, although all three species do cross them, particularly when suitable crossing points are available. Roads can also represent a significant source of mortality for bobcats and coyotes, particularly larger secondary roads. The largest freeways may present a greater barrier than secondary roads, but less of a direct mortality threat: roadkill surveys on three freeways revealed that mortality was inversely related to traffic volume. Over the long-term, an important question is whether freeways also disrupt gene flow. For both bobcats and coyotes, we found that genetic differentiation was significantly greater across a freeway as opposed to along it, and that the degree of differentiation was greater than would be expected based on genetic and telemetry estimates of the number of migrants. Carnivore home range boundaries often run along roads and development. In territorial animals, these hard boundaries may represent social barriers to gene flow as migrants, often young animals, are unable to find empty territories across the road and therefore do not contribute genetically. Our results confirm that maintaining connectivity across roads is critical for the long-term conservation of carnivore populations in urban landscapes, and that techniques are available to facilitate cross-highway movement by carnivores.

## Bighorn Sheep and Interstate Highways: Using Genetics to Optimize Connectivity Models for Managing the Landscape of the Future

**Clinton W. Epps** (510-643-3918, buzzard@nature.berkeley.edu) and Justin S. Brashares, Department of Environmental Science, Policy and Management, University of California Berkeley, 137 Mulford Hall, Berkeley, CA 94720-3114 USA

**John D. Wehausen**, White Mountain Research Station, University of California, 3000 E. Line Street, Bishop, CA 93514 USA

**Vernon C. Bleich**, California Department of Fish and Game, Sierra Nevada Bighorn Sheep Recovery Program, 407 West Line Street, Bishop, CA 93514 USA

**Steven G. Torres**, California Department of Fish and Game, Wildlife Investigations Laboratory, 1701 Nimbus Road, Suite D, Room # 170, Rancho Cordova, CA 95670 USA

Proliferating road networks are thought to have fragmented habitat for many species. However, dispersal and gene flow are often poorly understood, making it difficult to develop planning tools to analyze or mitigate disruption of landscape connectivity by transportation networks. Least-cost GIS analyses are frequently employed to estimate the relative cost of dispersal between habitat patches, identify likely movement corridors, and analyze the connectivity of human-affected landscapes. However, without detailed data on animal movements, such models may be little better than untested hypotheses. Here, we optimize and extend such an approach using genetic and radio telemetry data from 26 populations of desert bighorn sheep *Ovis canadensis nelsoni*. We test hypotheses about the effects of distance, topography, and human-made barriers on gene flow by incorporating those predictor variables into series of least-cost models in which we vary the relative cost of different habitat types. We apply matrix-based regression techniques to identify the model that best correlated with estimates of gene flow among these populations. The best-fit model is then used to predict which populations are connected by active corridors and to identify the least costly paths for dispersal among populations. Known inter-population movements compare well with those predicted by our model. We apply the model to examine the effects of existing highways, future highway projects, and population translocations on landscape connectivity for this species. We also discuss the implications of these findings in the context of climate-related fluctuations in habitat quality.

## Eight Reasons Not to Use GIS Analysis for Corridor Design

**Paul Beier** (928-523-9341, Paul.Beier@nau.edu), Dan Majka, and Wayne Spencer, Northern Arizona University, School of Forestry, Flagstaff, AZ 86011-5018 USA

As advocates for using GIS tools to design corridors based on needs of focal species, we must admit that skeptics have several legitimate objections, including (a) Corridors for focal species can fail to conserve ecological processes, (b) Corridors are typically designed for highly mobile habitat generalists (large carnivores) and won't serve less mobile habitat generalists, (c) Corridor models uncritically assume that animal movement follows the same rules as habitat selection, (d) Corridor models rely on land cover maps, digital elevation models, and road overlays simply because these data layers are available – not because these factors explain animal movement well, (e) Climate change will render corridor designs useless, (f) GIS models always produce a "best" corridor – even if the best is not good, (g) These movement models fail to consider the fact that many species will need generations to move their genes through a corridor, and (h) These models ignore practical issues such as stakeholder involvement and transaction costs. Based on our experience designing 30 wildland linkages in Arizona and southern California, we developed an approach and GIS toolkit (available free at www.corridordesign.org) that honestly acknowledge and confront these issues. Key elements in our approach include using multiple focal species (including sedentary habitat specialists and species tied to ecological process), sensitivity analysis to disclose impacts of key assumptions, involvement of stakeholders throughout the design process (including the involvement of non-scientists in scientific issues), providing plans that integrate habitat conservation and highway crossing structures, and tools to allow implementers to evaluate alternative corridor designs.

## Road Ecology in the Southern Rockies –Science, Policy and Outreach

**Julia Kintsch** (303-454-3344, julia@restoretherockies.org), Program Director, Southern Rockies Ecosystem Project, 1536 Wynkoop, Denver, CO 80202 USA

The Southern Rockies span from southern Wyoming, through Colorado and into northern New Mexico. They contain a wealth of biological diversity, with over 500 vertebrate species, thousands of natural plant communities, and rugged wildlands. Mountain lions still roam the region's majestic mountain country, native cutthroat trout can be found in the purest mountain streams, and grand old stands of ponderosa pine can still be found in the most remote foothills. These biological treasures are threatened by human population growth, a history of destructive land use, road widening and development, and poor land management decisions. To address habitat fragmentation in this region, the Southern Rockies Ecosystem Project (SREP) has been developing programs in the emerging field of Road Ecology that include sound science, policy, as well as education and outreach. Through our *Linking Colorado's Landscapes* project, SREP conducted in-depth assessments in high priority wildlife linkages. Assessments included roadway engineering inventories, wildlife movement data, land status, and a range of mitigation measures to ensure safe passage for wildlife. As an on-the-ground component to this work, SREP spearheaded the construction of a wildlife bridge at West Vail Pass to reconnect habitat for a diversity of species in the White River National Forest as well as improve driver safety. CDOT is currently developing a scope of work that will begin planning for the wildlife bridge. As a wildlife monitoring component to this project, SREP is engaging Citizen Scientists to collect wildlife movement data along I-70 through the use of motion-triggered cameras. With sound science in place, SREP is now beginning to address real policy change at the local, state and federal level to ensure safe passage for wildlife is a priority at all levels of government.Finally, affecting change on the ground requires educating the public as well as professionals in the engineering and biological fields. To accomplish this goal, SREP is: 1) offering a continuing education course for transportation professionals and biologists, 2) developing a "Safe Passage" technical wildlife crossings handbook for engineers, biologists and conservationists, 3) distributing tens of thousands of driver safety tip sheets across Colorado in conjunction with semi-annual press releases that reach millions of people, and 4) offering a Wildlife Crossing Field course in Washington in 2008, focusing on the I-90 corridor.

## Environmental Considerations in Public-Private Partnerships Panel Discussion

The objective of this session, organized by the ICOET 2007 Program Committee, was to increase awareness of public-private partnerships (PPPs) in transportation and to prepare transportation and ecology professionals to effectively engage and support partnerships that improve the efficiency of transportation systems while maintaining and enhancing the quality of the natural environment. Current issues of concern regarding the use of PPPs include ensuring adequate environmental protection/regulatory compliance and monitoring; understanding the value of ecological assessments and strategic habitat conservation planning tools to address uncertainty associated with future environmental concerns; addressing administrative procedures and challenges related to multi-organizational coordination and logistics; balancing government "sunshine laws" with private entities' proprietary information and intellectual property rights, and linking land use and transportation needs.

Panel discussants included the following:

**David Williams, Vice President/Senior Program Manager, Carter-Burgess**
What are public-private partnerships? Mr. Williams provided a welcome, introduction of speakers, and brief overview of PPPs.

**Randy Blankenhorn, Executive Director, Chicago Metropolitan Agency for Planning**
Highly respected by the FWS as the leading planner for one of the largest U.S. metropolitan areas, Mr. Blankenhorn described his philosophy and experiences, including how to manage traffic congestion, from over two decades of partnering with Federal, state and local agencies. He described the potential roles that PPP's can play now and in the future. CMAP is a new regional agency created by merging metropolitan Chicago's previously separate organizations for land-use and transportation planning.

**Bruce A. Stein, Vice President and Chief Scientist, NatureServe**
Dr. Stein shared his organization's experience in incorporating ecological considerations into transportation, infrastructure planning, and resource management efforts. NatureServe coordinates a nationwide public-private partnership that provides scientific information and technology tools at local, regional, and national scales. These information products and services are designed to help agencies and private-sector industries not only meet legal requirements, but to go beyond compliance and promote positive conservation outcomes. In particular, decision support tools, such as NatureServe Vista software, can provide agencies and private investors with a defensible and transparent means to understand ecological values and reduce environmental/project risks.

**David Greenblatt, Analyst, Living Cities Program, Environmental Defense**
Mr. Greenblatt discussed why a public-private partnership on a toll road is not necessarily a good or bad proposition. Well-designed PPP deals have the potential to save motorists time, raise revenue, boost transit choices, and curb fuel use and emissions. The flip side is that PPPs can also spur pollution, fragment the transportation network and facilitate sprawl for years to come. The final outcomes of a PPP depend, in large part, on what a public agency is contracting for. Is the goal simply to increase short-term cash flow? Or is it to create better, more sustainable communities for all? Or some combination thereof?

## Awards Luncheon for the Recipients of the 2007 Federal Highway Administration Environmental Excellence Awards Program

ICOET 2007 was pleased to host the 2007 FHWA Environmental Excellence Awards ceremony. This awards program recognizes the people, organizations, and projects that forge creative solutions and innovations for balancing the needs of a safe and efficient transportation network with environmental sensitivity. This year 13 winners were selected from 12 categories. A panel of four judges also named four honorable mentions from the 174 entries submitted. Following opening remarks by Arkansas Division Administrator Sandra Otto, FHWA Administrator Richard Capka and FHWA Associate Administrator for Planning, Environment and Realty Gloria Shepherd presented the awards, with assistance from Carol Adkins and Patricia Cazenas of FHWA's Natural Systems Unit. For more information on the 2007 awards program and winners, please refer to FHWA's Web site at http://www.fhwa.dot.gov/environment/eea2007/index.htm.

### Excellence in Environmental Streamlining

**Arizona's Wildlife Linkages Assessment**
*(Arizona Department of Transportation, Arizona Game and Fish Department, Bureau of Land Management, Federal Highway Administration Arizona Division, Northern Arizona University, Sky Island Alliance, The Wildlands Project, USDA Forest Service, U.S. Fish and Wildlife Service)*
Working together, these Federal, State, and non-profit organizations conducted a statewide assessment to ensure a level of consistency and uniformity toward conservation and highway safety goals, while accommodating the growth of Arizona's population, an expanding economy, and associated infrastructure. This assessment identifies large blocks of protected habitat, the potential wildlife movement corridors through and between them, and the factors that could possibly disrupt these linkage zones. Recognizing that habitat connectivity is a landscape issue involving multiple land jurisdictions, the assessment has been distributed statewide. It provides a starting point for detailed consultation between State and federal agencies, county planners, land conservancies, tribes, private landowners and other organizations for a cohesive, comprehensive, landscape-scale approach. By integrating wildlife considerations into the forefront of transportation and regional planning processes, it is possible to achieve the greatest advantage to wildlife and the traveling public while reducing delays and costs in project development. This project has engaged in unprecedented interagency cooperation, facilitated discussions, and formed partnerships to promote a unified approach to wildlife linkage conservation and management.

**Caltrans Cumulative and Growth-Related Impacts**
*(California Department of Transportation, Federal Highway Administration California Division, Environmental Protection Agency Region 9, Carter Burgess, Karen Bahus Technical Writing and Research, and Fox Mediation)*
A strong partnership consisting of Caltrans, FHWA, and EPA, consulting with USACE, worked collaboratively to develop key guidance for conducting cumulative and growth-related indirect impacts analysis for California surface transportation projects. The objectives of this effort were to reduce project and process delays, protect and enhance the environment, and integrate and enhance interagency coordination. This successful partnership resulted in two key guidance documents - Guidance for Preparers of Cumulative Impacts Analysis and Guidance for Preparers of Growth-related, Indirect Impacts Analyses - that provide agencies, local government, and the public with a clear set of expectations about when and how to perform cumulative and growth-related indirect impacts analysis. The guidance documents reflect long-term discussions among the partnering agencies encompassing their various perspectives on vocabulary, definitions, and methodologies, which led to agreement on reasonable analytical approaches. The documents provide decision makers with a systematic approach for analyzing complex environmental issues for transportation projects in a consistent and comprehensive manner and offer a "practical, how-to approach" to cumulative and growth-related impact analysis. The important collaborative effort of developing the guidance documents built trust between the partnering agencies and greatly enhanced the ability of future practitioners to work collaboratively to develop feasible avoidance, minimization, and mitigation measures that protect the public trust.

## Excellence in Cultural and Historical Resources

### Scattered Village Exhibits and Curriculum

*(North Dakota Department of Transportation; Mandan Public Library; Mandan, Hidatsa, and Arikara Nation; Mandan Public Schools; Color and Design; Whattadame Productions)*

The Scattered Village Exhibits and Curriculum Project is an outreach program providing interpretive and educational materials resulting from the discovery of a significant pre-historic village during the construction of a street in Mandan, North Dakota. The site, adjacent to an elementary school, provided a unique opportunity to educate the local children about their heritage. The children would question the archaeologists each day to find out what was being unearthed. Bringing this information back to the public is an important way for people to truly understand and appreciate their heritage. Together, the project sponsors have involved a wide audience in the development of museum quality displays and educational curriculum to honor the inhabitants of Scattered Village. The exhibits located in the Mandan Public Library recreate the story of the archaeological dig, the recovered artifacts and the valuable information discovered at the site. Then taking it a step further, they took the opportunity to draw on the oral traditions of the Three Affiliated Tribes to fit the scientific facts to the traditions and history of the tribes, linking the historical site to the past. Through these truly outstanding efforts, this unique project provides many outreach and educational exhibits, including maps, brochures and information on local historic sites which promote tourism while preserving historical data and information for future generations.

## Excellence in Air Quality Improvement

### I-5 Corridor: Saving Fuel and Reducing Pollution

*(Cascade Sierra Solutions)*

Cascade Sierra Solutions (CSS), a non-profit agency, is taking an innovative regional approach to reducing diesel emissions and fuel consumption for long-haul trucks that operate on the I-5 corridor. They are providing a single stop shopping place where truckers can learn about currently available emissions and fuel reduction technologies, have the technologies installed, learn about potential financial incentives, gain insight into air agency regulations and policies, and obtain information on a low-interest loan program structured to meet their financial situations. These incentives and amenities have produced a dramatic decrease in idling fuel consumption and reduced emissions by over 75 percent, which includes reductions in NOX, CO2 and more than 40 toxic substances found in diesel exhaust. The success of this program relies on its numerous public and private stakeholders while providing a national model that uses technology improvements combined with incentive-based programs to reduce the consumption of fuel and reduce pollution from the long-haul fleet operating in Washington, Oregon and California.

## Excellence in Roadside Resource Management and Maintenance

### Tennessee Roadscapes – Cultivating the Road Ahead

*(Tennessee Department of Transportation)*

A new initiative from the Tennessee Department of Transportation provides opportunities for a variety of environmental stewardship and beautification programs along the interstates and highways of Tennessee. Under a comprehensive program, emphasis was placed on combining maintenance specific needs with environmental obligations as a way of enhancing and improving the state's roadways. This effort focused on decreasing maintenance costs through the use of sustainable native vegetation, which requires less maintenance and mowing, and increasing additional transportation resources through community involvement and volunteers. Volunteers help with litter removal and plantings and commit to long-term maintenance agreements to improve the aesthetic appeal of Tennessee roadways. Landscaping has helped promote tourism, developed community pride, enhanced economic development and improved the quality of life for the traveling public. This program shows what can be done to develop and implement an outstanding statewide program that utilizes partnerships to integrate widely separate functions into a comprehensive roadside management plan for plantings, maintenance and environmental stewardship.

## Excellence in Scenic Byways

### Grand Rounds Wayfinding Program

*(Minnesota Department of Transportation, Minnesota Park and Recreation Board)*

The "Wayfinding" program's main focus is to provide residents and visitors with a friendly orientation to the byway through a means of communication that includes interpretation, environmental education and recreational opportunities by providing accurate mapping and guidance along the way. The byway's qualities are enhanced through the dedication of local and community participation and stewardship efforts. The "Wayfinding" project was completed in 2004, with 53 kiosks located throughout the byway and over 200 directional signs that are strategically located. Involving the local community to participate in identifying the byway's natural qualities has created a sense of ownership and stewardship. The program is a cost-effective way to promote and disseminate information using a non-traditional method. This service to visitors has enriched the appeal of the Twin Cities to visitors, contributing to the vitality of the area's tourism industry. The byway provides a tremendous resource, explaining the activities and history of the area in an easy to use format. The success of this project is shown by the increase in byway usage, now serving over 15 million visitors annually.

## Excellence in Environmental Research

**Alaska Way Viaduct and Seawall Replacement Project**
*(Washington State Department of Transportation, Seattle Department of Transportation, Federal Highway Administration Washington Division, Parsons Brinckerhoff, Parametrix, EnviroIssues)*
At an early stage of development, sound decision-making and building public consensus are at the forefront of having a successful environmental planning process. The Alaskan Way Viaduct and its support structure, the Alaskan Way Seawall, have a reader-friendly EIS that informed the public of the project's tradeoffs and environmental considerations to generate support for a $4 billion dollar project that will take years to construct in the heart of Seattle's densely developed downtown. By using innovative approaches and inter-agency coordination and advanced planning, the project transportation team blended state, city and consultant staff to create a collaborative, interactive venue for everyone to understand the emerging project issues and offer advice and suggestions that will ultimately make regulatory approval faster and easier. The computer simulations included in the environmental documentation have advanced this approach to a new level by giving detailed, accurate simulations of the finished project and extensive depictions of the construction phase. The state-of-the-art simulations are educational and innovative, providing a jump start into planning and reducing the effects of the project on adjoining neighborhoods. These decision-making and leadership tools that support better public understanding and effective communication showcase a best practice in planning tools for NEPA documents.

## Excellence in Recycling and Reuse

**Reuse of Petroleum Contaminated Soil: The Mn/DOT Biomound Process**
*(Minnesota Department of Transportation)*
Biomounding is an effective, environmentally friendly process for treating petroleum-contaminated soil. Minnesota Department of Transportation developed an innovative remediation technique that combines petroleum- contaminated soil, manure and low-grade wood chips into a reusable material which is used as a topsoil amendment. The biomound remediation process has resulted in the reuse of large volumes of waste materials. Since 1991, Minnesota has used the biomound treatment process to successfully treat over 30,000 cubic yards of petroleum-contaminated soil excavated from more than 15 projects and has produced a video encouraging the use of this proven treatment technique. This successful process has been effective and accepted by local agencies of government and the general public. The innovative combination of waste materials that are remediated, recycled and reused as topsoil amendments for use on future roadway construction projects continues to result in a practical, cost-effective and environmentally sound approach to dealing with contaminated soil.

## Excellence in Nonmotorized Transportation

**Massachusetts Highway Project Development and Design Guide**
*(Massachusetts Highway Department)*
The new edge-to-center design approach recommended by the Massachusetts Highway Project Development and Design Guide is a breakthrough effort to mainstream non-motorized planning into the project development process. The needs of, and the methods to accommodate, non-motorized modes of transportation are no longer segregated into their own sections or chapters but now are addressed in every chapter of the guide. The guidebook directs the designer to begin at the edge with the pedestrian and work their way in, to ensure that the needs of non-motorized users remain integral to project planning and design. This change in thinking facilitates the use of context-sensitive design, environmental protection and the careful consideration of the safety and accessibility needs of pedestrians, bicyclists and non-motorized facility users. The statewide manual, which was developed in partnership with a task force composed of 28 members, addressed a broad range of constituency concerns but focused on adding streamlining measures and design flexibility in the project development process. By integrating multi-modal planning and design into every chapter of the development and design guide, the final result supports a transportation system providing seamless, functional and safe access for all users.

## Excellence in Livable/Sustainable Communities

**Maryland Route 45: York Road**
*(Maryland State Highway Administration)*
This community-generated project was guided by the Maryland State Highway Administration and a multi-disciplinary task force comprised of agency representatives and community and business leaders, who worked together to blend transportation improvements with urban redevelopment. The partnering team consisted of State, local agencies and businesses, and nine communities who all were vital links in identifying the desires of the community and disseminating the project information. The revitalization work included: upgrading and interconnecting the traffic signal system, drainage improvements, improving pavement conditions and sidewalk accessibility, adding traffic calming elements, decorative lighting, street furniture and bus shelters, and extensive landscaping within the corridor. On a fixed budget the project team collaborated and partnered on many items to stay within the scope and budget of the project. The success of this project is measured by the continued involvement of the task force in monitoring the project's outcome through project surveys, site walks and interacting with the community, which demonstrates the strong commitment to promoting local cohesion, along with social and economic development.

## Excellence in Ecosystems, Habitat, and Wildlife

**Legacy Parkway and Nature Preserve**

*(Utah Department of Transportation, Federal Highway Administration Utah Division, and U.S. Army Corps of Engineers)*
This 14-mile, four-lane, limited access divided highway provides an important alternate route for Northern Utah commuters. The project resulted in a unique environmental mitigation project: the Legacy Nature Preserve. A collaborative design team working with the public incorporated many unique and innovative features into the final parkway design. Some of the features included observation points and trailheads along with roadside pull-off lots, landscaping with native species, use of vegetated berms for screening, connections to other trails and communities and designing narrower paved portions of the roadway. UDOT found that they could meet their safety standards while also designing a roadway which was aesthetically compatible with the local communities and protected the environmental integrity of the area. The Legacy Nature Preserve, restores and preserves over 2,100 acres of important wetland and wildlife habitat from encroaching development and provides buffers that are important to the survivability of wildlife along the Great Salt Lake. By enhancing and maintaining the wetlands, habitat values, and uplands to maximize their use by a diverse array of vegetation and migratory species UDOT is ensuring that the outstanding environmental resources around the Great Salt Lake will be available for future generations.

## Excellence in Wetlands, Watersheds, and Water Quality

**Bob Jacobson Restoration Site (Wingard WMA)**

*(Minnesota Department of Transportation)*
This comprehensive approach to ecosystem restoration started when a number of State agencies combined their resources to restore well over a hundred wetland basins in an area that was historically tall-grass prairie. Their cooperative effort resulted in an 1800-acre wetland restoration initiative situated on the flat expanse of historic Lake Aggasiz in the Red River Valley. Through these efforts the site is being restored to a natural condition that will benefit the local watershed in terms of water quality and flood storage. The success of the project can be documented by the wildlife already frequenting this area. They include migratory waterfowl, moose, sand hill cranes, trumpeter swans and bald eagles. This wetland bank was constructed to offset losses from federally funded State highway projects as well as other local developments. The enormous size of this ecosystem restoration area, which has produced valuable results in terms of habitat, wildlife, wetlands, and water quality, shows what can be done through a coordinated partnership effort to preserve and protect environmental values that will be utilized by generations yet to come. This restoration site is named in honor of Bob Jacobson (1958-2007), the Mn/DOT botanist who played a key role in the vegetative restoration of the site.

## Excellence in Environmental Leadership

**Benito (Buddy) Cunill III, Florida Department of Transportation**

Mr. Cunill has led an outstanding and exceptional career with Florida Department of Transportation. He is an excellent example of the results that can be obtained by one individual's personal dedication to an area of environmental stewardship in the transportation field. He is responsible for developing, negotiating and managing the implementation of 21 interagency agreements among individual federal, State, and regional agencies to achieve statewide implementation of Florida's newly developed Efficient Transportation Decision-making (ETDM) process. He shaped how Florida DOT conducted business in satisfying the National Environmental Policy Act (NEPA) and defined the process and environmental analysis to be used in developing the transportation projects that fully satisfied federal and State environmental laws and regulations. Besides meeting criteria placed on projects at the national level, he has always placed a strong emphasis on "grassroots" citizen involvement and participation at the local level in all of Florida's transportation planning programs. One of these "grassroots" programs was Florida's Scenic Highway Program, under his management the program grew and today there are eleven designated scenic highways in Florida. His leadership and involvement at the State and National level proved instrumental in the development of a program known as Community Impact Assessment that increases the awareness of the needs of the human community and evaluating community impacts from a transportation project. This award recognizes his many accomplishments and distinguished career which has demonstrated a strong leadership role in developing programs to protect and enhance our human and natural environment, while still providing a safe and efficient transportation system for all to enjoy.

## Honorable Mentions

**Air Quality - 2006 Spare the Air/Free Transit Campaign**

*(Oakland Metropolitan Transportation Commission)*
The Metropolitan Transportation Commission (MTC) and the Bay Area Air Quality Management District (BAAQMD) partnered with 26 Bay Area transit operators to offer free rides, all-day, on the first six, non-holiday Spare the Air weekdays to increase transit ridership and reduce emissions.

**Nonmotorized Transportation - Great Streets**

*(District Department of Transportation)*
The goal of the Great Streets program in the District of Columbia is to increase neighborhood livablility, economic growth and encourage community interactions by building a safe, walkable community with streetscape improvements that allow for a range of transportation options.

**Roadside Resource Management and Maintenance - Minnesota Biological Weed Control Program**
*(Minnesota Department of Transportation)*
The Minnesota Department of Transportation proactively deploys biological control agents, typically beneficial insects, as a complement to traditional mechanical, cultural and chemical methods of managing vegetation in an Integrated Roadside Vegetation Management Program.

**Wetlands, Watersheds and Water Quality - Highway Runoff Manual**
*(Washington Department of Transportation)*
The Washington State Department of Transportation (WSDOT) developed the Highway Runoff Manual (HRM) to direct the planning, design and implementation of stormwater management facilities that require the involvement of multiple disciplines, to address the needs of its statewide transportation-related facilities.

**<u>2007 Awards Judges</u>**

- Paul Anderson, Transportation Liaison, USDA Forest Service
- Fred Bank, Senior Environmental Scientist, Mulkey Engineers & Consultants, Inc.
- David Burwell, Senior Associate, Transportation Project for Public Spaces
- Bob Hargrove, Director, NEPA Compliance Division, Environmental Protection Agency

# Appendices
*Final Program*

**Sunday, May 20**

**2:00 - 5:00** **Conference Registration and Check-In (Balcony)**

Speaker Ready Room - Open all week (Peck)

**7:30 - 9:30** **ICOET 2007 Steering Committee Business Meeting (Upper Pinnacle)**

**Monday, May 21**

**7:30 - 8:30** **Continental Breakfast (Salons B & C Foyer)**

**8:30 - 9:15** **Conference Welcome and Opening Remarks (Salons B & C)**

*Moderator:* Debra Nelson, New York State DOT

James Martin, Associate Director, CTE

Dan Flowers, Director, Arkansas State Highway and Transportation Department

**9:15 - 10:00** **Session 1: Update on U.S./International Activities (Salons B & C)**

*Moderator:* Hans Bekker, IENE

Hans Bekker, Liaison, Infra Eco Network of Europe

Rodney van der Ree, Ecologist, Australian Research Centre for Urban Ecology

Rodney Schlickeisen, President, Defenders of Wildlife

Mamie Parker, Assistant Director, U.S. Fish and Wildlife Service - Fisheries and Habitat Conservation

Carol Adkins, Water and Ecosystems Team Leader, Federal Highway Administration

**10:00 - 10:30** **Break (Salons B & C Foyer)**

**10:30 - Noon** **Session 2: Cross-Cutting Session (Salons B & C)**

*Moderator:* Debra Nelson, New York State DOT

Stewart Airport Ecosystem: Taking Off with Innovative Approaches
(Debra Nelson, New York State DOT, Albany, NY, USA)

Supporting Transportation, Water and Ecological Systems in the Great Lakes Basin
(Judy Beck, Great Lakes National Program Office, Chicago, IL, USA)

Arizona's Wildlife Linkages Assessment (Bruce Eilerts, Arizona DOT, Phoenix, AZ, USA)

Overcoming the Barrier Effect of Roads: How Effective Are Mitigation Strategies?
(Rodney van der Ree, Australian Research Centre for Urban Ecology, Melbourne, Victoria, Australia)

**Noon - 1:30** **Lunch (on your own)**

**Noon - 1:30** **Defenders of Wildlife Workshop (By Invitation Only):**
**"Getting Up To Speed: A Symposium on Wildlife and Transportation for Advocates" (Chicot)**

The purpose of this session is to inform, educate and inspire conservation advocates and improve relationships among all those working on surface transportation issues at any level. The panel will consist of veterans from professional sectors and agencies involved in conservation and transportation. Together, participants and panelists will develop recommendations for further improving relationships between agencies and advocates. Box lunches provided.

**1:30 - 3:00** **CONCURRENT SESSIONS 3A, 3B and 3C**

**Session 3A:** **Coordination & Regulatory Compliance (Salon A)**

*Moderator:* Paul Garrett, FHWA

Streamlining ESA Section 7 Consultations: Bedell Street Bridge Project, Del Rio, Texas
(Allison Arnold, U.S. Fish and Wildlife Service, Austin, TX, USA)

Oregon DOT's OTIA III Bridge Program: Three Years of Environmental Stewardship
(Shelley Richards, HDR Engineering, Inc., Salem, OR, USA)

Geyerserville: 1,000 Feet in 110 Days
(Charles Morton, California Department of Transportation, Oakland, CA, USA)

Regulatory Compliance on Multistate and Multimodal Projects: Bridging the Gaps Between States and Among NEPA Co-leads (Heather Gundersen, Oregon Department of Transportation, Vancouver, WA, USA)

**Session 3B:** **Transportation Operations – Part I of III (Conway)**

*Moderator:* Phillip Moore, Arkansas HTD

Conservation Management of Historic Road Reserves in Australia
(Peter Spooner, Charles Sturt University, Albury, New South Wales, Australia)

Goals, Pros and Cons of a Massive Increase in Roadside Woody Vegetation
(Richard T.T. Forman, Harvard University, Cambridge, MA, USA)

Prescribed Fire is Cool on Florida Highway (Jeff Caster, Florida DOT, Tallahassee, FL, USA)

Establishment Success of Native Versus Non-native Herbaceous Seed Mixes on a Revegetated Roadside in Central Texas
(Jeannine Tinsley, Lady Bird Johnson Wildflower Center, University of Texas at Austin, Austin, TX, USA)

**Session 3C:** **Wildlife & Terrestrial Ecosystems (Data Surveys & Decision Support Guidelines) (Salons B & C)**

*Moderator:* Paul Wagner, Washington State DOT

North American Decision Guidelines for Mitigating Roads for Wildlife
(John Bissonette, USGS Utah Cooperative Research Unit, Utah State University, Logan, UT, USA)

Animal-Vehicle Collision Data Collection Throughout the United States and Canada
(Marcel Huijser, Western Transportation Institute, Montana State University, Bozeman, MT, USA)

Can Wildlife-Vehicle Collisions be Decreased by Increasing the Number of Wildlife Passages in Korea?
(Tae-Young Choi, Environmental Planning Institute, Seoul National University, Gwanak-gu, Seoul, South Korea)

Inventory and Typology of Fauna Passages on French Transport Structures (Sabine Bielsa, SETRA [French Technical Service of Roads and Motorways], Bagneux, Ile de france, France)

**3:00 - 3:30** **Break (Salons B & C Foyer)**

**3:30 - 5:00** **CONCURRENT SESSIONS 4A, 4B and 4C**

**Session 4A:** **Wildlife & Terrestrial Ecosystems (Herpetiles) (Salon A)**

*Moderator:* Susan Hagood, Humane Society of the United States

Use of Existing Mitigation Measures by Amphibians, Reptiles and Small- to Medium-Size Mammals in Hungary: Crossing Structures Can Function as Multiple Species-Oriented Measures
(Miklós Puky, Hungarian Danube Research Station, Institute of Ecology and Botany, JÃ¡vorka, Hungary)

Effectiveness of Amphibian Mitigation Measures Along a New Highway
(Jed Merrow, McFarland-Johnson, Inc. Concord, NH, USA)

Road Effects on a Population of Copperhead Snakes in the Land Between the Lakes National Recreation Area, KY (Valorie Titus, Binghamton University, Brookhaven National Laboratory, Upton, NY, USA)

**Session 4B:** **Transportation Operations – Part II of III (Conway)**

*Moderator:* Alison Berry, UC-Davis Road Ecology Center

Developing Fauna-Friendly Transport Structures
(Christof Elmiger, Swiss Agency for the Environment, Bern, Switzerland)

Road Crossing Structures for Amphibians and Reptiles: Informing Design through Behavioral Analysis
(Hara Woltz, Nelson Byrd Woltz Landscape Architects, New York, New York, USA)

Ecological Performance of Mitigation Wetlands in a Predominantly Agricultural Landscape
(Terry J. VanDeWalle, Natural Resources Consulting, Inc., Independance, IA, USA)

Effective Wetland Mitigation Site Management: Plant Establishment to Closeout
(Paul Wagner, Washington State DOT, Olympia, WA, USA)

**Session 4C:** **Integrating Transportation & Conservation Planning (New Developments) (Salons B & C)**

*Moderator:* Trisha White, Defenders of Wildlife

Watershed Approaches to Compensatory Mitigation: Using Comprehensive Mitigation Planning to Achieve More Effective Mitigation for Transportation Projects
(Jan Cassin, Parametrix, Inc., Bellevue, WA, USA)

Integrating Wildlife Crossings into Transportation Plans in Projects in North America
(Patricia Cramer, USGS Cooperative Unit, Utah State University, Logan, UT, USA)

Missing Linkages: Nationwide Survey of State-Based Habitat Connectivity and/or Wildlife Linkage Analyses (Jesse Feinberg, Defenders of Wildlife, Washington, DC, USA)

**5:00** **Adjourn**

**6:00 - 9:00** **International Welcome Reception at the Clinton Presidential Library and Museum**

Thanks to our sponsors! ARCADIS-US/NL, The Nature Conservancy, URS Corporation

**<u>Tuesday, May 22</u>**

**7:30 - 8:30** **Continental Breakfast (Salons B & C Foyer)**

**8:30 - 10:00** **CONCURRENT SESSIONS 5A and 5B**

**Session 5A:** **Integrating Transportation & Conservation Planning (Eco-Logical Approaches) (Conway)**

*Moderator:* Mary Gray, FHWA Headquarters

Application of Ecological Assessments to Regional and Statewide Transportation Planning
(Joe Burns, U.S. Fish and Wildlife Service, Arlington, VA, USA)

Applying the Eco-Logical Framework in Montana: The Good, The Bad and The Ugly
(Ted Burch, FHWA-Montana Division; Scott Jackson, U.S. Fish and Wildlife Service; Deborah Wombach, Montana Department of Transportation, Bozeman, MT, USA)

Justifying Environmental Stewardship: Oregon Department of Transportation's Wildlife Collision Prevention Plan Case Study (Melinda Trask, Oregon Department of Transportation, Salem, OR, USA)

Habitat Linkage within a Transportation Network
(Sherri Swanson, HDR Engineering, Inc., Sarasota, FL, USA)

**Session 5B:** **Transportation Operations – Part III of III (Arkansas Ballroom)**

*Moderator:* Tom Linkous, TRB ADC 30 Committee Chair

Washington State DOT Bridge Maintenance and Inspection Guidance for Protected Terrestrial Species
(Marion Carey, Washington State DOT, Olympia, WA, USA)

Dark Beaches: Florida DOT's Continued Efforts to Implement Environmentally Sensitive Lighting Systems
(Ann Broadwell, Florida DOT District 4, Fort Lauderdale, FL, USA)

Oregon Strategies for Transportation Compliance with the Migratory Bird Treaty Act
(Chris Maguire, Oregon DOT, Salem, OR, USA)

Canasawacta Creek Watershed Initiative
(Mary O'Reilly, New York State DOT Region 9, Binghampton, NY, USA)

**10:00 - 10:30** **Break (Salons B & C Foyer)**

**10:30 - 12:00** **CONCURRENT SESSIONS 6A and 6B**

**Session 6A:** **Acoustic Ecology - Wildlife & Terrestrial Ecosystems (Partnerships for Success) (Conway)**

*Moderator:* Chris Servheen, U.S. Fish and Wildlife Service

Measuring the Success of Wildlife Movement Across Highways and Linkage Efforts
(Christopher Servheen, U.S. Fish and Wildlife Service, Missoula, MT, USA)

Case Study: Harbor Boulevard Wildlife Underpass, Los Angeles County, CA
(Andrea Gullo, Habitat Authority, Whittier, CA, USA)

Under the Boardwalk: Case History — St. John's Sideroad at the McKenzie Wetland, Aurora, Ontario, Canada (Ian Buchanan, Regional Municipality of York, Newmarket, Ontario, Canada)

Coordination of Agency and Citizen Involvement in Project Development and Monitoring for the I-90 Snoqualmie Pass East Project (Jen Watkins, I-90 Wildlife Bridges Coalition, Seattle, WA; and Patty Garvey-Darda, USDA Forest Service, Cle Elum, WA, USA)

**Session 6B:** **Fisheries & Aquatic Ecosystems–Part I of II (Arkansas Ballroom)**

*Moderator:* Ann Campbell, EPA Headquarters

Strategic Approach for Identification and Correction of Fish Passage on National Forest Lands for Pacific Northwest (David Heller, USDA Forest Service, PNW Region, Portland, OR, USA)

Review of the Influences of Road Crossings on Warmwater Fishes Movement and Fish Communities in Ouachita Mountain Streams, Ouachita National Forest
(Richard Standage, Ouachita National Forest, USDA Forest Service, Hot Springs, AR, USA)

Juvenile Salmon Passage in Sloped-Baffled Culverts
(David Thurman, University of Washington, Seattle, WA, USA)

Protecting and Enhancing River and Stream Continuity
(Scott Jackson, University of Massachusetts Extension Amherst, MA, USA)

**12:00 - 1:30** **FHWA Environmental Awards Luncheon (Salons B & C)**

**1:30 - 3:00** **CONCURRENT SESSIONS 7A and 7B**

**Session 7A:** **Poster Session (Salon A)**

**Session 7B:** **Fisheries & Aquatic Ecosystems – Part II of II (Arkansas Ballroom)**

*Moderator:* John Harris, Arkansas HTD

Erasing the False Hard Line Between Aquatic and Terrestrial Passages: Recommendations for Integrating Objectives in Transportation Planning (Sandra Jacobson, USDA Forest Service, Arcata, CA, USA)

Inventory and Sediment Modeling of Unpaved Roads for Stream Conservation Planning
(Ethan Inlander, The Nature Conservancy, Fayetteville, AR, USA)

Assessment of Freshwater Mussel Relocation as a Conservation Strategy
(Andrew Peck, Arkansas State University, Little Rock, AR, USA)

Habitat Restoration and Mitigation on the Impact of a Transportation Network on Hyporheic Organisms Dwelling in the Upper Ganges, India
(Ramesh C. Sharma, H.N.B. Garhwal University, Srinagar-Garhwal, Uttaranchal, India)

**3:00 - 3:30** **Break (Salons B & C Foyer)**

**3:30 - 5:00** **CONCURRENT SESSIONS 8A and 8B**

**Session 8A:** **Poster Session (Salon A)**

**Session 8B:** **Integrating Transportation & Conservation Planning (Urban Areas) (Conway)**

*Moderator:* Randal Looney, FHWA-Arkansas Division

Green Infrastructure, Environmental Mitigation and Transportation Planning in Kansas City
(Tom Jacobs, Mid-America Regional Council, Kansas City, MO, USA)

Impacts of Different Growth Scenarios in the San Joaquin Valley, CA
(Karen Beardsley, Information Center for the Environment, Davis, CA, USA)

Sonoran Desert Conservation Plan and Regional Transportation Planning: A Case Study in Challenges for Protecting and Restoring Wildlife Connectivity in Urbanized Areas
(Carolyn Campbell, Coalition for Sonoran Desert Protection, Tucson, AZ, USA)

Limitations to Wildlife Habitat Connectivity in Urban Areas
(Melinda Trask, Oregon Department of Transportation, Salem, OR, USA)

**5:00** **Day Two Sessions Adjourn, Dinner (on own)**

**7:00** **TRB Committee on Ecology and Transportation Business Meeting (By Invitation Only) (Arkansas Ballroom)**

**7:00** **PARC Roads Task Force Meeting (By Invitation Only) (Manning)**

**<u>Wednesday, May 23</u>**

**7:00 - 8:00** **Muffin/Coffee To-Go Station. Pick up box lunches. (Salons A & B Foyer)**

**8:00 - 5:00** **FIELD TRIPS**

Thanks to Carter-Burgess Little Rock for providing snack refreshments!
Field Trip Option 1: White River Bridge Replacement, Clarendon, AR
Field Trip Option 2: Rixey Bayou Wetlands Mitigation Area and Fourche Creek Watershed Restoration Project/Little Rock - Audubon Nature Center

**6:00 - 9:00** **Little Rock Barbecue at the Museum of Discovery**

Thanks to HDR Engineering, Inc. for their generous support of this event, along with Garner Engineers and Historic Preservation Associates!

**<u>Thursday, May 24</u>**

**7:00 - 8:30** **SCB Board Meeting (By Invitation Only) (Manning)**

**7:30 - 8:30** **Continental Breakfast (Salons B & C Foyer)**

**8:30 - 10:00** **CONCURRENT SESSIONS 9A and 9B**

**Session 9A:** **Wildlife & Terrestrial Ecosystems (Large Mammals & Ungulates) (Salon C)**

*Moderator:* Hans Bekker, IENE/Ministry of Transport and Water Management, The Netherlands

Construction of a Highway Section Within a White-Tailed Deer Winter Yard Near Quebec City, Quebec, Canada: Mitigation Measures, Monitoring and Preliminary Results
(Yves Leblanc, Tecsult Inc., Quebec City, Quebec, Canada)

Using Site-Level Factors to Model Areas at High Risk of Deer-Vehicle Collisions on Arkansas Highways
(Philip Tappe, University of Arkansas at Monticello, Monticello, AR, USA)

Behavioral Responses of White-Tailed Deer to Vehicle-Mounted, Sound-Producing Devices
(Sharon Valitzski, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA, USA)

Evolution of Wildlife Exclusion Systems on Highways in British Columbia
(Leonard Sielecki, British Columbia Ministry of Transportation, Victoria, BC, Canada)

**Session 9B:** **Wildlife & Terrestrial Ecosystems (Multispecies Approaches) (Salon B)**

*Moderator:* Melinda Trask, Oregon DOT

Habitat, Highway Features and Animal-Vehicle Collision Locations as Indicators of Wildlife Crossing Hotspots
(Sarah Barnum, New Hampshire Audubon, Concord, NH, USA)

Utilizing a Multi-Technique, Multi-Taxa Approach to Monitoring Wildlife Passageways on the Bennington Bypass in Southern Vermont (Mark Bellis, University of Massachusetts at Amherst, Wilmington, VT, USA)

Ecological Effects of Road Infrastructure on Herpetofauna: Understanding Biology and Increasing Communication are Critical for Wildlife Conservation
(Kimberly Andrews, University of Georgia, SREL, Aiken, SC, USA)

Surveying and Modeling Roadkills (Shyh-Chyang Lin, National Kinmen Institute of Technology, Kinmen, Taiwan)

**10:00 - 10:30 Break (Salons B & C Foyer)**

**10:30 - 12:00 CONCURRENT SESSIONS 10A and 10B**

**Session 10A: Wildlife & Terrestrial Ecosystems (Large Mammals & Ungulates) (Salon C)**

*Moderator:* Sandra Jacobson, USDA Forest Service

Wildlife Mitigation and Human Safety for Sterling Highway Milepost 58-79, Kenai Peninsula, AK
(Richard Ernst, U.S. Fish and Wildlife Service, Soldotna, AK, USA)

Use of Global Positioning Satellite Telemetry to Assess the Effectiveness of Measures to Promote Permeability Across a Highway in Central Arizona
(Norris Dodd, Arizona Game and Fish Department, Pinetop, AZ, USA)

Effects of Traffic Volume on Elk Distribution and Crossing Patterns Along an Arizona Highway
(Jeff Gagnon, Arizona Game and Fish Department Phoenix, AZ, USA)

Transportation Corridors in Arizona and Mexico and Pronghorn
(Norris Dodd, Arizona Game and Fish Department, Phoenix, AZ, USA)

**Session 10B: Wildlife & Terrestrial Ecosystems (Small Mammals & Carnivores) (Salon B)**

*Moderator:* Bill Ruediger, Wildlife Consulting Resources

Management Considerations for Designing Carnivore Highway Crossings
(Bill Ruediger, Wildlife Consulting Resources, Missoula, MT, USA)

Patterns of Carnivore Road Casualties in Southern Portugal
(Clara Grilo, Faculdade de Ciências da Universidade de Lisboa, Lisboa, Portugal)

Major Roads: A Filter to the Movement of the Squirrel Glider (Petaurus norfolcensis)
(Silvana Cesarini, Monash University, Melbourne, Victoria, Australia)

Roads and Desert Small Mammal Communities: Positive Interaction?
(Silvia Rosa, Utah State University, Almada, Portugal)

**12:00 - 1:30 LUNCHEON and KEYNOTE PRESENTATION (Statehouse Convention Center, Wally Allen Ballroom)
Mr. Jim Martin, Conservation Director, Berkley Conservation Institute, Pure Fishing**

Thanks to our sponsors! Electrobraid Fence, Inc.; EMS Scientists, Engineers, Planners, Inc.; Engineering Compliance and Construction, Inc.; Michael Baker Jr., Inc.; Mulkey Engineers & Consultants, Inc.; RPM Ecosystems, LLC; Parsons; PBS&J

**1:30 - 3:00 CONCURRENT SESSIONS 11A, 11B and 11C**

**Session 11A: Poster Session (Salon A)**

**Session 11B: Integrating Transportation & Conservation Planning (State Wildlife Action Plans) (Salon B)**

*Moderator:* Michael Culp, FHWA Headquarters

Unanimous! What the State Wildlife Action Plans Have to Say About Transportation and Wildlife
(Patricia White, Defenders of Wildlife, Washington, DC, USA)

State Wildlife Action Plans: State Wildlife Agencies and Transportation Agencies Working Together to Prevent Wildlife from Becoming Endangered
(David Chadwick, Association of Fish and Wildlife Agencies, Washington, DC, USA)

Using Tools that Support Decision-Making Toward Multiple Benefits in Transportation and Conservation (Shara Howie, NatureServe, Boulder, CO, USA)

A Multi-scale and Context-Sensitive Statewide Environmental Mitigation Planning Tool for Transportation Projects in California (James Thorne, Information Center for the Environment, University of California at Davis, Davis, CA, USA)

**Session 11C:** **SCB-North American Section Symposium: Reconciling Conservation Planning and Transportation Planning on a Regional Scale (Salon C)**

*Moderator:* Reed Noss, University of Central Florida/SCB-North American Section

Welcome (Reed Noss, University of Central Florida, USA)

Approach to Integrating Transportation and Conservation Planning: Examples from Florida (Daniel Smith, WTI, Montana State University, USA, and Reed Noss, University of Central Florida, USA)

Effects of Roads and Traffic on Populations of Small Animals: Implications for Transportation Planning (Lenore Fahrig, Carlton University, Canada)

Applications of Local-Scale Research for Planning and Evaluating Measures Designed to Restore Regional Landscape Connectivity (Anthony Clevenger, WTI, Montana State University, USA)

Effects of Roads on Carnivore Behavior and Ecology in Southern California: Movements, Mortality, and Gene Flow. (Seth Riley, R.M. Sauvajot, J.P. Pollinger, E.C. York, S. Ng, and R.K. Wayne; UCLA Department of Ecology and Evolutionary Biology, USA)

**3:00 - 3:30** **Break (Salons B & C)**

**3:30 - 5:00** **CONCURRENT SESSIONS 12A, 12B and 12C**

**Session 12A:** **Poster Session (Salon A)**

**Session 12B:** **Ecological Impacts of Other Transportation Modes (Salon B)**

*Moderator:* Vicki Sharpe, Florida DOT

Kennedy Space Center Launch Pad Bird Abatement and Related Roadkill Abatement (Roland Schlierf, NASA Kennedy Space Center, FL, USA)

Quantifying Risk Associated with Potential Bird-Aircraft Collisions (Laurence Schafer, USDA/APHIS Wildife Services, Olympia, WA, USA)

Trains, Grains and Grizzly Bears: Reducing Wildlife Mortality on Railway Tracks in Banff National Park (Jim Pissot, Defenders of Wildlife Canada, Canmore, Alberta, Canada)

Impacts of Ferry Terminals on Juvenile Salmon Movement along Puget Sound Shorelines (Ronald Thom, PNNL, Sequim, WA, USA)

**Session 12C:** **SCB-North American Section Symposium (Salon C)**

*Moderator:* Reed Noss, University of Central Florida/SCB-North American Section

Bighorn Sheep and Interstate Highways: Using Genetics to Optimize Connectivity Models for Managing the Landscape of the Future (Clinton W. Epps, J.D. Wehausen, V.C. Bleich, S.G. Torres, and J.S. Brashares, University of California at Berkeley, USA)

Eight Reasons Not to Use GIS Analysis for Corridor Design (Paul Beier-presenter; Dan Majka and Wayne Spencer, Northern Arizona University, USA)

Road Ecology in the Southern Rockies - Science, Policy and Outreach (Julia Kintsch, Southern Rockies Ecosystem Project, USA)

**5:00** **Adjourn, Dinner (on own)**

**5:30 - 7:30:** **SCB - North American Chapter Business Meeting (Salon C)**

**Friday, May 25**

**7:30 - 8:30** **Continental Breakfast (Salons B & C Foyer)**

**8:30 - 10:00** **CONCURRENT SESSIONS 13A and 13B**

**Session 13A:** **Integrating Transportation & Conservation Planning (State Case Studies) (Salon A)**
*Moderator:* Gregg Erickson, Caltrans

California's Integrated Approach to Collaborative Conservation in Transportation Planning (Gregg Erickson, Caltrans, Sacramento, CA, USA)

Linking Statewide Connectivity to Highway Mitigation: Taking the Next Step in Linking Colorado's Landscapes (Julia Kintsch, Southern Rockies Ecosystem Project Denver, CO, USA)

Wildlife Connectivity Across Utah's Highways (Paul West, Utah DOT, Salt Lake City, UT, USA)

Patch Occupancy Models and Black Bear Management in the Southeastern Coastal Plain: A Potential Tool? (Jay Clark, University of Tennessee, Knoxville, TN, USA)

**Session 13B:** **Integrating Transportation & Conservation Planning (Habitat Analysis Tools) (Conway)**

*Moderator:* Lynn Malbrough, Arkansas HTD

Use of Habitat Suitability Indices (HSIs) for Evaluating Impacts to, and Assessing Mitigation for, Terrestrial Wildlife Habitats for Transportation Projects
(Rick Black, HDR Engineering, Inc., Salt Lake City, UT, USA)

Is Strategic Environmental Assessment an Effective Tool to Conserve Biodiversity Against Transport Infrastructure Development? (Csaba Varga, BirdLife Hungary, Budapest, Hungary)

Effects of Configuration of Road Networks on Landscape Connectivity
(Jochen A.G. Jaeger, ETH Zurich, Zurich, Switzerland)

Integrating Habitat Fragmentation Analysis Into Transportation Planning Using the Effective Mesh Size Landscape Metric (Evan Girvetz, Road Ecology Center and Graduate Group in Ecology, University of California at Davis, Davis, CA, USA)

**10:00 - 10:30** **Break (Salons B & C Foyer)**

**10:30 - 11:45** **Session 14: Public-Private Partnerships Panel (Salons B & C)**

*Moderator:* David Williams, Vice-President/Senior Program Manager, Carter-Burgess

**11:45 - 12:00** **Session 15: Conference Wrap-Up (Salons B & C)**

*Moderator:* Leroy Irwin, ICOET 2007 Conference Chair; Paul Wagner, Washington State DOT (ICOET 2009 Conference Chair)

**12:00** **Conference Adjourns**

## List of Participants

**Achiron-Frumkin, Tamar**
*Ecological and Environmental Consultant*
Mevasseret-Zion, IL 90805 Israel
972-2-533-2028
Tamar.achiron@gmail.com

**Adamcik, Robert**
*National Wildlife Refuge System*
Falls Church, VA 22043 USA
703-848-0222
adamcikb@pobox.com

**Adams, Cindy**
*Caltrans*
Sacramento, CA 95814 USA
916-653-5157
cindy.adams@dot.ca.gov

**Adkins, Carol**
*Federal Highway Administration*
Washington, DC 20590 USA
202-366-2054
carol.adkins@dot.gov

**Albritton, Jason**
*The Nature Conservancy*
Arlington, VA 22201 USA
703-841-4105
jalbritton@tnc.org

**Alcott, Jason**
*Minnesota DOT*
St. Paul, MN 55155 USA
651-366-3605
Jason.Alcott@dot.state.mn.us

**Alexander, Mark**
*Connecticut DOT*
Newington, CT 06131 USA
860-594-2931
Mark.W.Alexander@po.state.ct.us

**Allen, Brian**
*FHWA-Federal Lands Highway*
Vancouver, WA 98661 USA
360-619-7511
brian.allen@fhwa.dot.gov

**Ament, Robert**
*Western Transportation Institute*
Bozeman, MT 59717 USA
406-994-6423
rament@coe.montana.edu

**Anderson, Russell**
*Maryland State Highway Admin*
Baltimore, MD 21202 USA
410-545-8839
randerson2@sha.state.md.us

**Anderson, Paul**
*USDA Forest Service*
Arlington, VA 22209 USA
703-605-4617
panderson@fs.fed.us

**Andrews, Kimberly**
*Savannah River Ecology Lab, University of Georgia*
Aiken, SC 29802 USA
803-725-0422
andrews@srel.edu

**Arnold, Allison**
*U.S. Fish and Wildlife Service*
Austin, TX 78758 USA
512-490-0057
Allison_arnold@fws.gov

**Ascensao, Fernando**
Lisbon, Portugal
351-96-380-5043
fernandoascensao@yahoo.com

**Bain, Hal**
*ARCADIS*
Raleigh, NC 27607 USA
919-854-1282
hal.bain@arcadis-us.com

**Baldridge, David**
*Arkansas State University*
State University, AR 72467 USA
417-252-0614
david.baldridge@smail.astate.edu

**Bank, Fred**
*Mulkey Engineers and Consultants, Inc.*
Cary, NC 27511 USA
703-472-9616
fbank@mulkeyinc.com

**Banks, Sharon**
*Cascade Sierra Solutions*
Coburg, OR 97408 USA
541-302-0900
sharon@cascadesierrasolutions.org

**Barnum, Sarah**
Concord, NH 03301 USA
603-224-9909
sbarnum@nhaudubon.org

**Barrett, Thomas**
*Mulkey Engineers & Consultants*
Cary, NC 27518 USA
919-851-1912
tbarrett@mulkeyinc.com

**Bayless, Mylea**
*Bat Conservation International*
Austin, TX 78716 USA
512-383-1385
mbayless@batcon.org

**Beardsley, Karen**
*Information Center for the Environment*
Davis, CA 95616 USA
530-752-5678
kbeardsley@ucdavis.edu

**Beck, Judy**
*US EPA*
Chicago, IL 60604 USA
312-353-3849
beck.judy@epa.gov

**Bekker, Hans**
*Ministry of Transport Netherlands*
Delft, 2804 HS Netherlands
0-15-251-8470
hans.bekker@rws.nl

**Belcher, Jeffrey**
Columbia, SC 29201 USA
803-253-3187
jeffrey.belcher@fhwa.dot.gov

**Bellis, Mark**
*Univ. of Mass. at Amherst*
Whitingham, VT 05361 USA
413-519-7908
mbellis@forwild.umass.edu

**Benouar, Katie**
*UC Davis Road Ecology Center*
Sacramento, CA 95864 USA
530-752-3608
kbbenouar@ucdavis.edu

**Berry, Alison**
*University of California*
Davis, CA 95616 USA
530-752-7683
amberry@ucdavis.edu

**Berry, K. Lynn**
*Federal Highway Administration*
Atlanta, GA 30303 USA
404-562-3692
klynn.berry@fhwa.dot.gov

**Bible, Shawn**
*TDOT*
Nashville, TN 37243 USA
615-532-3488
Shawn.A.Bible@state.tn.us

**Bielsa, Sabine**
*Ministry of Transport*
Bagneux, RP 9225 France
0-14-611-3049
sabine.bielsa@equipement.gouv.fr

**Biron, Daniel**
*CT DEP Inland Water Resources*
Hartford, CT 06106 USA
860-424-3892
dan.biron@po.state.ct.us

**Bissonette, John**
*USGS Utah Cooperative Fish and Wildlife Research Unit*
Logan, UT 84322-5290 USA
435-797-2511
john.bissonette@usu.edu

**Black, Rick**
*HDR Engineering, Inc.*
Salt Lake City, UT 84107 USA
801-743-7831
rick.black@hdrinc.com

**Blankenhorn, Randall S.**
*Chicago Metropolitan Agency for Planning*
Chicago, IL 60606 USA
312-386-8600
rblankenhorn@cmap.illinois.gov

**Bonaker, Paige**
Missoula, MT 59801 USA
970-620-0079

**Boszor, Brian**
*Indiana Department Of Natural Resources*
West Lafayette, IN 47906 USA
765-567-2152
bboszor@dnr.in.gov

**Bowden, Alison**
*The Nature Conservancy-MA Chapter*
Boston, MA 02114 USA
617-227-7017
abowden@tnc.org

**Briggs, Dionne**
*US Fish and wildlife Service*
Laurel, MD 20724 USA
240-882-0401
dionne_briggs@fws.gov

**Broadwell, Ann**
*FDOT-District 4*
Fort Lauderdale, FL 33309 USA
954-777-4325
ann.broadwell@dot.state.fl.us

**Brooks, Rhonda**
*Washington State Department of Transportation*
Olympia, WA 98504-7372 USA
360-705-7945
Brookrh@wsdot.wa.gov

**Brown, Michelle**
*The Nature Conservancy*
Keene Valley, NY 12943 USA
518-576-2082
michelle_brown@tnc.org

**Brown, Steve**
*North Carolina Department of Transportation*
Raleigh, NC 27699-1548 USA
919-733-7844
slbrown@dot.state.nc.us

**Bruton, V. Charles**
*Mulkey Engineers and Consultants*
Cary, NC 27518 USA
919-951-1912
cbruton@mulkeyinc.com

**Bryson, David**
*ElectroBraid Fence, Inc.*
Halifax, NS B3H 341 Canada
902-422-6678
dbryson@electrobraid.com

**Buchanan, Ian**
*The Regional Municipality of York*
Newmarket, ON L3Y 7E2 Canada
905-830-4444
ian.buchanan@york.ca

**Bump, Cameron**
*Wisconsin Department of Natural Resources*
Madison, WI 53707-7921 USA
608-267-9742
Cameron.Bump@Wisconsin.gov

**Buncick, Marella**
*USFWS*
Asheville, NC 28801 USA
828-258-3939
marella_buncick@fws.gov

**Burak, Greg**
*Idaho Fish and Game*
Boise, ID 83707 USA
208-287-2712
gburak@idfg.idaho.gov

**Burbank, Cynthia**
*Parsons-Brinckerhoff*
Washington, DC 20005 USA
202-661-9262
burbank@pbworld.com

**Burch, Theodore**
*FHWA-MT Division*
Helena, MT 59601 USA
406-449-5302
theodore.burch@fhwa.dot.gov

**Burns, Joseph**
*U.S. Fish and Wildlife Service*
Arlington, VA 22203 USA
703-358-1712
joseph_burns@fws.gov

**Burroughs, Anne**
*North Carolina Department of Transportation*
Raleigh, NC 27699-1598 USA
919-715-1336
amburroughs@dot.state.nc.us

**Cain, Ed**
*Parsons*
Memphis, TN 38115 USA
901-248-6190
robert.mcivor@parsons.com

**Campbell, Ann**
*USEPA Region III*
Philadelphia, PA 19103 USA
202-657-3117
campbell.ann@epa.gov

**Carey, Marion**
*WSDOT*
Olympia, WA 98504-3771 USA
360-705-7404
careym@wsdot.wa.gov

**Carlson, Lars**
*Jacobs Engineering Group Inc*
Boston, MA 02108 USA
617-994-4354
lars.carlson@jacobs.com

**Carlson, David**
*FHWA-HQ*
Washiington, DC  20590  USA
202-366-6263
David.Carlson@dot.gov

**Caron, Maya**
*Stantec Consulting Ltd.*
Hamilton, ON  L8W 3N9  Canada
905-381-3218
maya.caron@stantec.com

**Carson, Bob**
*Mason, Bruce & Girard*
Portland, OR  97205  USA
503-224-3445
bcarson@masonbruce.com

**Casey, Peggy**
*FHWA*
Jefferson City, MO  65109  USA
573-638-2620
peggy.casey@fhwa.dot.gov

**Cashin, Charlotte**
*Caltrans*
Oakland, CA  94623-0660  USA
501-286-4879
charlotte.cashin@dot.ca.gov

**Caster, Jeff**
*Florida Department of Transportation*
Tallahassee, FL  32399  USA
850-414-5267
Jeff.Caster@dot.state.fl.us

**Cazenas, Patricia**
*Federal Highway Adminstration*
Washington, DC  20590  USA
202-366-4085
patricia.cazenas@dot.gov

**Chambers, Marla**
*NCWRC*
Oakboro, NC  28129  USA
704-984-1070
marla.chambers@ctc.net

**Chang, Yi-Wen**
*Public Construction Commision, Executive Yuan*
Taipei, TW  11010  Taiwan
2-8789-7805
ewen@mail.pcc.gov.tw

**Charry, Barbara**
*Maine Audubon*
Falmouth, ME  04105  USA
207-781-2330
bcharry@maineaudubon.org

**Choi, Myungsun**
Namwon, CH  590-756  South Korea
17-615-2270
gumiran3@snu.ac.kr

**Choi, Tae young**
Chollabukdo, KR 590-756 South Korea
gumiran3@snu.ac.kr

**Christensen, Robert**
*NDDOT*
Bismarck, ND  58505  USA
701-328-4539
rchriste@nd.gov

**Clark, Jay**
*University of Tennessee*
Hazel Green, AL  35750  USA
931-308-7570
jayclarkmusic@bellsouth.net

**Clark, Richard**
*USDA-Forest Service*
Cheyenne, WY  82002  USA
307-777-3697
richardclark@fs.fed.us

**Clevenger, Anthony**
*Western Transportation Institute*
Bozeman, MT  59717  USA
403 760 1371
tony.clevenger@pc.gc.ca

**Collier, Linda**
*ITRE/NC State University*
Raleigh, NC  27695-8601  USA
919-515-7990
linda_collier@ncsu.edu

**Compton, Karen**
*US Forest Service*
Asheville, NC  28801  USA
828-257-4230
kcompton@fs.fed.us

**Connally, Wendy**
*PBS&J*
Austin, TX  78730  USA
512-327-6840
waconnally@pbsj.com

**Corey, Kennon**
*U.S. Fish and Wildlife Service*
Carlsbad, CA  92011  USA
760-431-9440
emily_reed@fws.gov

**Cote, Don**
*FHWA Resource Center*
Lakewood, CO  80228  USA
720-963-3210
don.cote@fhwa.dot.gov

**Cox, David**
*NC Wildlife Resources Commission*
Creedmoor, NC  27522  USA
919-628-9886
david.cox@ncwildlife.org

**Cramer, Patricia**
*USGS-Utah Coop Unit - Utah State University*
Logan, UT  84322-5290  USA
435.797-1289
pcramer@ccu.usu.edu

**Crawford, Tom**
*Praxis Northwest, LLC*
Olympia, WA  98507-2578  USA
360-357-6134
tom@praxisnw.com

**Crump, Michael**
*USDA Forest Service*
Russellville, AR  72801  USA
479-964-7053
mcrump@fs.fed.us

**Culp, Michael**
*Federal Highway Administration*
Washington, DC  20009  USA
2023669229
michael.culp@dot.gov

**Cunill, Bento**
*Florida Dept. of Transportation*
Tallahassee, FL  32399  USA
850-414-5249
Buddy.Cunill@dot.state.fl.us

**DalPorto, Gary**
*FHWA - Arkansas*
Little Rock, AR  72201  USA
501-324-6441
gary.dalporto@fhwa.dot.gov

**Davidson, Deborah**
*Wilburforce Foundation*
Bozeman, MT  59771  USA
406-586-9796
deb@wilburforce.org

**Davis, Leslie**
*Engineering, Compliance & Construction, Inc.*
Little Rock, AR  72205  USA
501-663-8247
ldavis@ecci.com

**Davis, Michael**
*Carter & Burgess, Inc.*
Oakland, CA  94612  USA
510-457-0027
mike.davis@c-b.com

**Davis, Gary**
*Washington State Department of Transportation*
Seattle, WA  98133-9710  USA
206-440-4533
davisg@wsdot.wa.gov

**Dawkins, Janet**
*EMS Scientist, Engineers, Planners, Inc*
Alamonte Springs, FL  32701  USA
407-260-0883
jdawkins@ems-sep.com

**DeCoursey, Brigid**
*U.S. Department on Transportation*
Washington, DC  20590  USA
202-366-8914
brigid.decoursey@dot.gov

**DeLamar, Nancy**
*The Nature Conservancy*
Little Rock, AR  72205  USA
501-614-5070
ndelamar@tnc.org

**DellaSala, Dominick**
*National Center for Conservation Science & Policy*
Ashland, OR  97520  USA
541-482-4459
dominick@nccsp.org

**Denisoff, Craig**
*Westervelt Ecological Services*
Sacramento, CA  95834  USA
916-646-3644
cdenisoff@westervelt.com

**Dietz, Matthew**
*The Wilderness Society*
San Francisco, CA  94110  USA
415-710-7064
matt_dietz@tws.org

**Dillard, Lester**
*University of Wisconsin - Stevens Point*
Stevens Point, WI  54481  USA
920-257-7175
ldillard@uwsp.edu

**Dodd, Norris**
*Arizona Game and Fish Department; Research Branch*
Pinetop, AZ  85935  USA
928.368.3017
doddnbenda@cybertrails.com

**Dolan, Lisa**
*University  College Cork*
Cork City, Mu  00000  Ireland
87-957-8356
ecolandscapedesign@eircom.net

**Donaldson, Bridget**
*Virginia Transportation Research Council*
Charlottesville, VA  22903  USA
434-293-1922
bridget.donaldson@vdot.virginia.gov

**Doupe, Chris**
*Canadian Federal Gov't*
Edmonton, AB  T5J 1S6  Canada
(780) 497-3868
chris.doupe@pwgsc.gc.ca

**Durbin, Dennis**
*FHWA*
Washington, DC  20590  USA
202-366-2066
Dennis.Durbin@fhwa.dot.gov

**Earsom, Stephen**
*Federal Highway Administration*
Raleigh, NC  27601  USA
919.856.4354
steve.earsom@dot.gov

**Easley, Mark**
*URS Corporation Southern*
Tampa, FL  33607  USA
(813 ) 636-2113
mark_easley@urscorp.com

**Edmonds-Hess, Ivy**
*Parsons Brinckerhoff (PB)*
San Francisco, CA  94587  USA
415-243-4724
edmondshess@pbworld.com

**Effinger, Laurie**
*Oklahoma Dept. of Transportation*
Oklahoma City, OK  73105  USA
4055212535
leffinger@odot.org

**Eilerts, Bruce**
*Arizona Department of Transportation*
Phoenix, AZ  85007  USA
602-712-7398
beilerts@azdot.gov

**Elliott, David**
*California State University, Fullerton*
La Habra, CA  90631  USA
562-697-5807
delliott@fullcoll.edu

**Elmiger, Christof**
*Kaden und Partner AG*
Zurich,   8003  Switzerland
01141444511485
christof.elmiger@gmx.ch

**Eoloff, Nicholas**
*Minneapolis Parks & Recreation*
Minneapolis, MN  55411  USA
612-230-6465
neoloff@minneapolisparks.org

**Epps, Clinton**
*University of California, Berkeley*
Berkeley, CA  94720-3114  USA
510-643-3918
buzzard@nature.berkeley.edu

**Erickson, Gregg**
*Caltrans*
Sacramento, CA  95817  USA
(9616) 654-6296
gregg.erickson@dot.ca.gov

**Ernst, Richard**
*U.S. Fish & Wildlife Service*
Soldotna, AK  99669  USA
907-262-7021
rick_ernst@fws.gov

**Fahrig, Lenore**
Ottawa, ON  K1S 5B6  Canada
613-520-2600
lenore_fahrig@carleton.ca

**Feinberg, Jesse**
*Defenders of Wildlife*
Washington, DC  20036  USA
202-772-3219
jfeinberg@defenders.org

**Feld, David**
*GeesePeace*
Falls Chuch, VA  22041  Uited States
703 608 2274
davidfeld@geesepeace.org

**Felder, David**
*USFWS*
Jackson, ms  39211  USA
6013211139
david_felder@fws.gov

**Finch, Virginia**
*Federal Highway Administration*
Washington, DC 20590 USA
202-366-4258
Ginny.Finch@dot.gov

**Finton, Andy**
*The Nature Conservancy*
Boston, MA 02114 USA
617-227-7017
afinton@tnc.org

**Fitzgerald, John**
*Society for Conservation Biology*
Arlington, VA 22203 USA
703-276-2384
jfitzgerald@conbio.org

**Fleming, Elizabeth**
*Defenders of Wildlife*
St. Petersburg, FL 33701 USA
727 823 3888
efleming@defenders.org

**Foresman, Kerry**
*The University of Montana*
Missoula, MT 59812 USA
406-243-4492
foresman@mso.umt.edu

**Forman, Richard**
*Harvard University*
Cambridge, MA 02138 USA
617-495-1930
rforman@gsd.harvard.edu

**Fuller, Shelby**
*Federal Highway Administration*
Springfield, IL 62703 USA
217-492-4625
Matt.Fuller@fhwa.dot.gov

**Gagnon, Jeff**
*Arizona Game and Fish Department*
Flagstaff, AZ 86004 USA
928-522-8164
jeff_gagnon@yahoo.com

**Gamble, David**
*FHWA Resource Center*
Baltimore, MD 21201 USA
410-962-0982
dave.gamble@dot.gov

**Garvey-Darda, Patricia**
*U.S. Forest Service*
Cle Elum, WA 98922 USA
(509)852-1029
pgarveydarda@fs.fed.us

**Gentry, Benjamin**
*USDA Forest Service*
Paris, AR 72855 USA
479-963-3076
bgentry@fs.fed.us

**Gilbert, Terry**
*URS Corporation*
Tallahassee, FL 32317 USA
(850) 402-6311
terry_gilbert@urscorp.com

**Gingras, Glenn**
*Vermont Agency of Transportation*
Montpelier, VT 05633-5001 USA
802-828-3979
glenn.gingras@state.vt.us

**Girvetz, Evan**
*University of California, Davis*
Davis, CA 95616 USA
530-219-8442
ehgirvetz@ucdavis.edu

**Goodmen, Catherine**
*New Hampshire Department of Transportation*
Concord, NH 03302 USA
603-271-6781
cgoodmen@dot.state.nh.us

**Granillo, Kathleen**
*US Fish & Wildlife Service*
Albuquerque, NM 87103 USA
505-248-6818
Kathy_Granillo@fws.gov

**Gray, Mary**
*FHWA*
Olympia, WA 98501 USA
360-753-9487
mary.gray@fhwa.dot.gov

**Grettenberger, John**
*US Fish & Wildlife Service*
Lacey, WA 98503 USA
360-753-6044
john_grettenberger@fws.gov

**Griep, Margaret**
*USDA Forest Service*
Tallahassee, FL 32303 USA
850-523-8567
mgriep@fs.fed.us

**Grilo, Clara**
*Faculdade de Ciencias de Lisboa*
Lisboa, 1749 Portugal
966079307
claragrilo@hotmail.com

**Gullo, Andrea**
*Puente Hills Landfill Native Habitat Preservation Authority*
Whittier, CA 90602 USA
562-945-9003
agullo@habitatauthority.org

**Gundersen, Heather**
*Columbia River Crossing Project-ODOT*
Vancouver, WA 98660 USA
360-816-2199
gundersen@columbiarivercrossing.org

**Gunson, Kari**
Baldwinsville, NY 13027 USA
315-374-3760
kegunson@syr.edu

**Haddad, Nick**
*North Carolina State University*
Raleigh, NC 27695 USA
919-515-4588
nick_haddad@ncsu.edu

**Hagood, Susan**
*The Humane Society of the U.S.*
Washington, DC 20037 USA
301 258-3149
shagood@hsus.org

**Harris, Stephen**
*RPM Ecosystems*
Dryden, NY 13053 USA
607-844-9590 x225
slh@rpmecosystems.com

**Harris, John**
*Arkansas Highway & Transportation Department*
Little Rock, AR 72203 USA
501 569-2281
john.harris@arkansashighways.com

**Hart, Tom**
*Wyoming Department of Transportation*
Cheyenne, WY 82009 USA
307-777-4495
thomas.hart@dot.state.wy.us

**Hatchitt, James**
*ARMASI Inc.*
Gainesville, Fl 32608 USA
352-333-8393
jim@armasi.com

**Hazlehurst, Tim**
*Worens Group*
Seattle, WA 98109 USA
(330) 414-1995
thazlehurst@worensgroup.com

**Heilman, Jeff**
*Parametrix, Inc.*
Portland, OR 97232 USA
5037364806
jheilman@parametrix.com

**Heller, Dave**
*USDA Forest Service*
Portland, OR 97204 USA
503-808-2994
dheller@fs.fed.us

**Hershfeld, Wendy**
*Scheda Ecological Associates*
Sarasota, FL 34240 USA
(941) 544-8848
whershfeld@scheda.com

**Holdsworth, Andrew**
*Minnesota Chapter SCB*
Minneapolis, MN 55406 USA
612-724-8110
arholdsworth@gmail.com

**Howie, Shara**
*NatureServe*
Boulder, CO 80303 USA
703-797-4811
shara_howie@natureserve.org

**Huijser, Marcel**
*Western Transportation Institute - MSU*
Bozeman, MT 59717-4250 USA
406-543-2377
mhuijser@coe.montana.edu

**Hull, Alex**
*Inwood Consulting Engineers, Inc.*
Oviedo, FL 32765 USA
407-971-8850
ahull@inwoodinc.com

**Hunt, Harold**
*CalTrans*
Sacramento, CA 95814 USA
(916)324-2903
harold_hunt@dot.ca.gov

**Inlander, Ethan**
*The Nature Conservancy*
Fayetteville, AR 72701 USA
479-973-9110
einlander@tnc.org

**Irving, Daraleigh**
*Ministry of Transportation*
London, ON N6E 1L3 Canada
519-873-4820
daraleigh.irving@ontario.ca

**Irwin, Leroy**
*Mulkey Engineering and Consultants*
Tallahassee, FL 32308-0507 USA
8503855843
irwinler@comcast.net

**Jackson, Scott**
*U.S. Fish & Wildlife Service*
Helena, MT 59601 USA
406-449-5225
scott_jackson@fws.gov

**Jackson, William**
*Reynolds, Smith & Hills, Inc*
Austin, TX 78752 USA
512-382-2024
bill.jackson@rsandh.com

**Jackson, Scott**
University of Massachusetts Amherst
Amherst, MA 01003 USA
(413) 545-4743
sjackson@umext.umass.edu

**Jacobs, Tom**
*Mid-America Regional Council*
Kansas City, MO 64105 USA
816-701-8352
Tjacobs@marc.org

**Jacobson, Sandra**
*USDA Forest Service, PSW Research Station*
Arcata, CA 95521 USA
503-453-0593
sjacobson@fs.fed.us

**Jaeger, Jochen**
*ETH Zurich, Dep. Envir. Sciences*
Zurich, ZH CH-8092 Switzerland
44-6320826
jochen.jaeger@env.ethz.ch

**Johnson, Terry**
*UDOT*
Salt Lake City, UT 84114-8450 USA
(801)965-4598
terryjohnson@utah.gov

**Johnson, Brian**
*NDOR*
Lincoln, NE 68509 USA
402-479-3990
bjohnson@dor.state.ne.us

**Johnston, Ann**
*Bonterra Consulting*
Costa Mesa, CA 92626 USA
714-444-9199
ajohnston@bonterraconsulting.com

**Jones, Elizabeth**
*NC State University*
Raleigh, NC 27695 USA
919-515-7587
erjones@ncsu.edu

**Jordan, Gary**
*U.S. Fish and Wildlife Service*
Raleigh, NC 27636 USA
919-856-4520
gary_jordan@fws.gov

**Kathman, R**
*TN Dept of Transportation*
Nashville, TN 37243 USA
615 253-2472
R.Deedee.Kathman@state.tn.us

**Khaled, Maiser**
*FHWA*
Sacramento, CA 95814 USA
916-498-5020
maiser.khaled@fhwa.dot.gov

**Kintsch, Julia**
*Southern Rockies Ecosystem Project*
Denver, CO 80202 USA
303-454-3344
julia@restoretherockies.org

**Knapp, Keith**
*Texas Transportation Institute*
Bryan, TX 77802 USA
979-845-5686
k-knapp@tamu.edu

**Kociolek, Angela**
*Western Transportation Institute*
Bozeman, MT 59717-4250 USA
406 994 6308
angela.kociolek@coe.montana.edu

**Krannitz, Pam**
*Environment Canada*
Delta, BC V4K 3N2 Canada
604-940-4676
pam.krannitz@ec.gc.ca

**Krebs, Michael**
*University of Montana*
Missoula, MT 59812 USA
406-243-4492
michael.krebs@mso.umt.edu

**Kruidering, Anne Martine**
*ARCADIS*
Apeldoorn, 7300 AR Netherlands
06-27060654
a.m.kruidering@ardadis.nl

**Kucera, Charlotte**
*NOAA Fisheries*
Portland, OR 97232 USA
503-231-6848
charlotte.kucera@noaa.gov

**Kurgan, Kate**
*AASHTO*
Washington, DC 20001 USA
2026243635
kkurgan@aashto.org

**Landers, Lisa**
*EFLHD/FHWA/DOT*
Sterling, VA 20166 USA
512-536-5944
lisa.landers@fhwa.dot.gov

**Langen, Tom**
*Clarkson University*
Potsdam, NY 13699-5805 USA
315 268 7933
tlangen@clarkson.edu

**LaPierre, Anne**
*ITRE/CTE*
Raleigh, NC 27695-8601 USA
919-515-8031
anne_lapierre@ncsu.edu

**LaRue, Tricia**
*PBS&J*
Austin, TX 78730-5091 USA
512-342-3385
rllarue@pbsj.com

**Leblanc, Yves**
*Tecsult Inc.*
Quebec City, QC G1P 2J9 Canada
418-871-2444
yves.leblanc@tecsult.com

**Lee, Nancy**
*U.S. Fish and Wildlife Service*
Arlington, VA 22203 USA
703.358.2183
nancy_lee@fws.gov

**Len, Broberg**
*Environmental Studies, U. of Montana*
Missoula, MT 59812 USA
406-243-5209
len.broberg@umontana.edu

**Levin, Nancy**
*EPA*
San Francisco, CA 94105 USA
415-972-3848
levin.nancy@epa.gov

**Levy, Alexander**
*ARCADIS*
Atlanta, GA 30339 USA
(770) 431-8666
alex.levy@arcadis-us.com

**Lin, Shyh-Chyang**
*National Kinmen Institute of Technology*
Jinning, 892 Taiwan
0919786750
sclin1116@yahoo.com

**Linkous, Thomas**
Westerville, OH 43082-9019 USA
614 891-7997
mlinkous@insight.rr.com

**Looney, Randal**
*FHWA Arkansas Division Office*
Little Rock, AR 72201-3298 USA
501-324-6430
randal.looney@fhwa.dot.gov

**MacDonald, Doug**
*Washington State Dept. of Transportation*
Olympia, WA 98504-7316 USA
360-705-7054
macdond@wsdot.wa.gov

**Maguire, Christine**
*ODOT Geo-Environmental*
Salem, OR 97301 USA
503-986-3385
christine.maguire@odot.state.or.us

**Majerus, Kimberly**
*FHWA-RC*
Olympia Fields, IL 60461 USA
708-283-4346
kimberly.majerus@dot.gov

**Malbrough, Lynn**
*Arkansas Highway and Transportation Department*
Little Rock, AR 72203 USA
501.569.2281
Lynn.malbrough@arkansashighways.com

**Marshall, Kristine**
*David Evans and Associates, Inc*
Portland, OR 97201 USA
503.223.6663
kxm@deainc.com

**Martin, James**
*CTE*
Raleigh, NC 27695-8601 USA
919-515-8620
james_martin@ncsu.edu

**Mart¡n, Beatriz**
*Brown Bear Foundation*
Santander, Cantabria, 39007 Spain
+34 942234900
osopardo@grn.es

**Masching, Amy**
*Denver Zoological Foundation*
Denver, CO 80205 USA
303-376-4935
amasching@denverzoo.org

**McAbee, William**
*Michael Baker Jr., Inc*
Jackson, MS 39232 USA
601-932-8895
wmcabee@mbakercorp.com

**McDermott, Kathryn**
*CTE, NC State University*
Raleigh, NC 27695-8601 USA
919.515.8034
kpm@ncsu.edu

**McDougal, Leigh**
*USDA Forest Service*
Atlanta, GA 30309 USA
404-347-4082
jmcdougal@fs.fed.us

**McGowan, Lawrence**
*US Fish and Wildlife Service*
CAMBRIDGE, MD 21613 USA
410-228-2692
Larry_Mcgowan@fws.gov

**McLean, Johnny**
*U.S. Army Corps of Engineers*
Little Rock, AR 72201 USA
501-324-5296
johnny.L.McLean@usace.army.mil

**McPeake, Rebecca**
*Agricultural Cooperative Extension Service*
Little Rock, AR 72203 USA
501-671-2329
rmcpeake@uaex.edu

**Menke, Kurt**
*Bird's Eye View*
Albuquerque, NM 87106 USA
505-362-1776
kurt@birdseyeviewgis.com

**Mensah, Benjamin**
*Tamale Polytechnic*
Tamale, AC 00233 Ghana
00233244807358
gariba1983@yahoo.com

**Merrow, Jed**
*McFarland-Johnson*
Concord, NH 03301 USA
603-225-2978
jmerrow@mjinc.com

**Michalak, Julia**
*Defenders of Wildlife*
Washington, dc 20036 USA
(202) 772 3247
jmichalak@defenders.org

**Mittiga, Mary**
*U.S. Fish and Wildlife Service*
Panama City, FL 32405 USA
850-769-0552
mary_mittiga@fws.gov

**Moody, Kevin**
*FHWA - RC (ENV TST)*
Atlanta, GA 30303 USA
4048956227
kevin.moody@dot.gov

**Morton, Chuck**
*CALTRANS/UC Davis*
Oakland, CA 94623-0660 USA
510-286-5016
chuck.morton@dot.CA.gov

**Moulta Ali, Abu**
*US EPA*
Washington, DC 20460 USA
202-566-1068
moulta-ali.abu@epa.gov

**Muldrew, Kevin**
*EMS Scientist, Engineers, Planners, Inc.*
Altamounts, FL 32701 USA
407-260-0883
kmuldrew@ems-sep.com

**Murray, Eugene**
*CTE*
Raleigh, NC 27695-8601 USA
919-515-8037
eugene_murray@ncsu.edu

**Myers, Jordan**
*ARCADIS*
Atlanta, GA 30339 USA
770-431-8666
jordan.myers@arcadis-us.com

**Nagle, Fiona**
*Society for Conservation Biology*
Montrose, CA 91021 USA
310-826-2531
finagle@umn.edu

**Neil, Jason**
*HDR Engineering, Inc.*
Salem, OR 97301 USA
503-587-2939
Jason.Neil@hdrinc.com

**Neils, Aletris**
*University of Florida*
Gainesville, FL 32608 USA
602-717-2406
aletris_neils@yahoo.com

**Nelson, Debra**
*NYSDOT*
Albany, NY 12232 USA
518-485-5479
dnelson@dot.state.ny.us

**Nordhaugen, Siobhan**
*Arizona Department of Transportation*
Phoenix, AZ 85007 USA
602-712-6166
snordhaugen@azdot.gov

**Noss, Reed**
*University of Central Florida*
Orlando, FL 32725 USA
407-823-0975
rnoss@mail.ucf.edu

**Nyarirangwe, Maxwell**
*Ethiopian Civil Service College*
Addis Ababa, Et 0251 Ethiopia
0251-116462343
mnyarirang@yahoo.com

**Okeowo, Michael**
*University of Ibadan*
Ibadan, oy 23402 Nigeria
234-8028624658
michfrat@yahoo.com

**O'Quinn, Byron J.**
*Arcadis G&M, Inc.*
Raleigh, NC 27607 USA
919-854-1282
boquinn@arcadis-us.com

**O'Reilly, Mary**
*NYS DOT*
Binghamton, NY 13901 USA
607-721-8138
moreilly@dot.state.ny.us

**Orndorff, Stephanie**
*The Nature Conservancy*
Harrisburg, PA 17110 USA
717-232-6001
sorndorff@tnc.org

**Ortega, Brock**
*Dudek*
Encinitas, CA 92024 USA
760-942-5147
bortega@dudek.com

**Otto, Sandra**
*FHWA - Arkansas*
Little Rock, AR 72205 USA
501-324-5625
Sandra.Otto@DOT.gov

**Pafko, Frank**
*Mn Department of Transportation*
St. Paul, MN 55155 USA
651/366-3602
Frank.Pafko@dot.state.mn.us

**Parker, Israel**
*Texas A&M University*
Mesquite, TX 75149 USA
979-739-0679
iparker@tamu.edu

**Paul, Kylie**
*University of Montana*
MISSOULA, MT 59802 USA
612-910-9248
skylie101@gmail.com

**Peck, Andrew**
*ASU Aquatic Ecology Lab*
Jonesboro, AR 72401 USA
870-243-0095
andrew.peck@smail.astate.edu

**Pettigrew, Tom**
*Northern Region, USDA Forest Service*
Missoula, MT 59807 USA
406-329-3175
tpettigrew@fs.fed.us

**Pettler, Amy**
*Caltrans*
Sacramento, CA 95816 USA
9166518166
Amy_Pettler@dot.ca.gov

**Pierpont, Laurel**
*NCSU*
Raleigh, NC 27608 USA
9044465025
laurel.pierpont@gmail.com

**Pissot, Jim**
*Defenders of Wildlife Canada*
Canmore, AB T1W 3H9 Canada
403-678-0016
jpissot@defenders.org

**Poole, Keith**
*Indiana Dept. of Natural Resources*
Peru, IN 46970 USA
765 473-9324
kpoole@dnr.IN.gov

**Powers, Kathryn**
*Society for Conservation Biology*
Arlington, VA 22203 USA
7032762384
kpm@conbio.org

**Proudfoot, Darlene**
*Ministry of Transportation Ontario*
Toronto, On M3M1J8 Canada
416-235-4715
Darlene.Proudfoot@ontario.ca

**Puig, Jordi**
*University of Navarra*
Pamplona, NA E-31080 Spain
948 425 600
jpbaguer@unav.es

**Puky, Mikl¢s**
*Hungarian Danube Research Station*
G"d, HU 2131 Hungary
27345023
h7949puk@ella.hu

**Reed, Michael**
*Tufts University*
Medford, MA 02155 USA
617-627-3544
michael.reed@tufts.edu

**Register, Martha**
*ARCADIS*
Raleigh, NC 27607 USA
919/854-1282
martha.register@arcadis-us.com

**Richards, Shelley**
*HDR Engineering, Inc.*
Salem, OR 97301 USA
503-587-2900
shelley.richards@hdrinc.com

**Richards, Christina**
*TN Dept. of Transportation*
Nashville, TN 37243 USA
615 253-8690
Christina.Richards@state.tn.us

**Richards, Benjamin**
*TN Dept. of Transportation*
Nashville, TN 37243 USA
615 532-3880
b.m.richards@state.tn.us

**Riley, Seth**
*National Park Service*
Thousand Oaks, CA 91360 USA
805-370-2358
seth_riley@nps.gov

**Roaza, Ruth**
*URS*
Tallahassee, FL 32317 USA
850-574-3197
ruth_roaza@urscorp.com

**Roeder, Bryan**
*Colorado Dept of Transportation*
Colorado Springs, CO 80904 USA
719-633-5793
bryan.roeder@dot.state.co.us

**Rondinella, Mary Ann**
*Federal Highway Administration*
Lakewood, CO 80228 USA
(720) 963-3207
MaryAnn.Rondinella@fhwa.dot.gov

**Ruediger, Robert**
*Bureau of Land Management*
Salem, OR 97306 USA
503-375-5608
bob_ruediger@blm.gov

**Ruediger, William**
*Wildlife Consulting Resources*
Missoula, MT 59802 USA
406-721-4868
wildbill@montana.com

**Ruman, Laura**
*Missouri Department of Transportation*
Jefferson City, MO 65102 USA
573-526-5647
Laura.Ruman@modot.mo.gov

**Rydene, David**
*National Marine Fisheries Service*
St. Petersburg, FL 33701 USA
727-824-5379
David.Rydene@noaa.gov

**Sanders, Scott**
*FL Fish and Wildlife Conservation Commission*
Tallahassee, FL 32399 USA
850 488-3831
scott.sanders@MYFWC.com

**Sawaya, Michael**
*Montana State University*
Bozeman, MT 59715 USA
406-223-2425
mikesawaya@hotmail.com

**Schafer, Laurence**
*USDA Wildlife Services*
Olympia, WA 98502 USA
360.753.9884
laurence.m.schafer@aphis.usda.gov

**Schlesinger, Matthew**
*New York Natural Heritage Program*
Albany, NY 12233-4757 USA
518-402-8939
mdschles@gw.dec.state.ny.us

**Schlierf, Roland**
*Constellation Project*
Kennedy Space Center, FL 32899-0001 USA
321-867-5827
Roland.Schlierf-1@nasa.gov

**Schmidt, Paul**
*Reynolds, Smith & Hills*
Jacksonville, FL 32256 USA
904-256-2258
paul.schmidt@rsandh.com

**Schue, Keith**
*The Nature Conservancy*
Altamonte Springs, FL 32714 USA
407-448-0874
kschue@tnc.org

**Schwaab, Karrie**
*USFWS - Rachel Carson NWR*
Wells, ME 04090 USA
207-646-9226
karrie_schwaab@fws.gov

**Secord, David**
*Wilburforce Foundation*
Seattle, WA 98103 USA
206-632-1293
dave@wilburforce.org

**Servheen, Christopher**
*U.S. Fish and Wildlife Service*
Missoula, MT 59812 USA
406-243-4903
chris_servheen@fws.gov

**Sharma, Ramesh**
*H.N.B. Garhwal University*
Srinagar-Garhwal, UA 246174 India
1370-267740
drrameshcsharma@yahoo.com

**Sharpe, Vicki**
*Florida Department of Transportation*
Tallahassee, FL 32399 USA
850-414-5249
Vicki.Sharpe@dot.state.fl.us

**Shipley, Holly**
*KCI Technologies, Inc.*
Hunt Valley, MD 21030 USA
410-527-4414
hshipley@kci.com

**Shirley, Michael**
*AZTEC Engineering*
Phoenix, AZ 85008-4505 USA
602-458-9288
mshirley@aztec.us

**Sielecki, Leonard**
*BC Ministry of Transportation*
Victoria, BC V8W 9T% Canada
250-356-2255

**Singh, Sumita**
*University of Central Florida*
Deltona, FL 32725 USA
386-575-0776
ssingh@mail.ucf.edu

**Slesar, Chris**
*Vermont Agency of Transportation*
Montpelier, VT 05633-5001 USA
802-828-5743
chris.slesar@state.vt.us

**Sloppy, Mark**
*Iowa Department of Transportation*
Ames, IA 50010 USA
515-239-1225
mark.sloppy@dot.iowa.gov

**Slown, John**
*U.S. Fish and Wildlife Service*
Albuquerque, NM 87103 USA
505-248-7458
john_slown@fws.gov

**Smith, Brian**
*FHWA - Resource Center*
Olympia Fields, IL 60461 USA
708-283-3553
brian.smith@fhwa.dot.gov

**Snopek, Mark**
*Iowa Department of Transportation*
Ames, IA 50010 USA
515-239-1225
mark.snopek@dot.iowa.gov

**Spooner, Peter**
*Charles Sturt University*
Albury, NSW, 2640 Australia
02 6051 9620
pspooner@csu.edu.au

**Standage, Richard**
*USDA Forest Service*
Hot Springs, AR 71902 USA
5013215247
rstandage@fs.fed.us

**Stein, Bruce**
*NatureServe*
Arlington, VA 22209 USA
703-908-1830
bruce_stein@natureserve.org

**Stellini, Joanne**
*US Fish & Wildlife Service*
Lacey, WA 98503 USA
360-753-4323
joanne_stellini@fws.gov

**Stoermer, Stephanie**
*FHWA*
Lakewood, CO 80228 USA
720/963-3218
Stephanie.Stoermer@fhwa.dot.gov

**Strong, Murray**
*Stahly Engineering*
Helena, MT 59601 USA
406-442-8594
mstrong@seaeng.com

**Sullivan, Natina**
*The Nature Conservancy*
Tallahassee, FL 32301 USA
850-251-9407
tina_sullivan@tnc.org

**Sullivan, James D**
*FHWA Resource Center*
Atlanta, GA 30303 USA
404-562-3669
david.sullivan@fhwa.dot.gov

**Swanson, Sherri**
*HDR Engineering, Inc.*
sarasota, Fl 34232 USA
941-342-2707
sherri.swanson@hdrinc.com

**Switalski, Adam**
*Wildlands CPR*
Missoula, MT 59807 USA
406-543-9551
adam@wildlandscpr.org

**Tappe, Philip**
*University of Arkansas @ Monticello*
Monticello, AR 71656 USA
870-460-1352
tappe@uamont.edu

**Taylor, Jody**
*Monash University*
Clayton, Victoria, Vi 3135 Australia
0399055680
jody.taylor@sci.monash.edu.au

**Teachout, Emily**
*US Fish & Wildlife Service*
Lacey, WA 98503 USA
360-753-9583
emily_teachout@fws.gov

**Thom, Ronald**
*Battelle Marine Sciences Laboratory*
Sequim, WA 98382 USA
360-681-3657
ron.thom@pnl.gov

**Thurman, David**
*University of Washington*
Seattle, WA 98105 USA
503-780-2456
thurman@u.washington.edu

**Tinsley, Jeannine**
*Lady Bird Johnson Wildflower Center: The University of Texas at Austin*
Austin, TX 78739-1702 USA
(512) 292-4200
jtinsley@wildflower.org

**Titus, Valorie**
*Binghamton University/Brookhaven National Laboratory*
Upton, NY 11973 USA
607-232-0343
vtitus7@mac.com

**Toledo, Zak**
*HDR Engineering, Inc.*
Salem, OR 97301 USA
503-587-2900
zak.toledo@hdrinc.com

**Tonjes, Stephen**
*Florida Department of Transportation*
DeLand, FL 32720 USA
386-943-5394
stephen.tonjes@dot.state.fl.us

**Trask, Melinda**
*ODOT Geo-Environmental*
Salem, OR 97301 USA
503-986-3504
melinda.trask@odot.state.or.us

**Tucker, Gary**
*FTN Associates, Inc.*
Little Rock, AR 72801 USA
501-225-7779

**Turton, Tom**
*URS Corporation*
Tampa, FL 33607 USA
813-286-1711
Tom-Turton@urscorp.com

**Valitzski, Sharon**
*The Univeristy of Georgia*
Athens, GA 30605 USA
7062969048
valitzskis@warnell.uga.edu

**Van Peeters, William**
*Resource Center, San Francisco*
San Francisco, CA 94105 USA
415 7440116
william.vanpeeters@fhwa.dot.gov

**Vance-Borland, Ken**
*SCB Fresh Water Working Group*
Corvallis, OR 97330 USA
541.758.8772
kenvb@consplan.net

**Vander Giessen, Steven**
*University of Wyoming*
Laramie, WY 82071 USA
3077607171
zzyzx@uwyo.edu

**Vander Ree, Rodney**
*Australian Research Centre for Urban Ecology*
Parkville, Vi 3010 Australia
03 8344 3661
rvdr@unimelb.edu.au

**VanDeWalle, Terry**
*Natural Resources Consulting, Inc.*
Independence, IA 50644 USA
319-334-3755
tvandewalle@nrc-inc.net

**Varga, Csaba**
Veroce, P 2621 Hungary
302385646
varga.csaba@vnet.hu

**Vaughn, Colleen**
*New Mexico Dept. of Transportation*
Santa Fe, NM 87505 USA
505-827-3234
colleen.vaughn@state.nm.us

**Villamere, John**
*Hatfield Consultants Ltd.*
West Vancouver, BC V7V 1A6
Canada
604 926 3261
jvillamere@hatfieldgroup.com

**Waddell, James**
*US Army Corps of Engineers*
Atlanta, GA 30303 US
404-562-5270
james.m.waddell@usace.army.mil

**Wagner, Paul**
WSDOT
Olympia, WA 98504-3771 USA
360-705-7406
WagnerP@wsdot.wa.gov

**Walters, Charles**
*MDOT Environmental Division*
Jackson, MS 39215-1850 USA
601-359-7920
dallen@mdot.state.ms.us

**Walters, Dickie**
*Federal Highway Administration*
Jackson, MS 39202 USA
601 965-4217
dickie.walters@fhwa.dot.gov

**Wambach, Deborah**
*Montana Department of Transportation*
Helena, MT 59620-1001 USA
406-444-0461
dwambach@mt.gov

**Ward, Carl**
*WSDOT Olympic Region*
Olympia, WA 98504-7417 USA
360-570-6706
WardC@wsdot.wa.gov

**Warren, Kimberly**
*PBS&J*
Tampa, FL 33607 USA
863-533-7000
kwarren@pbsj.com

**Watkins, Jennifer**
I-90 Wildlife Bridges Coalition
Seattle, WA 98103 USA
2066759747
jwatkins@conservationnw.org

**West, Paul**
*Utah Department of Transportation*
Salt Lake City, UT 84114-8450 USA
801-965-4672
paulwest@utah.gov

**White, Patricia**
*Defenders of Wildlife*
Washington, DC 20036 USA
202-772-0236
twhite@defenders.org

**Williams, David**
*Carter & Burgess*
Austin, TX 78746 USA
512-314-3100
david.williams@c-b.com

**Williams, Todd**
*AZ Depart. of Transportation*
Phoenix, AZ 85007 USA
602-712-7391
tgwilliams@azdot.gov

**Williams, David**
*FTN Associates, Ltd.*
Fayetteville, AR 72704 USA
(479) 571-3334
dxw@ftn-assoc.com

**Wilson, Travis**
*North Carolina Wildlife Resources Commission*
Creedmoor, NC 27522 USA
919-528-9886
travis.wilson@ncwildlife.org

**Wilson, Troy**
*U.S. Fish & Wildlife Service*
Reynoldsburg, OH 43068 USA
614-469-6923
troy_wilson@fws.gov

**Wine, Mitch**
*U.S. Fish and Wildlife Service*
Conway, AR 72032 USA
501-513-4488
mitch_wine@fws.gov

**Woltz, Hra**
*NBWLA Landscape Architects*
Charlottesville, VA 22902 USA
434-295-0785
hwoltz@nbwla.com

**Wood, Stanley**
*Massachusetts Highway Department*
Boston, MA 02116 USA
6179737721
stanley.wood@mhd.state.ma.us

**Woods, William**
*ITRE/NC State University*
Raleigh, NC 27695-8601 USA
919-515-8033
bill_woods@ncsu.edu

**Woolford, Edward**
*FHWA ~ USDOT*
Salt Lake City, UT  84118  USA
8016567290
Edward.Woolford@fhwa.dot.gov

**Wrublik, John**
*U. S. Fish and Wildlife Service*
Vero Beach, FL  32960  USA
772-562-3909
john_wrublik@fws.gov

**Yanchik, Brian**
*FHWA - Resource Center*
Summerville, SC  29485  USA
443-522-9446
brian.yanchik@dot.gov

**Young, Rhonda**
University of Wyoming
Laramie, WY  82071  USA
3077662184
rkyoung@uwyo.edu

**Zach, Eric**
Nebraska Department of Roads
Lincoln, NE  68509-4759  USA
402-479-4766
ericzach@dor.state.ne.us

**Zarker, Carol**
*CTE @ ITRE*
Raleigh, NC  27695  USA
919-515-8657
cmzarker@ncsu.edu

**Zimmerman, Michelle**
*Southern Rockies Ecosystem Project*
Denver, CO  80202  USA
303.454.3341
michelle@restoretherockies.org

# Author Index