**ABSTRACT**

Determining all the impacts that roads and highways have on the natural environment can be difficult. Specific effects to wildlife are numerous and include habitat fragmentation, disruption of daily and seasonal movements, and direct mortality from collisions with vehicles. Over the past two decades, Utah’s human population has nearly doubled, and this has been accompanied by a sharp increase in the number of transportation projects statewide. During this same time period, the number of wildlife-vehicle collisions (WVCs) has also increased. In recent years, transportation and wildlife officials have partnered to try to determine the magnitude of the WVC problem associated with Utah’s increasing road system. Using carcass pickup data collected by Utah Division of Wildlife Resources (UDWR) personnel and contractors for the Utah Department of Transportation (UDOT), UDWR and UDOT have been better able to identify the number of WVCs occurring along major transportation routes, and use this information to “fine-tune” high kill zones or critical “hotspots” that have been identified within these reaches.

Since 2005, WVC data collected by DOT contractors and wildlife agency employees has been entered into a statewide roadkill database. This data can then be analyzed by individual routes or specific stretches deemed important by transportation and wildlife officials. Focus has been on the total number of WVCs by route, the number of WVCs by milepost, and the identification of critical high kill stretches. These “hotspots” denote zones where wildlife are trying but are unsuccessful at crossing over the roadway.

U.S. Highway 6 and Interstate 70 are two of Utah’s most heavily traveled roadways transecting critical wildlife ranges. WVC data for these routes was analyzed to determine high impact reaches where potential opportunities for wildlife mitigation existed. The data, in concert with field visits and previous efforts to identify hotspots, were then used to identify and recommend a variety of wildlife mitigation features including wildlife crossings and exclusionary fencing.

Since 2006, several bridged and culvert wildlife underpasses have been constructed on U.S. 6, designed primarily for mule deer and elk passage. An additional bridged underpass is planned for 2013. On I-70, WVC data was a decisive component in the construction of paired bridged underpasses intended to connect a historical seasonal migration route for big game that had been interrupted by the construction of the interstate. This was a stand-alone wildlife mitigation retrofit project, one of the few ever done in the state. Preliminary results of wildlife use of specific mitigation projects will be presented.

WVC data can be a valuable tool for transportation and wildlife officials in determining impacts to wildlife populations, and in helping identify the location, type, and frequency of mitigation actions needed along specific roadways. Utah’s ongoing effort to collect this data will continue to play an integral role in developing and implementing safer and more ecologically friendly transportation projects into the future.

**INTRODUCTION**

The impact that highways and roads have on the natural environment can be difficult to ascertain. Impacts undoubtedly vary depending on specific roadway characteristics such road width, speed limits, and topography, but most major roadways present some challenges for wildlife. These include the loss or fragmentation of habitats and
disruption of migration routes (Beckmann and Hilty 2010), and direct mortality from collisions with vehicles (Huijser and McGowen 2010).

Since 1990, Utah’s population has grown at an average annual rate of 2.5%, an increase of ~1.1 million people statewide (Governor’s Office of Planning and Budget 2009). The result has been a need for, and an increase in transportation infrastructure, including both new road construction as well as the reconstruction of existing routes aimed at increasing capacity for additional motorists. This usually results in the widening of the road footprint and an increase in speeds. The result is a higher occurrence of wildlife-vehicle collisions (WVCs) in these areas.

The Utah Division of Wildlife Resources (UDWR) and Utah Department of Transportation (UDOT) have been formally involved in removing wildlife carcasses from heavily used transportation routes since the mid-1990’s. Although carcasses of all species were removed, the focus was on big game species, primarily mule deer (Odocoileus hemionus) and elk (Cervus canadensis), as these two species have the highest occurrence of WVCs and pose the greatest safety threat to the traveling public. Initially, this effort was done primarily to clear the ROW of “litter” and to minimize the social outcry of the traveling public at seeing dead animals along the road. UDOT has hired private contractors for this effort, while UDWR continues to use existing personnel. Early on, there was no requirement to document the number of carcasses being collected so very few records were kept. After a time, it was realized that the number of WVCs was significant, and there was a need to quantify the problem. Beginning in 2003 at the request of UDWR, UDOT began requiring their contractors to track the number of WVCs occurring along specified routes by logging each carcass they collected to the nearest milepost. UDWR also required logging of carcass removals by their own personnel. In an effort to become better coordinated, UDWR and UDOT entered into a Memorandum of Understanding in 2007 outlining specific responsibilities of both agencies including: specific transportation routes each entity was responsible for, standardized data forms to document carcasses being removed, and the creation of a roadkill database where WVC data would be housed long-term. This agreement remains in effect at the present time.

The collection of WVC data during the past decade has allowed transportation and wildlife officials to better understand the impact that major transportation routes are having on wildlife populations in Utah, and to look at ways to improve public safety. Coincidentally, the collection and analysis of WVC data just happened to correspond to the planning and implementation of several high profile transportation reconstruction projects in the state. Two of these, U.S. Highway 6 (US 6) and Interstate 70 (I-70), will be used as case studies to discuss how WVC data was used in concert with other tools to identify, recommend, and implement successful transportation mitigation in Utah. The US 6 examples correspond to major reconstruction projects that had been identified in environmental planning documents, while the I-70 example was a stand-alone wildlife mitigation retrofit project.

STUDY AREAS

U.S. Highway 6

Due to the high number of annual traffic accidents, US 6 from Spanish Fork to Price is a 63-mile (101 km) stretch often referred to as one of the most dangerous roadways in Utah (see Figure 1). It lies in central Utah and transects a variety of critical wildlife habitats throughout much of its course, including critical big game winter ranges and important fish passage corridors. US 6 traverses a variety of vegetation zones that range from pinyon-juniper hills and sagebrush flats to aspen forests. Elevation ranges from 1,500 -1,700 m (4,500 – 5,500 feet) at Spanish Fork and Price respectively, to nearly 2,300 m (7,500 feet) at Soldier Summit. US 6 bisects the Wasatch Mountain Range which is characterized by high peaks and steep canyons. This stretch of US 6 transects many streams and creeks, and parallels a major rail line resulting in numerous water and rail crossings. The number of average daily vehicle trips ranges from about 9,000 near Spanish Fork to 12,000 at Price (Utah Department of Transportation 2009).

Interstate 70

I-70 from the junction of Interstate 15 (I-15) to Richfield lies in south central Utah. Elevation ranges between 1,600 – 2,130 m (5,200 to 7,000 feet). In this area, I-70 crosses through critical big game winter ranges and a historical migration route. The first seven miles of I-70 near its junction with I-15 is the second study area presented in this paper (see Figure 1). Vegetation types are composed mainly of pinyon-juniper woodlands, mixed sagebrush-oakbrush, and mountain brush. This stretch of I-70 runs nearly east-west and transects the Pahvant Range to the north and the Tushar Mountains on the south. Daily vehicle trips range between 5,000 near Cove Fort on the west to nearly 7,000 at Richfield to the east (Utah Department of Transportation 2009).
METHODS

Carcass removal logs were collected from UDWR personnel and UDOT contractors, and entered into a Microsoft Access database. The database provided general, cursory information including annual mortality by individual species, annual mortality by route, and cumulative mortality by species and route. In addition, UDWR and UDOT personnel kept separate datasets that allowed a more detailed analysis of the WVC data (Merrill 2010, Sakaguchi 2011). This allowed personnel to determine the number of WVCs occurring on a finer scale including annual and cumulative mortality by individual milepost, and mean number of WVCs at individual mileposts.

Figure 1. Location Map of Study Areas.
Once this finer scale analysis was complete, wildlife managers and transportation officials were able to take a closer look at specific stretches of roadway, US 6 and I-70 in our examples, and were able to detect which stretches along these routes had the highest level of WVCs. They were able to compare the highest WVC areas to other “hotspots” (Kassar and Bissonette 2005) and high priority habitat linkages (Ruediger 2007, Ruediger et. al. 2007a) that had been previously identified.

RESULTS

Wildlife Vehicle Collision Data

US 6

The cumulative number of big game WVCs along the US 6 study area is shown for the period 2005-2010 (see Figure 2). A total of 1,911 mule deer and 121 elk carcasses were removed from this 63-mile (101 km) stretch of highway ROW during this 6-year period, a combined average of 339 annually (Sakaguchi 2011). This level is three times higher than that reported in the final Environmental Impact Statement (EIS) for US 6 using UDOT traffic and safety data (US 6 FEIS 2005). In addition to mule deer and elk, mortalities from a variety of other wildlife species were also documented including: black bear (Ursus americanus), moose (Alces alces), pronghorn (Antilocapra americana), red fox (Vulpes vulpes), raccoon (Procyon lotor), coyote (Canis latrans), bobcat (Lynx rufus), badger (Taxidea taxus), beaver (Castor canadensis), wild turkey (Meleagris gallopavo) and several species of raptors.

The presence of several mortality spikes on the graph, primarily those at milepost(s) 178, 187, 201-206, 211, 221, and 232-237, identify the highest collision areas within this stretch of US 6, and these areas were prioritized as needing additional analysis to determine whether potential mitigation was needed.

I-70

The cumulative number of big game WVCs for the I-70 study area is shown for the period 1996-2009 (see Figure 3). A total of 450 big game carcasses were removed from this seven mile (11 km) stretch during that period, 367 of these being mule deer and 83 being elk (Merrill 2010). A spike in WVCs between mileposts 2 to 6 illustrates a consistent high kill zone for big game. Ruediger and others reported that this stretch of I-70 has the one of the highest rates of WVCs anywhere in Utah, and may be one of the highest for elk anywhere in the United States (Ruediger et. al. 2007a). The WVC data presented here support those claims. Carcass data for other species was not available in the I-70 dataset.

Mitigation Features

Wildlife and transportation officials were cognizant of the fact that the WVC information was collected only to the nearest milepost and could not be used exclusively in determining where specific mitigation features should be located. Field visits, knowledge of local biologists and transportation personnel, and other factors were also utilized to further define the most critical stretches of roadway and identify specific locations where mitigation projects should be targeted.

US 6

Since 2005, several major reconstruction projects have occurred on US 6, most of which have included significant wildlife mitigation features. With the WVC data showing a large number of collisions with deer and/or elk, several large wildlife crossing structures were programmed into highway reconstruction projects including three span bridged underpasses and one of the largest box culverts ever built in Utah (see Figures 4-7). These structures were designed with the idea that if built to pass big game, most other species of wildlife would use them as well. Wildlife exclusionary fencing and escape ramps were also included as part of the mitigation for these projects.

I-70

With more than a decade of documenting WVCs between mileposts 1 and 7, UDWR and UDOT personnel knew that mitigation was needed in this stretch, and felt confident they knew the location it should be placed. With the high number of big game collisions occurring, especially those involving elk, officials recommended that underpasses and fencing be installed. Using the WVC data coupled with a prior habitat linkage analysis (Ruediger et. al. 2007a), on-the-ground site visits, and photographic evidence, two paired bridged underpasses were planned for milepost 5.3. After several years of trying, funding was programmed and these features were installed in 2010 (see Figure 8). The use of WVC data was key to securing the needed funding for this project as a cost-benefit analysis showed that these structures would “pay for themselves” in a relatively short period of time.
Figure 2. Big game carcasses removed during a 6-year period on US 6 between Spanish Fork Canyon (MP 177) and Price (MP 240).

Figure 3. Big game carcasses removed during a 14-year period on seven miles of Interstate 70 in south central Utah.
Figure 4. US 6 bridge underpass at MP 200.7. Photo courtesy of Ashley Green.

Figure 5. US 6 bridge underpass at Tucker. Note the box culvert underneath the bridge that acted as the original stream crossing still lies in place during construction. Photo courtesy of Doug Sakaguchi.
Reducing Wildlife-Vehicle Collisions

Figure 6. US 6 bridge underpass at Beaver Creek. Note the small round culvert underneath the bridge was the original stream passage and still lies in place during construction. Photo courtesy of Doug Sakaguchi.

Figure 7. US 6 box culvert at Colton is one of the largest built in Utah. Dimensions are 16 feet high by 25 feet wide. Photo courtesy of Doug Sakaguchi.
Wildlife Crossing Camera Study

UDWR and UDOT needed to document the effectiveness of the newly placed mitigation features on US 6 and I-70. Future mitigation projects statewide would be determined by how well these “state-of-the-art” projects performed in facilitating wildlife passage across the roadway and at decreasing WVCs at these specific locations. Beginning in the summer of 2007, UDOT used transportation research funds to begin a 3-year study to determine the effectiveness of planned wildlife mitigation features throughout Utah. Dr. Patricia Cramer with Utah State University was awarded a contract to monitor wildlife use on a variety of crossing structures, both new and existing, including those on US 6 and I-70 presented here. Dr. Cramer's research included both pre- and post-construction monitoring using Reconyx trail cameras. A main objective of the study was to document the number of successful wildlife passes through these structures as well as calculating the rate of repel for at least 2 years post-construction. Following the initial 3-year study period, and since several new structures were either still under construction or had just been completed, UDWR and UDOT felt it important to continue the study for an additional three years. Since 2010, UDWR has used internal research funds as well as monies provided by local sportsmen’s organizations to continue the study.

Data presented here are preliminary as most of the post-construction monitoring has yet to reach the minimum thought necessary to draw sound conclusions. Tables 1 and 2 summarize crossing statistics for four structures on US 6 and the paired bridge underpasses on I-70. Data shown are post-construction only, and were taken from interim reports and data summaries provided by Dr. Cramer to UDWR and UDOT officials.

Days of post-construction monitoring varied from 138 to 579 on the US 6 structures, with mule deer having the highest number of passes of any species at all structures. The highest number of deer passes occurred at the MP 200.7 bridge underpass with 1,410 deer passes being documented. The lowest frequency of deer passes occurred at the Tucker bridge underpass, the same location where WVCs were shown to be the highest, although this location has the fewest number of monitoring days of those in the study to date. At this location, 132 successful deer passes have been documented since the structure was completed in the fall of 2010. Particularly noteworthy is the high success rate of deer passes, and the low repel rates for deer which range from 1.7% at the MP 200.7 bridge to 10.1% at the Beaver Creek bridge. Although several elk were photographed pre-construction at both locations, no elk have been documented using any of the crossing structures on US 6 to date. Other species that have been documented using the
crossings on US 6 include: moose, black-tailed jackrabbit (*Lepus californicus*), bobcat, coyote, red fox, badger, squirrels, marmot (*Marmota flaviventris*), raccoon, and domestic dogs and cats.

In the first 165 days of monitoring at the I-70 underpasses, 86 deer and eight elk were documented using these structures. Success rates were high, and repel rates fairly low at 15.7% for deer and 11% for elk. The successful use of these structures by elk is encouraging as very few elk have been documented using any crossing structures in Utah to date. Incidentally, all eight of the elk passes were by bulls.

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<tr>
<th>Table 1. Preliminary wildlife crossing statistics from 4 structures on Utah’s US 6. Taken from 2011 preliminary report (Cramer 2011a).</th>
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<td>Days of post-construction monitoring</td>
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<td>Days of post-construction monitoring</td>
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<td>Number of deer observations at the entrances</td>
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<td>Number of deer through</td>
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<td>Total deer through / number of days</td>
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<td>Success Rate – number of deer through as proportion of those photographed</td>
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<td>Repel Rate - those turned away as a proportion to total observed at entrances*</td>
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<td>Other species observed</td>
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*All animals that approached structure did not attempt to use it. These were not counted as repels.

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<th>Table 2. Preliminary wildlife crossing statistics from the milepost 5.3 bridged underpasses on Utah’s I-70. Taken from 2011 preliminary data summary (Cramer 2011b).</th>
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<td>Days of post-construction monitoring</td>
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<td>Success Rate – number through as proportion of those photographed</td>
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<td>Repel Rate - those turned away as a proportion to total observed at entrances</td>
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DISCUSSION AND MANAGEMENT CONSIDERATIONS

Wildlife Vehicle Collision Data

US 6

Initially, coarser scale analyses were used to identify where wildlife mitigation might be needed. A report entitled “Deer-Vehicle Crash Hotspots in Utah: Data for Effective Mitigation” (Kassar and Bissonette 2005) used traffic and safety data from UDOT to identify the highest occurrence of deer-vehicle collisions and hence where mitigation might be targeted. UDOT’s traffic and safety data includes only those accidents reported to the agency by public safety officials resulting from significant property damage, personal injury, or both, and as a result, underestimates the number of WVCs that actually occur. The other was a linkage analysis funded by UDOT shortly after the completion of the final EIS for US 6. This analysis used existing GIS information, and on-the-ground knowledge from land management, wildlife, and transportation agency personnel, to identify locations where fish and wildlife resources were a concern, and to help with the planning and coordination of mitigation measures (Ruediger 2007). The linkage analysis process was important for looking at fish and wildlife needs on a large corridor scale. Once hotspots and/or high priority linkage zones were identified, the location specific WVC data could then be used with these other analyses to “fine-tune” where mitigation was warranted, and what options might be used to meet objectives.

Prior to any wildlife mitigation being accomplished, wildlife managers and transportation officials had to better understand one another’s position, and better define the magnitude of the problem that vehicle traffic on the US 6 corridor was having on public safety and wildlife mortality. The WVC data, in part, provided the information needed that allowed this to happen. In the final EIS for US 6, it was reported that 28% of all motor vehicle accidents along this route could be attributed to collisions with wildlife, stating that between 1991-2000, about 110 accidents involving wildlife occurred, or an average of 110 per year (US 6 FEIS 2005). As previously mentioned, because traffic and safety data includes only those accidents reported to the DOT by public safety officials resulting from significant property damage, personal injury, or both, wildlife managers knew that the reported level of WVCs contained in the EIS was extremely conservative. At that time, however, they had nothing to back up this assertion.

As a result, UDWR biologists requested the carcass removal data that UDOT had required of its contractors, and committed to analyze this information for a different look at the collision problem. Between the time that the draft EIS was issued for public comment in the fall of 2004, and when the final EIS was published in September 2005, analysis of the carcass pickup data showed that the actual number of WVCs was much higher than what had been indicated in the EIS. As a result, UDOT and the Federal Highways Administration (FHWA) included reference to this in the Record-of-Decision (ROD), added the data summary to the administrative record, and committed that the WVC information would be used to develop future mitigation measures (Record of Decision 2005).

The ROD also directed FHWA and UDOT to create a wildlife coordinating committee made up of UDOT, UDWR, and other entities to discuss wildlife needs and make mitigation recommendations as construction projects came online. For the next several years, and continuing to the present time, this committee has met regularly to identify wildlife issues, and to provide wildlife mitigation recommendations for transportation reconstruction projects. Incidentally, the US 6 Wildlife Coordinating Committee was the recipient of a 2010 FHWA Exemplary Ecosystem Initiative Award for their partnership efforts to ensure wildlife and wildlife habitat were mitigated during the long-term reconstruction of the US 6 corridor.

I-70

Concurrently with the collection of WVC data, UDOT initiated a linkage analysis for I-70 similar to that described above for US 6 (Ruediger et. al. 2007a). As was the case for US 6, the linkage analysis process identified the highest priority areas where wildlife impacts were occurring, and hence, the most important areas for potential mitigation. In addition, a partner report to the linkage analysis provided specific wildlife mitigation recommendations for I-70, including the stretch that represents the study area in this paper (Ruediger et. al. 2007b). In the mitigation recommendations report, the authors specify that new underpass bridges should be placed between mileposts 5 and 6. In addition to numerous on-site visits, the WVC data that had been collected and analyzed were key in justifying this recommendation and in helping to identify the exact location to place the underpasses (Bruce Bonebrake personal communication 2011).

Intuitively, the documentation of road kills would be well suited for determining where wildlife crossings should be located (Clevenger and Ford 2010), although some research suggests that this may not be the case (Clevenger et al. 2002). It has also been suggested that road kill data should be combined with habitat linkage mapping or movement models in identifying the location of wildlife crossing structures (Clevenger and Ford 2010). The case studies presented here show that Utah officials are aware of the limitations in using WVC data as a stand-alone source when
making wildlife mitigation recommendations, and that habitat linkage mapping, on-the-ground site visits, and others
tools should also be employed when making these decisions.

Mitigation Features

The newly constructed mitigation features on US 6 and I-70 are showing promising results. The mitigation features
presented here were built with the largest wildlife species being the limiting factor, in this case mule deer and elk. The
bridged underpasses have shown use by a variety of species, and their general acceptance by mule deer is
encouraging. Elk have shown little acceptance of most crossing structures in the past, and in Utah, very few elk (less
than two dozen) have been documented using even large underpasses. With eight bull elk photographed using the I-70
bridged underpass shortly after completion in 2010, transportation and wildlife officials are optimistic that this design
might be a model that can be used in the future.

Wildlife Crossing Camera Study

In reference to wildlife mitigation actions, Forman et al. (2003) indicated that evaluating the success of mitigation is often
based on opinion rather than research, and that few states have based their conclusions on research results. They also
argue that there is an urgent need for rigorous evaluations, and that future mitigation should be tested and evaluated.

The wildlife crossing camera study currently underway in Utah has been instrumental in evaluating the effectiveness of
a variety of mitigation features statewide. It is one of the few studies to place wildlife trail cameras at mitigation sites
pre-construction. With this data we are able to compare the species and their numbers pre- and post-construction, and
are able to better evaluate the efficacy of the crossings in passing a diversity of wildlife. The study has also played a
key role in providing needed information that wildlife and transportation officials can use to plan and implement future
actions. Documenting which mitigation features are working, and at what level, is necessary if sufficient mitigation
features can be expected to be included in future transportation projects. The cost of effective wildlife mitigation is
significant, and without hard data showing they work, future mitigation options will be limited in both frequency and
scope. Dr. Cramer’s research has provided the baseline needed for Utah officials to feel comfortable that the inclusion
of wildlife mitigation infrastructure in transportation projects is a good investment, and that recent recommendations
for type and size of structures is warranted. It is expected that this effort will continue through June 2013, upon which
time, Utah officials feel they will have significantly improved their knowledge base and can make sound mitigation
recommendations in the future, both ecologically and financially.

CONCLUSIONS

Transportation projects are expensive, and the inclusion of wildlife mitigation features only adds to the cost. As a
result, careful analysis has to be done when wildlife mitigation recommendations are made. Although WVC data do not
provide all the answers, it can be useful, especially when used in concert with other tools, to document significant
impacts to wildlife populations and to provide the needed justification for mitigation actions to be carried out. The case
studies presented here show that WVC data is a valuable piece of the puzzle when trying to solve complex interactions
between transportation corridors and wildlife populations.

ACKNOWLEDGMENTS

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of photos. Special thanks to UDOT, UDWR, the Mule Deer Foundation, Sportsmen for Fish and Wildlife, the Rocky
Mountain Elk Foundation, and the Foundation for North American Wild Sheep for their support in funding Dr. Cramer’s
research. Thanks to the US 6 Wildlife Coordinating Committee participants for their work in providing technical
assistance for mitigation recommendations, and to UDOT and FHWA for listening to those recommendations and
including them in transportation projects.

BIOGRAPHICAL SKETCHES

Ashley Green is a Wildlife Program Coordinator for the Utah Division of Wildlife Resources currently responsible for
managing the Division’s land and water assets and also works on wildlife-highway issues statewide. He earned B.S.
and M.S. degrees from Brigham Young University in Conservation Biology-Wildlife and Range and Wildlife Resources.
He has spent nearly 15 years with the Division in a variety of roles including vegetation monitoring, habitat restoration,
lands management, and impact analysis.
Patricia Cramer is a Research Assistant Professor at Utah State University. She is currently researching wildlife and roads across Utah, along US 93 in Montana, and across Washington State. Dr. Cramer was co-author with John Bissonette on the National Academies’ Research Project, ‘Evaluation of the Use and Effectiveness of Wildlife Crossings.’ This 4 year study helped us understand the state of the practice and science of mitigating roads for wildlife in North America. She received the Denver Zoo's Conservationist Award for 2010.

Doug Sakaguchi is a biologist in the Habitat Section of the Utah Division of Wildlife Resources Central Region office, where his focus has been impact analysis. He has been instrumental in analyzing wildlife carcass pickup data from approximately 15 highways in the region and has worked closely with the Utah Department of Transportation in recommending and including wildlife mitigation in transportation projects. Doug received his B.S. degree in fishery science from Cornell University, and his M.S. degree in freshwater ecology from Brigham Young University. After working for the UDWR for more than 31 years, he is presently considering spending more time fishing with his two grandchildren.

Nathan Merrill is the Southwest Area Traffic & Safety Engineer for the Utah Department of Transportation's Region Four. His responsibilities include highway signing, work zone traffic control, traffic signal operations, traffic studies and traffic accident data on State and Federal highways within six counties. Additionally, Nathan has prior experience in pavement preservation, design, and construction during his 23 years with UDOT. He is a licensed Professional Engineer and holds a bachelor’s degree in Civil Engineering from Utah State University. He believes in staying young by being physically active and in his spare time enjoys hiking in southwest Utah. He also works as a part-time lifeguard at the Cedar City Aquatic Center.

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IDENTIFICATION AND EVALUATION OF SITES FOR LOW-COST WILDLIFE MITIGATION

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ABSTRACT

The Bozeman Pass transportation corridor between Bozeman and Livingston, Montana, includes Interstate 90 (I-90), frontage roads, and a railroad. Data collected indicate the highway had become a hazard to wildlife and a partial barrier to animal movements in the Bozeman Pass area, which is considered a corridor for wildlife moving north and south between the Greater Yellowstone Ecosystem and other habitat. Studies were begun with the objective of identifying areas of elevated roadkill and employing mitigation measures whose success could then be measured.

In 2001 field data collection began on Bozeman Pass to determine the extent of animal–vehicle collisions (AVCs) and where such conflicts may best be mitigated. Subsequent funding from MDT, the Federal Highway Administration (FHWA) and the Western Transportation Institute (WTI) resulted in a multi-year safety and wildlife connectivity study centered around a Montana Rail Link (MRL) bridge reconstruction site. Data on wildlife crossings and AVCs were collected before and after installation of wildlife exclusion fencing to evaluate its efficacy in reducing AVCs and funneling animal movements under the highway via existing culverts and the MRL bridge. Data collection included 1) road kill surveys; 2) track-bed monitoring at fence ends, jump-outs, and under the MRL bridge; 3) remote camera monitoring at fence ends and culverts; 4) infrared counter and remote camera monitoring at jump-outs; and 5) opportunistic snow tracking at track-bed sites and along the length of the highway in the study area.

Ungulate–vehicle collisions (UVCs) have decreased significantly inside the fenced roadway since the installation of the wildlife fencing. No significant increase in UVC rates has resulted either at the fence ends or in the study area as a whole. In addition, track-bed and remote camera data indicate increased wildlife movement under the MRL bridge and through culverts. An analysis of road kill density “hotspots” before and after the fencing indicates one hotspot has been mitigated by the fence.

Because wildlife mitigation measures were added to the bridge structure replacement project, the costs of this project were lower than they would have been if MDT were constructing a new wildlife crossing structure. Increased usage under the bridge and through other structures suggests that wildlife fencing leading to existing crossing structures is an effective method of reducing the risk to both motorists and wildlife while improving wildlife connectivity. Incorporating wildlife connectivity measures into scheduled road projects early in the planning stages can be a cost-effective way to reduce AVCs.

INTRODUCTION

Wildlife move across the landscape to meet daily, seasonal (migration), and lifetime (dispersal) needs. Highways often intersect wildlife movement routes with the potential for direct mortality, injury, displacement, habitat fragmentation, loss of habitat connectivity and even genetic isolation (Clevenger and Wierzchowski 2006; Clevenger et al. 2001; Corlatti et al. 2009; Forman et al. 2003; Forman and Alexander 1998; Proctor et al. 2002, 2004) depending upon the highway location, topography, design, and traffic. The most direct effects are mortality and injury. Currently, 21 federally listed threatened or endangered animal species in the United States have been documented as species for which road mortality is a major threat to survival (Huijser et al. 2008a). Indirect effects impact animals by reducing their effective habitat and interfering with necessary movement. Roads can often form a barrier to such movement, and when this happens there can be effects on wildlife populations and longer-term effects on genetic variability (Riley et al. 2006; Proctor et al. 2002, 2004).

Methods to mitigate animal–vehicle collisions (AVCs) typically include installing wildlife fencing and jump-outs in conjunction with a variety of underpasses, overpasses, elevated spans, or culverts animals can use to traverse safely from one side of road to the other (Clevenger and Huijser 2010; Clevenger et al. 2001; Forman et al. 2003; Huijser et al. 2008b). Such crossing structures have been evaluated in many areas with similar habitat (Forman and Hersperger 1996; Jackson 1999; Jones 2000; Clevenger and Waltho 2000; Paquet et al. 1996), and those evaluations have
demonstrated underpasses and extended bridge spans are an effective means to increase permeability for some species of wildlife.

One of the most cost effective measures to reduce AVCs is by incorporating wildlife mitigation features in road construction and upgrades already scheduled by departments of transportation (Forman et al. 2003, MacDonald and Smith 1999). In many cases bridges and culverts already exist in areas where AVCs occur. Simply installing fencing that guides animals through these structures, while preventing them from accessing the highway surface, can effectively reduce AVCs and maintain connectivity at a fraction of the cost of installing new crossing structures.

In 2001, the Craighead Institute began systematically collecting field data on Bozeman Pass to identify accurate road kill locations and to document wildlife movement along I-90 between Bozeman and Livingston, Montana from milepost (MP) 309.5 to MP 333.0. The initial phase of the project, known as the Bozeman Pass Wildlife Linkage and Highway Safety Study, was supported with private funding. Data analyses from the project highlighted areas of higher than average road kill near Bozeman and other areas closer to Livingston. One of these areas of elevated road kill was in the vicinity of the Montana Rail Link (MRL) bridge (MP 314) that was scheduled to be rebuilt in 2005. In 2003, a continuation of the project focusing on the site of the planned MRL bridge reconstruction was funded by MDT and FHWA. This phase, the Bozeman Pass Wildlife Channelization Intelligent Transportation Systems (ITS) project, provided pre-construction wildlife field data. Analysis of data from 2001-2005 led to recommendations to incorporate wildlife connectivity measures into the reconstruction of the MRL bridge and a final report was completed in June 2006 (Hardy et al. 2006). The recommended measures included wildlife fencing along approximately one mile of east- and west-bound lanes, double cattle guards, and landscape design modifications. These measures were incorporated into the project design by MDT. With additional funding provided by the MDT, FHWA, and WTI, the final phase of the project, known as the Bozeman Pass Post-Fencing Wildlife Monitoring Project, was begun to support post-construction field data collection for evaluating the effectiveness of wildlife fencing. Post-fencing data was collected from August 2007 to June 2010 after the wildlife fence and four jump-outs were completed as a part of the bridge reconstruction project.

**STUDY AREA**

Bozeman Pass (I-90, MP 309.5–333.0) is located in south-western Montana north of Yellowstone National Park. The study area in and around Bozeman Pass encompasses approximately 908 km² (350 miles²) and includes the cities of Bozeman and Livingston with I-90 bisecting the area. The MRL line runs parallel to the highway, crossing underneath at MP 321 and 314. The distance between Bozeman and Livingston is approximately 33.6 km (21 miles). Summer annual daily traffic (ADT) was 8,000–10,000 and winter ADT was 12,000–17,000 during the course of this study. For reference, in Canada’s Banff National Park, wildlife movements were found to be impaired by 300 to 5,000 vehicles per day (Alexander et al. 2005). A frontage road and railway traffic through the Bozeman Pass area is also a factor, with approximately 30 trains using the tracks daily, moving under the MRL bridge at approximately 48 kph (30 mph).

Bozeman Pass is surrounded by a mosaic of residential, agricultural and public lands. Elevation varies from 1398 meters (4586 feet) at its low point near Livingston to 1733 meters (5685 feet) at the top of the pass. The area includes a large amount of wildlife habitat on both public and private lands which is somewhat fragmented by human development and transportation routes. I-90 is a partial barrier to wildlife movement in the region (Figure 1). Regionally, Bozeman Pass has been identified as an important wildlife corridor connecting wildlife habitat in the Greater Yellowstone Ecosystem in the south to habitat further north (Craighead et al. 2001; Hardy et al. 2006; Walker and Craighead 1997; Reudiger et al. 1999). Accordingly, the Craighead Institute and other partners worked to maintain habitat on both sides of the highway near the mitigation site to ensure animals crossing here would have secure habitat beyond the roadway. Safe highway crossings are a key feature in larger efforts for comprehensive natural resource management. Larger conservation approaches include components such as integrated planning, the exploration of a variety of mitigation options, and performance measurement (Brown 2006).

This area is rich in wildlife, including black bear (*Ursus americanus*), mountain lion (*Puma concolor*), bobcat (*Felis rufus*), elk (*Cervus elephas*), moose (*Alces alces*), mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), red fox (*Vulpes vulpes*), coyote (*Canis latrans*), and a variety of smaller mammals, reptiles, and a diversity of bird species. Many of these species utilize this area in their daily, seasonal and lifetime dispersal movements. Grizzly bears (*Ursus arctos horribilis*) and gray wolves (*Canis lupis*) are occasionally seen in the area but none have been documented crossing I-90 or recorded as road kill.
Mitigation Measures

The MRL bridge is located approximately at milepost 314.1 and spans the railroad and access right-of-ways beneath I-90. Concurrent with the bridge replacement in 2005–2007, wildlife mitigation measures were installed, specifically wildlife fencing, jump-outs, cattle guards, and improved grading to enhance wildlife movement underneath the bridge. Wildlife fencing (1.2 meter [8 ft] high) was installed along 1.44 km (.9 mile) of I-90 encompassing the bridge between MP 313.5 and 314.4 along both east- and west-bound lanes. Four jump-outs were installed within the fenced areas; two are located on each east- and west-bound lane at MP 313.9 and 314.2. Jump-out walls range from about 6 to 8 feet high. To discourage animals from making “end runs” around the end of the fences, modifications were made to include two sets of double cattle guards, or Texas guards, installed at the western termini of the fence at the Bear Canyon interchange access ramps. The eastern wildlife fence ends encompass a large double culvert and a steep embankment before tying into the traditional barbed wire fence that runs the length of the right-of-way.

METHODS

Data Collection

Road kill

Road kill data collection began in 2001 on Bozeman Pass. Biologists at Craighead Institute and volunteers drove along I-90 over the pass and recorded the date, location (to the closest 1/10th mile using mile markers), and species of road kills observed. Sex was recorded for carnivores and ungulates, if possible. A more standardized survey protocol, without volunteers, began in 2003, with Craighead Institute personnel driving I-90 between Bozeman and Livingston three times a week to collect road kill data. Driver speed for Craighead Institute personnel was kept between 88 and 105 kph (55–65 mph) during the surveys. Through June 30, 2010, the pass was surveyed 1,272 times between MP 309.5 and 333.0, representing 85,478 km (53,424 miles).

Searches of agency records provided additional wildlife collision data. Road kill data were obtained from a variety of sources including Montana Fish, Wildlife and Parks and MDT. Supplemental data from MDT maintenance reports
included in this project represent carnivores, moose and elk. MDT reports of deer species (mule and white-tailed) were not included due to the difficulty in reconciling duplicate records. At a minimum, supplemental data contained the date, location, and species killed. Power analyses were applied to the pre-fencing ungulate–vehicle collision (UVC) data to determine what degree of change in UVC rates would be statistically detectable when comparing pre- and post-fencing road kill data (Hardy et al. 2006). Results from the power analyses (power =0.8; a = 0.05) indicated a three to five year post-fencing study would be sufficient to allow quantitative comparisons (Hardy et al. 2006). The post construction monitoring period included three years of data collection through June 30, 2010.

**Track-bed**

To determine the number and species of animals crossing beneath the MRL bridge, a sand track-bed was constructed on the north side of the railroad tracks. The track-bed was approximately 46 meters (150 ft) long and 2.5 meters (8 ft) wide. Due to the configuration of the highway and railroad, the track-bed covered approximately two-thirds the width of the passage; construction closer than 25 feet to the railroad was prohibited. Because it was not possible to census the entire area for animal movements, the track-bed observations provided an index of crossing activity. However, observations of snow tracks during winter indicated that very few animals crossed underneath the bridge without also crossing the track-bed. Track-bed surveys began in October 2003 and continued through October 2004, after which bridge reconstruction began. During the construction phase, equipment, materials and fill were present at the track-bed site making it impossible to maintain and monitor the track-bed until construction was completed. Accordingly, the track-bed was rebuilt in the fall of 2006. The fencing was completed in the spring of 2007. Post-fencing track-bed monitoring commenced in August 2007.

Prior to construction, the track-bed was surveyed and then raked every three to four days on average. The number of tracks counted was divided by the number of days lapsed since the previous survey to provide a count of tracks per day. Post-construction, surveys were conducted on four consecutive days every other week. The bed was raked at the beginning of the week, then counted and raked every day for the next four days to provide a count of tracks per day. This was done to avoid confusion (and loss of data) resulting from occasionally large numbers of tracks accumulating over multiple days (Hardy et al. 2006). During winter months, tracks would freeze and weather events confounded track identification. Therefore, post-construction track-bed surveys were conducted May through October.

**Jump-outs**

Initially, the jump-outs were monitored using small track-beds constructed at the top of the jump-out and supplemented with Trailmaster motion-sensor counters. The counters soon proved unreliable and were replaced with RECONYX motion-sensor cameras (see below). Jump-out track-beds were surveyed in conjunction with the main track-bed surveys (May 1–October 31). Photos from the jump-out cameras were downloaded periodically.

**Remote cameras**

In the pre-construction period, Trailmaster cameras were used with passive infrared (IR) beam or active IR beam triggers. Cameras were first placed in paired culverts (two culverts side by side) at MP 314.4, 314.8, and 315. Post-construction, RECONYX digital motion-sensor cameras were used and increased security measures were taken to avoid theft. Cameras were deployed in the culverts at MP 314.4. Cameras were maintained for constant monitoring and the photos were downloaded periodically.

**Data Analyses**

Data from the entire Bozeman Pass study area (MP 309.5–333.0) were examined to identify yearly or monthly trends. Post-fencing data were then used to compare the spatial distribution of locations with high density UVCs. Hardy et al. (2006) used a criterion of three standard deviations above the mean to define a road kill “hotspot.” Due to errors in underlying data, that criterion was adjusted to two standard deviations above the mean. This criterion was then applied to the post-fencing data to explore spatial changes in mortality due to the fencing.

A second analysis of high density UVC areas was conducted using “SANET –Spatial Analysis on Networks” (Okabe et al. 2009) software that is specifically designed to analyze data that lie along a network, such as a roadway. Network density analyses were performed to elucidate changes in the locations of high density UVC areas from pre- to post-fencing, as well as to identify additional sections of highway that may be of mitigation interest. In SANET, the band width determines the distance along the network within which the algorithm will include carcass occurrences in calculating a local density. As it moves along the network, the estimator is re-calculated at each step and the resulting image is a network segmented into UVC density estimations. The cell width is user defined and describes approximately
the length of the road segments for which the estimator is calculated. In this study, the band width was set at 550 meters and the cell width at 10 meters. Sections of roadway representing the top 25 percent and 50 percent of UVC density clusters were identified to assess the spatial location of UVC hotspots along Bozeman Pass.

**Road kill**

Pre-mitigation data indicated UVC rates were significantly higher within the proposed mitigation zone than elsewhere along the highway using 2001–2004 data (Hardy et al. 2006). This analysis was expanded to include all pre-mitigation UVC data (January 1, 2001 to April 4, 2005) and recomputed to verify that UVC rates remained significantly higher within the zone.

During the bridge reconstruction period, traffic patterns were restricted to two lanes and speeds were reduced to 56 kph (35 mph). Recorded UVC numbers dropped sharply during this time. UVC data were therefore divided by period (Table 1). To determine if the disruption and changes in traffic during the interim period affected UVC rates, pre-fencing and interim data were compared both inside and outside the fenced zone. A significant difference in UVC rates during the interim period would require those interim data to be omitted from further analysis.

**Table 1. Time periods for which data were pooled in analyses.**

<table>
<thead>
<tr>
<th>Period</th>
<th>Start Date</th>
<th>End Date</th>
<th>Number of Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-construction</td>
<td>1-8-01</td>
<td>3-31-05</td>
<td>1544</td>
</tr>
<tr>
<td>Interim</td>
<td>4-1-05</td>
<td>7-4-07</td>
<td>825</td>
</tr>
<tr>
<td>Post-construction</td>
<td>7-5-07</td>
<td>6-30-10</td>
<td>1092</td>
</tr>
</tbody>
</table>

To determine the effectiveness of the fence in reducing UVC rates, a series of two- and one-tailed t-tests were computed on UVC means both spatially and temporally. Spatial comparisons examined UVC rates inside and outside the fence, while temporal comparisons examined UVC rates pre- and post-fencing. Research has indicated that while wildlife fencing decreases ungulate mortality within fenced areas, outside the fenced area a majority of animals get killed at fence ends (Clevenger et al. 2001). To account for this possible end run effect, a buffer of an additional 0.2 miles (322 meters) of roadway was added to each end of the fenced area, and road kill occurrences within the buffer were included with those from the fenced zone for some analyses (Hardy et al. 2006). In these cases where data from the actual fenced section and the buffer areas were combined, the data set is referred to as “fence/buffer.”

**Track-bed**

In addition to reducing mortality caused by the highway, the mitigation project intended to ensure connectivity or passage across the highway corridor (beneath the bridge), allowing local and regional movements to continue. To test the effects of the fencing and bridge re-build on animal movements underneath the highway, we conducted a one-sided t-test on the mean number of tracks per day observed in the track-bed to see if use had increased post-fencing. Track-bed data were broken down into pre- and post-mitigation periods. Since the survey methods were slightly different in the pre- and post-fencing periods, only those data collected in a single 24-hour pre-fencing period were used to compare to the post-fencing data. That is, if more than one day elapsed between raking the track-bed and reading the tracks, those data were excluded from analysis.

**Jump-outs and remote cameras**

Track-bed data for jump-outs were only collected post-fencing. The number of animal tracks was recorded and augmented by remote cameras. Although there were hundreds of photos from remote cameras at the mile post 314.4 culverts, statistical comparisons between pre- and post-construction were not feasible due to pre-and post-fencing differences in camera type and survey effort. However, the culvert photos provide an index of animals using the culverts.
RESULTS

Pass-wide Data Summary

Between January 2001 and June 2010, 2,272 animals representing 49 different species of mammals, birds and reptiles were recorded as road kill on Bozeman Pass between Bozeman and Livingston, Montana. The majority of animals killed were ungulates (44%), followed by meso-carnivores (27%), birds (11%), medium-sized rodents (8%), small rodents (4%), unknown (3%), domestics (2%), large carnivores (1%), and reptiles (0.2%). The number of animals killed on the roadway is presumed to be greater than the number whose deaths are recorded; these data only represent an index of the actual number of animals hit. In many cases, scavengers will drag carcasses away from the roadside (Antworth et al. 2005; Slater 2002). UVC totals across the entire study area fluctuated yearly over the span of the study with peaks in 2003 and 2007 and a low in 2006 (Figure 3).

![Figure 3. UVC totals by year, mileposts 309.5–333.0. 2010* represents the first six months only.](image)

Seasonally, most ungulates were killed in the autumn months of October and November, followed by a smaller peak in the summer months of June and July (Figure 4). Road kill in winter generally tended to be low.

![Figure 4. UVC totals by month, mileposts 309.5–333.0. Data from 2001 through 2009.](image)

UVCs tend to be spatially clustered along I-90 on Bozeman Pass. As reported in Hardy et al. (2006, amended); eight 1/10-mile stretches were identified as road kill “hotspots.” These occurred at MP 309.9, 310.1, 312.2, 312.8–312.9, 313.2, and 313.8–313.9. The last two were contained by the wildlife fencing installed in the fall of 2006. The same analysis was conducted using the post-fencing data. Eleven 1/10-mile stretches in five clusters were identified, occurring at MP 309.5–309.9, 312.8–312.9, 320.9, 328.3–328.4, and 332.5 (Figure 5).
Figure 5. Distribution of UVCs along Bozeman Pass. Pre-fencing data are shown in gray, with hotspots identified by a gray *. Post-fencing data are shown in black, with hotspots identified by a black #. The location of the wildlife fencing is indicated with a series of bold black Xs.

The network kernel density function in SANET resulted in similar "hotspot" results (Figure 5). Pre-fencing data resulted in three clusters representing 25 percent of the total UVC density pass-wide. These occurred at MP 309.7–310.2, 312.6–313.1, and 313.6–314.0.

Figure 6. UVC hotspots along Bozeman Pass pre-fencing and post-fencing. Double (red) and thick (yellow) sections represent areas that account for 25 percent and 50 percent of the pass-wide UVC density, respectively. Numbered points are mileposts and the series of hatch marks (green) represents the location of the wildlife fencing.

Post-fencing data resulted in two clusters representing 25 percent of the total UVC density pass-wide. These occurred at MP 309.5–310.1, 312.7–313.1. The hotspot initially present in the area to be fenced no longer appears, suggesting that one significant UVC hotspot was successfully mitigated by the fencing.
Road kill

Within the mitigation zone (MP 309.5–319.0) prior to fencing, there were significantly more UVCs in the proposed fenced area (fence) compared with the area outside of the proposed fenced area (outside) (data set January 1, 2001–March 31, 2005; one-tailed T-test, P=.06). This finding confirms the conclusion from Hardy et al. (2006) that this area had higher than average road kill and justifies the placement of the mitigation fencing along that stretch of highway.

During the interim period of construction and fencing (April 1, 2005–July 4, 2007), UVC rates were reduced in the mitigation zone (Table ). There was a pass-wide dip in road kill during 2006, while 2005 and 2007 represent average road kill years. The construction activities in the mitigation study zone resulted in lower traffic speeds and two-lane traffic patterns during this time. Regardless of confounding influences, the mean number of UVCs in the mitigation zone during the interim period was significantly lower than during the pre-fencing period both inside and outside the fenced area (paired t-test, P=.01 [outside], P<.01 [fence]). All interim data were therefore omitted from further analyses.

<table>
<thead>
<tr>
<th>Stretch</th>
<th>Pre-fence</th>
<th>Interim</th>
<th>Post-fence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fence</td>
<td>11.6</td>
<td>2.2</td>
<td>2.7</td>
</tr>
<tr>
<td>Outside</td>
<td>6.9</td>
<td>4.8</td>
<td>7.3</td>
</tr>
<tr>
<td>Entire Zone</td>
<td>7.4</td>
<td>4.5</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Analyses of pre- and post-fencing road kill data identified the fenced stretch as the only area where mean UVC rates were changed (Figure 7). In other words, the mitigation fencing significantly reduced UVC rates in only the fenced area (one-tailed t-test, P=.004). In the four and a quarter years of pre-fence monitoring, 49 ungulates were killed in the area to be fenced, accounting for 17 percent of all UVCs in the study area. In the three years of post-fence monitoring, only eight ungulates were killed there, accounting for 4 percent of all UVCs, and half of those were found at the fence ends (Figure 8).

![Figure 7. Mean UVC rates with 95 percent confidence intervals by section, pre- and post-fencing.](image_url)
To assess the end-run effect, data from the buffer stretches were combined with those of the fenced stretch and reanalyzed. The significant reduction was still apparent (one-tailed t-test, \( P=.01 \)). In the buffer sections there was no significant change in UVCs attributable to attempted end-run activity at the end of the fence (two-tailed t-test, \( P=.8 \)). However, due to a very small sample size, such an effect would have to be extreme to be detectable statistically. The conclusion of no effect in the buffer areas (Figure 9) should be considered tentative. Additionally, the fencing resulted in no significant change on the UVC rates outside the fenced area, nor in the study zone as a whole (pre- and post-fencing comparison of means: two-tailed t-tests, \( P=.6 \) [outside]; \( P=.5 \) [study area]).

**Figure 8. Pre- and post-fencing UVCs at individual mile markers within the fence.**

**Figure 9. Pre- and post-fencing UVCs within the fence and buffer stretches.**

**Track-bed**

Track-bed data from beneath the MRL bridge show a sample of species using the passage over time. Species of interest that appear in only the post-fencing dataset include black bear, mountain lion and moose. Elk were not recorded post-fencing. Species other than deer were recorded infrequently, and no definitive conclusions can be drawn from their inclusion in one or the other dataset.
After the mitigation fencing was installed, the mean number of daily deer crossings under the MRL bridge significantly increased from 4.6 to 7.2 crossings per day (two-tailed t-test, $P= .01$). On a monthly basis from May through October, the largest increase in ungulate crossings per day occurred in the months of September and October (Figure 10).

![Figure 10. Mean ungulate crossings per day under the MRL bridge.](image)

**Jump-outs**

During the post-fencing monitoring period, 42 of 164 surveys resulted in track identification. A total of 62 different tracks were recorded in the four jump-outs, representing at least eight species of mammals and reptiles.

**Remote cameras**

Post-fencing data indicated that animals were reliably photographed in the vicinity of the fence ends and jump-outs. Pre-fencing photograph comparisons at jump-outs and fence ends are not applicable because there was no pre-fencing coverage. The RECONYX cameras proved to be more sensitive and more reliable than the Trailmaster cameras and motion sensors that were used initially. Pre- and post-fencing photograph comparisons in the culverts are also not applicable in this study because the data from pre-fence Trailmaster cameras were unreliable and the data record is incomplete. However, data show that the same suite of species utilized the culverts to pass underneath the highway both pre- and post-fencing. Animals associated with aquatic habitats dominate the suite using the culverts. The exceptions are black bears, domestic dogs, birds and humans. The data also indicate that the east culvert (which has little or no water most of the year) was used more heavily than the west culvert (which usually contains about 2 feet of water).

**DISCUSSION AND RECOMMENDATIONS**

This project demonstrates that effective highway research and mitigation projects can be completed in phases with funding secured sequentially and dependent upon results of the previous phase. Thus the initial data-gathering phase provided justification to fund the subsequent mitigation and pre- and post-mitigation monitoring. Data gathering can be effective using a collaborative partnership approach and combined with planned construction/maintenance activities to identify areas where reduced cost mitigations can be effective at reducing AVCs. Pre- and post-monitoring at such mitigation sites can provide a measure of effectiveness.

**Pass-wide Assessment and Hotspots**

Over the nine and a half years of data collection along Bozeman Pass, all large-bodied wild animals known to inhabit the area were documented as road kill, with the exception of wolverine and grizzly bear. The yearly fluctuation of UVCs along Bozeman Pass is not surprising, given that similar variability is seen in the population dynamics of many ungulate species.
The seasonal fluctuations are indicative of the migratory movement patterns of ungulates to some extent, particularly white-tailed deer. Two road kill peaks were identified (Figure 3): one in summer (June), and one in autumn (October–November). Other studies have shown an increase in roadkill in the spring/summer months, ranging from May through August (Clevenger et al. 2003; Huijser et al. 2008a; Grilo et al. 2009). The autumn peak is mirrored by an increase in movement underneath the highway in track-bed counts (Figure 9). The summer road kill peak is not as pronounced and there is no significant increase in track bed counts. Hardy et al. (2006) suggested the summer road kill peak may correspond with green-up, and the increased animal movement may be in response to forage availability. The road kill peak in the summer (May–July) may be due to increasing traffic volume on the highway (Figure 11 and increased likelihood of collisions (Waller et al. 2006) rather than increased animal movement. It is likely that the majority of deer tracks recorded on the track bed are white-tailed deer, which are observed regularly in the area. Females do not travel as widely during the period when they have fawns (Ozoga et al. 1982, Scanlon and Vaughan 1985) so the track-bed may be recording mainly local movements of resident animals in spring and summer.

Before the fencing was installed, eight 1/10-mile stretches were identified as road kill hotspots. Post-fencing, eleven 1/10-mile stretches in five clusters were identified. The SANET network kernel density analysis showed that prior to fencing, three hotspots accounted for the top 25 percent of all pass-wide UVC density. These hotspots were all located between Bozeman and the Jackson Creek exit. Installation of the fence resulted in the disappearance of the one hotspot where the fence was located. Post-fencing, two significant UVC hotspots remain, still accounting for the top 25 percent of all pass-wide UVC density. Their locations remain essentially unchanged from the pre-fencing period, lying between Bozeman and the fenced area.

Considering the relatively short time period of these studies, all areas identified either during the pre- or post-fencing periods should be considered as likely hotspots. The section of highway between the fencing site and the outskirts of Bozeman, because of its relatively short length (about 4 miles), could be considered in its entirety as a high-risk area for UVCs.

Mitigation Effectiveness Assessment

Road kill data from this study indicate that the installation of wildlife fencing and jump-outs has significantly reduced UVCs, and thus motorist safety, in the fenced area, with no accompanying significant increase in UVCs outside the fenced area. Specifically, the end-run effect, or increased road kill at fence ends, has not occurred. Animals still try to
cross at the fence ends, as road kill data and photo monitoring document, but no more or less than before fence installation. Data from the track-bed underneath the bridge show an increase in ungulate use. Taken together, these results indicate the effectiveness of fencing in excluding animals from the highway, thereby making the fenced area safer for motorists, while maintaining or improving habitat connectivity under the bridge. Data also indicate that few animals are utilizing the jump-outs as an effective means of exiting the highway, though at least one species, coyotes, have successfully exited in this fashion. Culvert monitoring has documented the long term use by a variety of animals and people as a means to cross safely beneath the highway.

**Financial Assessment**

The Bozeman Pass project highlights the effectiveness of reducing UVC through the wildlife mitigation practices used. It demonstrates that fencing projects alone can be added to help direct animals through existing structures. It also highlights the need for innovative monitoring techniques pre- and post-mitigation to provide quantitative measures of effectiveness.

Costs for this project were much lower than new wildlife crossing structures because the fencing was added to a structure replacement project for an existing bridge which functions as a wildlife underpass. While the cost of the mitigation techniques is not inexpensive, working with transportation managers and planners before planned rebuilds and upgrades can keep costs to a minimum. The cost of the planned MRL bridge rebuild in 2005–2006 was approximately six to eight million dollars (Deb Wambach, MDT, pers. comm.). The actual cost of the wildlife fencing and jump-outs (Table ) was $104,269.46 (Lisa Durbin, MDT, pers. comm.) which increased the total cost of the reconstruction project by only about 1.25 percent. However, the cost for the bridge re-build was larger than most other infrastructure projects due to the size of the structure required to span the MRL tracks and meet Interstate design standards, so although the wildlife costs were about 1% of the total, that percentage would be higher in many other circumstances, based on total contract price (Deb Wambach, MDT, pers. comm.). Such investments are intended to increase motorist safety and benefit wildlife. It is only a fraction of the cost that insurance companies pay out yearly for reported UVCs.

<table>
<thead>
<tr>
<th>Mitigation</th>
<th>Cost (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrier fencing</td>
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</tr>
<tr>
<td>Single panel fencing</td>
<td>6,381.60</td>
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<tr>
<td>Double panel fencing</td>
<td>18,065.05</td>
</tr>
<tr>
<td>Jump-outs</td>
<td>22,280.00</td>
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<tr>
<td>7.2m cattleguards</td>
<td>36,000.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>104,269.46</strong></td>
</tr>
</tbody>
</table>

During the post-fencing monitoring period, there were a total of eight UVCs in the fenced area (four within the fence, four at the fence ends), compared with 49 in the pre-fence period. The post-fence time period was shorter than the pre-fence time period (1092 and 1544 days respectively). To compare equivalent numbers before and after fencing we estimated that 0.70 of the 49 animals recorded pre-fencing, or approximately 35 UVCs, were killed during the same length of time as the post-fence period. Thus by adjusting for the differences in length of each period, an estimated net of 27 UVCs was avoided due to the fence (35=27+8). This is only a rough estimate for purposes of discussion since road kill rates are not constant and vary according to season, weather, traffic density, etc. However, as a rough illustration, if an average cost of $6,617 per collision (Huijser et al. 2009) is assumed, approximately $178,659 in direct economic costs has been saved by society, nearly double the cost of the project. The overall benefits of the fencing to animals, drivers, and society are already being realized.

**Wealth Accounting Costs**

Recent global initiatives such as the Millennium Assessment (Millennium Ecosystem Assessment. 2005) and the World Bank Global Partnership for Wealth Accounting and the Valuation of Ecosystem Services have institutionalized wealth accounting practices as a means to measure the true values of communities and the true costs of goods, services, and relationships. An extension of this approach suggests that the cost of the loss of an organism such as a mule deer can
be considered in terms of its economic costs, social costs, and environmental costs. As wealth accounting becomes applied at finer scales, more precise estimates of the true costs of animal-vehicle collisions may include such things as (rough estimates): the loss of a full day of work to the motorist who hit the deer ($200), the loss of efficiency at work due to injury or stress ($500), the delays in commerce of trucking accidents ($100), the value of the deer meat to a hunter who is unable to harvest the animal ($200), the value to a game processor who could have butchered and wrapped the meat ($150), the loss of future reproduction in the deer population ($400), loss of carbon sequestration, loss of prey to carnivores, decline in carrying capacity of the environment for carnivores and subsequent loss of hunting and viewing, and so on. Although many of these costs may seem trivial, when multiplied by the number of UVCs across the nation it is likely that the true environmental and social costs of current highway designs will add significantly to the direct financial costs of UVCs and collisions with other animals.

Design Recommendations for Bozeman Pass Study Area

The effectiveness of underpasses and overpasses at reducing AVCs has been estimated at an average of 86 percent when used in combination with large-mammal fencing (Huijser et al. 2008b). Our remote camera data indicate that existing underpasses, without wildlife fencing, vary greatly in use by wildlife and this may be due to differences in the structures themselves or the terrain nearby.

Fencing

Additional wildlife fencing would probably increase the use of existing bridges and culverts if it were placed so that wildlife were directed to those crossing structures. Photo data from additional remote cameras indicate that a variety of species currently utilize other culverts. Snow track data indicate that deer cross the highway in winter in areas where they could more safely travel through nearby bridge or culvert underpasses.

Underpasses

The construction of new underpasses would not be as cost-effective as adding wildlife fencing to existing structures, but new structures near the hotspot sites around MP 309.7 and 313 would likely be effective at reducing AVCs. There are no existing structures immediately adjacent to those sites. Underpasses may also be effective if built close to the hotspots near MP 321, 325, 328, and 332 on the Livingston side of Bozeman Pass. Although the existing underpasses near MP 328 were not observed to be used by wildlife, a better design of culvert, underpass, or elevated span that provides more space and visual openness should be much more effective (Clevenger and Huijser 2010).

Overpasses

Along with underpasses, overpasses in combination with wildlife fencing are effective at reducing wildlife vehicle collisions (Huijser et al. 2008b). Overpasses would be much more expensive (a few million dollars) but if properly located could reduce AVCs and increase connectivity for many species of wildlife. Data from overpasses in other locales suggest that even if the overpass is not exactly in a traditional travel route for animals they are likely to learn of its location and begin to use it. Locating a crossing structure where there is adequate habitat or compatible land use adjacent to the highway is one of the most important considerations (Clevenger and Huijser 2010, Huijser et al. 2008b). Probable sites for an overpass were identified near the hotspots at MP 315 or 316 because of steep terrain and the proximity of the Interstate and the railroad. To be most effective an overpass would need to provide passage over both the highway and railroad (and/or frontage roads) and this area would require the least length of overpass.

Jump-outs

Our data suggested that most animals did not use the jump-outs as a means of exiting the highway. There are only two documented photos of a coyote jumping off the jump-out away from the highway. There were no data from tracks or photos documenting deer use of jump-outs although they visited the tops of the jump-outs many times. The fact that there were no deer road kills within the fence associated with these photos indicates that the deer were able to successfully exit the fenced area without getting hit. We concluded that the jump-outs were too high, with difficult landing areas, for most animals to use easily. Black bears appeared on the edge of the jump-out wall but could have climbed up or down the edge of the jump-out. Cougars were photographed passing over the top of the jump-outs.

Placing a berm of dirt at the bottom of the jump-outs to provide a more sloped landing and less of a drop should improve the design so that animals may use jump-outs more easily in this area. Amend the fence to ensure that there are no gaps between the fence and the jump-out wall such that animals can squeeze through either entering or leaving the fenced area.
Signage

Any application of temporary, seasonal signage warning drivers of wildlife crossing the road would be most effective during autumn when it appears there are more animals attempting to cross the highway. Signs alone are relatively ineffective. When used as part of an animal detection system (ADS) though, they can reduce AVCs about 87 percent (Huijser et al. 2008a).

ACKNOWLEDGEMENTS

We would like to thank all of the volunteers and citizen scientists who have provided us with road kill location data over the years. We would also like to thank all of the dedicated Craighead Institute staff and interns who systematically collected road kill data, made early morning observations at the fencing site, and helped with data compilation. We would like to thank our key partners at the Western Transportation Institute: Amanda Hardy and Rob Ament. Finally, we would like to thank Deb Wambach and Pierre Jomini at MDT for their help and support.

BIOGRAPHICAL SKETCHES

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Lauren Oechsli, MSc in Biological Sciences from Montana State University, Bozeman in 2000 and BA in Biological Sciences from Columbia University, N.Y. in 1992. Previously a GIS analyst working on road ecology, wildlife habitat and connectivity, and modeling, Lauren is starting a new career as a massage therapist.

Angela Kociolek, Research Scientist, Road Ecology focus – Western Transportation Institute. MSc in Biology (Conservation emphasis) and a Master’s Certificate in Interdisciplinary Studies from Montana State University in 1997. Angela works on a variety of road ecology field research projects primarily in Montana.

REFERENCES


ABSTRACT

Wildlife-vehicle collisions pose a major safety concern to motorists and can be a significant source of mortality for wildlife. A 13-mile section of US Highway 30 in southwest Wyoming that passes through Nugget Canyon has been especially problematic because it bisects the winter range and migration route of a large mule deer (Odocoileus hemionus) herd. Through the 1990’s, an average of 130 deer were killed each year. Accordingly, the Wyoming Department of Transportation (WYDOT) installed a series of 20’ span x 10’ rise x 60’ length concrete box culvert underpasses and game-proof fencing (8’ high and constructed of woven wire) to funnel deer to the underpasses. The purpose of this study was to quantify the number of mule deer that used the underpasses, identify their seasonal and temporal movement patterns, and evaluate how effective the underpasses were at reducing deer-vehicle collisions. Through two years of monitoring, we documented 25,886 mule deer move through the underpasses. Peak movements during the fall migration occurred in mid-December, while peak spring movements occurred in mid-March and early-May. Most mule deer moved through underpasses during morning (0600-0800 hrs) and evening (1800-2000 hrs) periods. Deer-vehicle collisions were effectively reduced 81%, from 0.75 per month at each milepost to 0.14 per/month. Provided that fence gates remain closed and cattle guards remain clear of snow, deer-vehicle collisions should be eliminated from Nugget Canyon in the near future. Importantly, other wildlife species such as elk (Cervus elaphus), pronghorn (Antilocapra americana), moose (Alces alces), cougar (Felis concolor), and bobcat (Felis rufus) benefited from underpass construction. Our results suggest that underpasses, combined with game-proof fencing, can provide safe and effective movement corridors for mule deer and other wildlife species and improve highway safety for motorists.

INTRODUCTION

Wildlife-vehicle collisions pose a major safety concern to motorists and can be a significant source of mortality for affected wildlife (Romin and Bissonette 1996, Putman 1997, Forman et al. 2003). Roadway conflicts are especially problematic for ungulates when roads bisect their winter range or migration routes, where animal densities can be especially high during certain times of the year. For example, a 13-mile section of US Highway 30 in southwest Wyoming passes through Nugget Canyon – an area that provides crucial winter range for thousands of mule deer (Odocoileus hemionus) and bisects an important migration route. Mule deer-vehicle collisions have historically been very high along this roadway, with an average of 130 deer killed per year since 1990 (Plumb et al. 2003). Despite a variety of mitigation measures implemented during the 1990’s aimed at slowing traffic and warning motorists of potential collisions with wildlife and deterring deer from entering the roadway (e.g., signs, reflectors, flashing lights), dozens of deer-vehicle collisions continued to occur each year in this 13-mile segment (milepost 28-41) of highway. The high rates of deer-vehicle collisions posed serious safety concerns for both motorists and mule deer. In an effort to move deer underneath the highway and reduce deer-vehicle collisions, the Wyoming Department of Transportation (WYDOT) installed seven miles of 8’-high game fence (milepost 28-35) and a concrete box culvert underpass at milepost 30.5 in 2001. This crossing structure was monitored for two years following construction and received high levels of deer use (i.e., hundreds), particularly during spring (March-April) and fall (November-December) migrations (Gordon and Anderson 2003). The dimensions of this structure (20’ span x 10’ rise x 60’ length) had an openness ratio of approximately 1.12 and was determined to be adequate for mule deer use (Gordon and Anderson 2003). Although the underpass and associated fencing was successful at reducing deer-vehicle collisions around milepost 30, remaining portions of the project area (i.e., mileposts 35-41) continued to have high levels of deer-vehicle collisions and it was apparent that additional crossing structures were needed. Accordingly, WYDOT approved construction of six new box culvert underpasses and seven additional miles of game fence to be completed in October 2008. The location of these structures generally corresponded with road segments that had high levels of deer-vehicle collisions and were installed at mileposts 35.25, 35.96, 37.44, 38.23, 39.00, and 40.62 (Fig. 1).
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Our study was designed to evaluate the effectiveness of the newly constructed underpasses and associated fencing. Specifically, we aimed to: 1) quantify how many mule deer (and other wildlife) used the underpasses; 2) identify temporal patterns of mule deer movements; 3) evaluate deer-vehicle collisions before underpass construction (1990-2000), after construction of one underpass (2002-2007), and after construction of six additional underpasses (2009-2010). This information was intended to improve the ability of wildlife and transportation agencies to sustain migratory ungulate populations and maintain public safety on roadways.

METHODS

We used digital photos from infrared Reconyx cameras to calculate the number of deer that used each underpass. Three cameras were mounted in each of the seven underpasses, including one at the entrance, one in the middle, and one at the exit (Fig. 2). This camera configuration allowed us to count the number of deer that approached and/or passed through the underpass from either direction. The underpasses were equipped with cameras from December 16, 2008 through May 31, 2010. This time period included the later part of the fall 2008 migration, and the entire spring 2009, fall 2009, and spring 2010 migrations. We examined seasonal temporal patterns by plotting the number of deer that passed through each structure each day, across the entire monitoring period. We examined the daily temporal patterns by calculating the number of deer that moved through structures each hour of the day, for a 10-day sampling period that corresponded with the peak levels of use during fall and spring migrations.

We used deer-vehicle collision data from WYDOT to assess how underpass and fence construction reduced deer-vehicle collisions. We compared the number of deer-vehicle collisions in three time periods: 1) January 1, 1990 – October 1, 2001, (141 months) prior to construction of the underpass at milepost 30.5, 2) October 1, 2001 – October 1, 2008, (82 months) following construction of the underpass at milepost 30.5, and 3) October 1, 2008 – May 1, 2010, (19 months) following construction of six additional underpasses. To make comparisons between the three periods that differed in temporal length, we standardized the number of deer-vehicle collisions by the number of months in each period.

Figure 1. Approximate location of game-proof fencing and underpasses (milepost = MP) along US 30 in Nugget Canyon, Wyoming.
RESULTS

Underpass Use by Mule Deer

We documented 25,886 mule deer move through the seven underpasses between December 2008 and May 2010 (Table 1), including 12,483 during the 2008-09 monitoring season (Dec. 16, 2008-May 20, 2009) and 13,403 during the 2009-10 monitoring season (October 1, 2009 through May 31, 2010). Most deer movement occurred at milepost 30.50 (57%; n=7,160 [2008-09] and 51%; n=6,834 [2009-10]) and mileposts 35.96 (31%; n=3,828 [2008-09] and 21%; n=2,775 [2009-10]; Table 1). During the 2008-09 season, the five other underpasses accounted for the remaining 12% of deer use. However, during the 2009-10 season, deer use was distributed more evenly between the five other structures and accounted for 29% of total deer use. Most underpass activity occurred during spring and fall migrations, but crossings occurred on a regular basis throughout the winter period (January and February) as well (Table 1).

Figure 2. Placement and configuration of three cameras on each of the seven underpasses.
Table 1. Number of mule deer that moved through underpasses during fall migration (October-December), winter (January – February), and spring migration (March – May), December 2008 – May 2010, Nugget Canyon, Wyoming.

<table>
<thead>
<tr>
<th>Monitoring Season</th>
<th>Fall Migration</th>
<th>Winter</th>
<th>Spring Migration</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>MP 30.50</td>
<td>1,552</td>
<td>3,308</td>
<td>2,112</td>
<td>1,228</td>
</tr>
<tr>
<td>MP 35.25</td>
<td>83</td>
<td>274</td>
<td>69</td>
<td>40</td>
</tr>
<tr>
<td>MP 35.96</td>
<td>638</td>
<td>885</td>
<td>233</td>
<td>104</td>
</tr>
<tr>
<td>MP 37.44</td>
<td>149</td>
<td>1,062</td>
<td>56</td>
<td>110</td>
</tr>
<tr>
<td>MP 38.23</td>
<td>18</td>
<td>151</td>
<td>16</td>
<td>22</td>
</tr>
<tr>
<td>MP 39.00</td>
<td>3</td>
<td>199</td>
<td>5</td>
<td>48</td>
</tr>
<tr>
<td>MP 40.62</td>
<td>47</td>
<td>374</td>
<td>37</td>
<td>75</td>
</tr>
<tr>
<td>Total</td>
<td>2,490</td>
<td>6,253</td>
<td>2,528</td>
<td>1,627</td>
</tr>
</tbody>
</table>

The amount of mule deer use at underpasses varied between fall and spring migrations, especially at milepost 30.5 and 35.96 (Figs. 3A&B). During the 2008 fall migration (Fig. 3A), 90% of deer crossings occurred at milepost 30.50 (73%) and milepost 35.96 (17%), but by the 2009 fall migration this percentage was reduced to 70%, including 57% at milepost 30.50 and 13% at milepost 35.96. In contrast to the fall where deer crossings were heavily skewed towards the underpass at milepost 30.50, deer use during the spring migrations was more evenly split between the underpasses at milepost 30.50 and 35.96 (Fig. 3B). The other five underpasses recorded a higher percentage use during the 2009-10 migration seasons compared to the 2008-09 season (Fig. 3A&B), suggesting some level of acclimation may have occurred.

The timing of peak movements during the fall migrations occurred in mid-December, with a maximum of 284 animals per day (Fig. 4). Spring migrations were characterized by multiple peaks of deer movement that generally occurred in mid-March and early-May, with a maximum of 223 animals per day (Fig. 4). On a daily basis, peak levels of underpass use occurred in the mornings (0600-0800 hrs) and evenings (1800-2000 hrs; Fig. 5). Morning use was more prominent during the spring, whereas evening use was more common in the fall.
Figure 3. (A) Proportional use of mule deer at each underpass during the fall 2008 and 2009 migrations, and (B) spring 2009 and 2010 migrations.
Figure 4. Total number of mule deer moving south to north (spring migration) and north to south (fall migration). Peak spring movements occurred in mid-March and early-May, while peak fall movements occurred in mid-December.

Figure 5. Number and time of day that mule deer moved through underpasses during a 10-day peak sample period during the spring and fall migrations.

Underpass Use by Other Wildlife

Between December 2008 and May 2010, we recorded 499 elk (Cervus elaphus), 39 pronghorn (Antilocapra americana), 13 coyotes (Canis latrans), 38 bobcats (Felis rufus), 5 badgers (Taxidea taxus), 8 moose (Alces alces), 1 raccoon (Procyon lotor), and 1 cougar (Felis concolor) move through the underpasses (Table 2; Fig. 6). Most elk, moose, and pronghorn use occurred at the milepost 30.50 underpass.
Table 2. Number of other wildlife species that moved through the Nugget Canyon crossing structures during the first 2 years of study.

<table>
<thead>
<tr>
<th>Underpass</th>
<th>Badger</th>
<th>Bobcat</th>
<th>Coyote</th>
<th>Elk</th>
<th>Moose</th>
<th>Cougar</th>
<th>Pronghorn</th>
<th>Raccoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>MP 30.50</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>487</td>
<td>6</td>
<td>0</td>
<td>38</td>
<td>0</td>
</tr>
<tr>
<td>MP 35.25</td>
<td>0</td>
<td>18</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MP 35.96</td>
<td>0</td>
<td>11</td>
<td>4</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MP 37.44</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MP 38.23</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>MP 39.00</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MP 40.62</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>5</strong></td>
<td><strong>38</strong></td>
<td><strong>13</strong></td>
<td><strong>499</strong></td>
<td><strong>8</strong></td>
<td><strong>1</strong></td>
<td><strong>39</strong></td>
<td><strong>1</strong></td>
</tr>
</tbody>
</table>

Figure 6. Photos of other wildlife, including elk at milepost 38.23 underpass (top left), bobcats in milepost 35.96 underpass (top right), mule deer and pronghorn moving through milepost 30.50 underpass (bottom left), and moose at milepost 30.50 underpass (bottom right).
Mule Deer-Vehicle Collisions

Before the underpass at milepost 30.50 was built in the summer of 2001, the number of deer-vehicle collisions varied across the 13 miles of highway and averaged 0.75 per month at each milepost. Across the 13-mile project area this translated into 9.75 deer fatalities per month. Road segments with the highest collision rates occurred near milepost 30, 35, 36, 37, and 38, and ranged from 0.89 to 3.06 deer fatalities per month (Fig. 7). Following construction of the underpass at milepost 30.50 in 2001, the average number of deer-vehicle collisions throughout the 13-mile stretch was reduced to 0.66 per month per milepost (or 8.58 deer fatalities per month), between 2001-2008 (Fig. 7). Although the total number of deer-vehicle collisions did not decline considerably (12%), the number of collisions near milepost 30.50 dropped by 79% (from 1.81 to 0.39 per month; Fig. 7). After the six new underpasses and seven additional miles of game fencing were constructed in 2008, the number of deer-vehicle collisions per month recorded at each mile post was reduced to 0.14, or 1.82 deer fatalities per month in the 13-mile corridor. Overall, the construction of seven underpasses and game-proof fencing reduced deer-vehicle collisions by 81%.

![Graph showing average number of mule deer-vehicle collisions per month before and after underpass construction.](image)

**Figure 7.** Average number of mule deer-vehicle collisions per month before underpass construction (1990-2001), after one underpass was constructed at milepost 30.50 (2001-2008), and after all seven underpasses were constructed (2008-2010). Vertical arrows at bottom of graph depict locations of underpasses. Horizontal lines below the arrows depict fencing associated with underpasses.

**DISCUSSION**

Game-proof fencing used in conjunction with underpasses can effectively move animals underneath roadways and reduce wildlife-vehicle collisions (McCollister and Van Manen 2010). Here, we show that continuous fencing between a series of underpasses reduced mule deer-vehicle collisions by >80% for a 13-mile stretch of US 30 in southwest Wyoming. Importantly, deer-vehicle collisions did not increase in areas immediately adjacent to the fencing (Sawyer and LeBeau 2010), where deer were free to move across US 30 at grade-level. Deer-vehicle collisions that occurred after underpass construction resulted from deer crossing cattle guards that filled with snow or passing through gates left open by recreational users. Fortunately, both of these problems are correctable and we expect deer-vehicle collisions to
be reduced further in future years. Maintaining infrastructure associated with the fencing (i.e., cattle guards, gates) will be especially important during the peak movement periods in December, March, and May.

Reducing deer-vehicle collisions is important for public safety and minimizing deer mortality. Of additional concern is maintaining habitat connectivity for wildlife in the affected region. In western Wyoming, mule deer migrate 12-100 miles between their seasonal ranges (Sawyer et al. 2005). Sustaining these deer herds will require functional migration routes remain intact. During the first two fall and spring migrations following underpass construction, we documented >25,000 mule deer move underneath US 30. Our data suggest that underpass and fence construction did not affect the permeability of US 30 to deer. Rather, the underpasses provided deer with a safe means to cross US 30 and maintain connectivity with their distant seasonal ranges.

The benefits of reduced vehicle mortality and safe passage across US 30 were not limited to mule deer. We documented a variety of other animals that utilized the underpasses. Of particular interest was use by pronghorn, moose, and elk. Although pronghorn use was documented at the milepost 30.50 underpass shortly after construction (Plumb et al. 2003), underpass use by all three species is relatively rare. A variety of small mammals (e.g., badger, raccoon) and carnivores (e.g., coyote, bobcat, cougar) also utilized the underpasses.

**BIOGRAPHICAL SKETCHES**

**Hall Sawyer** is a research biologist and project manager with Western Ecosystems Technology. Hall earned a BS degree in Wildlife Biology from Colorado State University and MS and PhD degrees in Zoology from the University of Wyoming. His specialty areas include migration ecology, resource selection, animal capture, GPS-telemetry, and impact assessment of ungulates. He currently leads several long-term studies that evaluate the migration ecology and potential impacts of energy development on mule deer, elk, and pronghorn.

**Chad LeBeau** is a biologist with Western Ecosystems Technology. Chad earned a BS degree in Wildlife and Fisheries Biology and Management and Environment and Natural Resources. Chad is currently pursuing a M.S. degree in Rangeland Management and Renewable Resources at the University of Wyoming. His work primarily focuses on sagebrush ecosystems, and he has experience conducting black-footed ferret surveys, raptor nest surveys, greater sage-grouse lek counts, pygmy rabbit surveys, mountain plover surveys, burrowing-owl surveys, swift fox surveys, and habitat mapping.

**Thomas Hart** is a wildlife specialist in the Wyoming Department of Transportation’s Environmental Services Section. Thomas earned a BS degree in Wildlife and Fisheries Biology and Management from the University of Wyoming. Before coming to WYDOT, Thomas did fisheries management work in Wyoming and South Dakota. Most of his work now consists of mitigating impacts to wildlife species from highway construction projects, monitoring wildlife crossing structures, raptor nest monitoring, and ensuring highway projects are in compliance with the Endangered Species, Migratory Bird Treaty, and Bald and Golden Eagle Protection acts.

**ACKNOWLEDGEMENTS**

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**LITERATURE CITED**


THE RELIABILITY OF TWO NEW ANIMAL DETECTION SYSTEMS AND RECOMMENDED REQUIREMENTS FOR SYSTEM RELIABILITY

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ABSTRACT

Animal–vehicle collisions affect human safety, property, and wildlife, and the number of animal–vehicle collisions has increased in many regions across North America. Animal detection systems can help reduce the number of wildlife–vehicle collisions and allow for safe crossing opportunities for wildlife. These systems detect large animals when they approach the road and once a large animal has been detected, warning signs are activated. Drivers can then respond by becoming more alert, reducing the speed of their vehicle, or both. For animal detection systems to be effective in reducing collisions, reliable systems are essential. For a previous project we investigated the reliability of nine systems from five manufacturers. The current study reports on the reliability of two new systems: 1. a buried cable that detects changes in an electromagnetic field when large animals walk over the cable and 2. a third generation break-the-beam system that uses microwave radio signals. The systems were investigated for their reliability in a controlled access test facility near Lewistown, Montana. The two new systems were also installed along real roadides; the buried cable system was installed along Hwy 160 near Durango, Colorado, and the microwave radio signal break-the-beam system was installed along Hwy 3 near Fort Jones, California. At the test facility near Lewistown, Montana, we used horses, llamas, and sheep as a model for wild ungulates. The animals roamed in an enclosure and data loggers recorded the date and time of each detection for both systems. Animal movements were also recorded by six infrared cameras with a date and time stamp. By analyzing the images and the detection data in different seasons, researchers were able to investigate the reliability for each system. The percentage of false positives (i.e., a detection is reported by a system but there is no large animal present in the detection zone) was relatively low for both systems (≤0.5%). However the percentage of false negatives (i.e., an animal is present in the detection zone but a system failed to detect it) differed substantially (1.9–16.8%). The percentage of intrusions (i.e., animal intrusions in the detection area) that were detected also varied substantially (88.6–99.5%). The results suggest that one of the two detection systems was quite reliable in detecting large mammals with few false positives and false negatives, whereas the other system had relatively many false negatives, mostly because of downtime. When we compared the reliability data to the recommended performance requirements that were obtained through interviews with three stakeholder groups we found that one of the two systems tested met the recommended requirements, while the other did not. Based on the results we know that some systems are quite reliable and may be considered for implementation along a roadside where they can be investigated for their effectiveness in reducing collisions with large wild mammals. However, experiences with installation, operation and maintenance suggest that the robustness of animal detection systems may have to be improved before the systems can be deployed on a large scale.

INTRODUCTION

Animal–vehicle collisions affect human safety, property, and wildlife, and the number of animal–vehicle collisions has been increasing in many regions across North America (Huijser et al. 2007). Here we investigate a relatively new mitigation measure aimed at reducing animal–vehicle collisions while allowing animals to continue to move across the landscape. We evaluated the reliability of a range of different animal detection technologies from different manufacturers.
Animal detection systems detect large animals (e.g., deer (*Odocoileus* spp.), pronghorn (*Antilocapra americana*), elk (*Cervus elaphus*) and moose (*Alces alces*)) as they approach the road (see reviews in Huijser et al. 2006; 2009a). When an animal is detected, signs are activated, warning drivers that large animals may be on or near the road at that time. Previous studies have shown variable effects of activated warning signs on vehicle speed: substantial decreases in vehicle speed (≥5 km/h (≥3.1 mi/h)) (Kistler 1998; Muurinen and Ristola 1999; Kinley et al. 2003; Gagnon et al. 2010); minor decreases in vehicle speed (<5 km/h (<3.1 mi/h)) (Kistler 1998; Muurinen and Ristola 1999; Gordon and Anderson 2002; Kinley, et al. 2003; Gordon, et al. 2004; Hammond and Wade 2004; Huijser et al. 2009a); and no decrease or even an increase in vehicle speed (Muurinen and Ristola 1999; Hammond and Wade 2004). This variability of the results is likely related to various conditions (see review in Huijser et al. 2009a):

- The type of warning signal and signs.
- Whether the warning signs are accompanied with advisory or mandatory speed limit reductions.
- Road and weather conditions.
- Whether the drivers actually see an animal.
- Whether the driver is a local resident.
- Perhaps the road length of the zone with the animal detection system and the road length that the warning signs apply to (the more location specific the better).
- Perhaps also cultural differences that may cause drivers to respond differently to warning signals in different regions.

Activated warning signs may also result in more alert drivers, which can lead to a substantial reduction in stopping distance: 20.7 m (68 ft) at 88 km/h (55 mi/h) (review in Huijser et al. 2009a). Finally, research from Switzerland has shown that animal detection systems can reduce ungulate–vehicle collisions by as much as 82 percent (Mosler-Berger and Romer 2003). In Germany collisions with large mammals were reduced by more than 80% (Strein 2010). In Montana a reduction of 58% was recorded (Huijser et al. 2009a) and data from Arizona showed a reduction of 97 percent (Gagnon et al. 2010).

Before animal detection systems can be effective, they must be able to detect large animals reliably. Therefore it is important to know how reliable animal detection systems are when detecting large animals and to establish minimum norms for system reliability. Until now, measuring and comparing the reliability of different animal detection systems has been problematic due to the following factors:

- Most systems have not been properly studied, or the results have not been published.
- Different studies have evaluated systems with regard to different parameters.
- Different studies used different methods.
- Different systems have been evaluated under varying conditions (e.g., varying road and climate conditions).

For a previous project we investigated the reliability of nine systems from five manufacturers (Huijser et al. 2009a; 2010). The current study reports on the reliability of two new systems: 1. a buried cable that detects changes in an electromagnetic field when large animals walk over the cable and 2. a third generation break-the-beam system that uses microwave radio signals. The systems were investigated for their reliability in a controlled access test facility near Lewistown, Montana. The two new systems were also installed along real roadsides; the buried cable system was installed along Hwy 160 near Durango, Colorado, and the microwave radio signal break-the-beam system was installed along Hwy 3 near Fort Jones, California. At the test facility near Lewistown, Montana, we used horses, llamas, and sheep as models for wild ungulates.

**METHODS**

**Test-bed location**

The RADS test-bed is part of the TRANSCEND cold region rural transportation research facility and is located along a former runway at the Lewistown Airport in central Montana (Fig. 1). The test-bed location experiences a wide range of temperatures, and precipitation ranges include mist, heavy rain, and snow; the topography is flat, and the rocky soil does not sustain much vegetation that may obstruct the signals transmitted or received by the sensors. The test-bed consists of an animal enclosure, the two animal detection systems, and six infrared cameras with continuous recording capabilities (Fig. 2). The distance covered was 50 m (164 ft) for buried cable system and 91 m (300 ft) for the microwave radio signal break-the-beam system (from the left to the right side of the enclosure).
Figure 1. The location of the test-bed along a former runway at the Lewistown Airport in central Montana. The current municipal airport is located on the upper right of the photo.

Figure 2. Test-bed design including an animal enclosure, the two detection systems (open circles = poles for sensors), the six infrared cameras aimed at the enclosure from the side (solid circles), and the office with data recording equipment. Arrows show the direction of transmitter.
Animal Detection Systems and Data Recording Equipment

The first system tested is a buried cable (Perimitrax®) that detects large mammals when they move across the cable (Table 1). The system is manufactured by Senstar Corporation, Carp, Ontario, Canada, and it is the exact same technology as originally installed along US Hwy 160 near Durango, CO, USA. The buried cable was placed in a trench and wrapped in sand and geotextile nine inches below the surface. The system was installed in Lewistown on 11 and 12 August 2009. The system generates an invisible electromagnetic field and when a large animal crosses the cable it causes a disturbance in this electromagnetic field. The electrical conductivity, size and speed of the animal all affect the magnitude of the disturbance. However, the threshold that needs to be met to declare an "alarm" or "detection" is adjustable and can be set depending on the size of the animal one wishes to detect. Detection messages are transmitted to a computer in the research trailer at the test-bed where they are saved in files for later analysis.

The second system tested is a microwave radio signal break-the-beam system manufactured by ICx Radar Systems (Scottsdale, Arizona (formerly Sensor Technologies and Systems, Inc.) (Table 1). The system is the third generation of this detection technology (RADS III). Previous generations (RADS I and RADS II) were evaluated for their reliability in an earlier project (Huijser et al. 2009b). The RADS III is the exactly the same detection technology as was installed along Hwy 3 near Fort Jones, CA, USA. The system was installed in Lewistown, MT on 16 December 2009. The center of the beam was set at about 73.7 cm (29 inches) above the ground. However, because of rises and depressions in the terrain, the center of the beam was estimated to have varied between 71.1 and 76.2 cm (28-30 inches) above the ground. Setting the center of the beam lower may have resulted in false positives as a result of the grass-herb vegetation in the enclosure.

<table>
<thead>
<tr>
<th>Manufacturer and system name</th>
<th>System type</th>
<th>Signal type</th>
<th>Maximum range</th>
<th>Installation date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magal Senstar (Perimitrax®)</td>
<td>Buried cable</td>
<td>Electromagnetic field</td>
<td>About 0.1 mi (161 m)</td>
<td>11/12 Aug 2009</td>
</tr>
<tr>
<td>STS (RADS III)</td>
<td>Break-the-beam</td>
<td>Microwave radio (± 35.5 GHz)</td>
<td>About 1/2 mi (804 m)</td>
<td>16 Dec 2009</td>
</tr>
</tbody>
</table>

Six infrared cameras (Fuhrman Diversified, Inc.) were installed perpendicular to the detection system. These cameras and a video recording system record all animal movements within the enclosure continuously, day and night. The two systems saved individual detection data with a date and time stamp in data logs. These data were compared to the images from the infrared cameras, which also had a date and time stamp, allowing the researchers to investigate the reliability of the system. Orange cones marked the location of the cable (first system) and the beam (second system) on the images.

Wildlife Target Species and Models

In a North American setting, animal detection systems are typically designed to detect white-tailed deer (Odocoileus virginianus) and/or mule deer (Odocoileus hemionus), pronghorn (Antilocapra americana), elk (Cervus elaphus) or moose (Alces alces). In Montana, it is not legal to have deer, elk or moose in captivity. Therefore the researchers used domesticated species as a model for wildlife. For this study, which took place within an enclosure, two horses, two llamas, and two sheep were used as models for these wildlife target species. Horses are similar in body shape and size to moose, llamas represent deer and elk, and sheep represent small deer (Tables 2 and 3). The body size and weight of the individual horses, llamas, and sheep used in this experiment are shown in Table 4.
Table 2. Height and length of wildlife target species and horses, llamas, goats and sheep.

<table>
<thead>
<tr>
<th>Species</th>
<th>Height at shoulder</th>
<th>Length (nose to tip tail)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target species</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moose</td>
<td>6'5&quot;-7'5&quot; (195-225 cm)</td>
<td>6'9&quot;-9'2&quot; (206-279 cm)</td>
<td>Whitaker (1997)</td>
</tr>
<tr>
<td>Elk</td>
<td>4'6&quot;-5' (137-150 cm)</td>
<td>6'8&quot;-9'9&quot; (203-297 cm)</td>
<td>Whitaker (1997)</td>
</tr>
<tr>
<td>White-tailed deer</td>
<td>27-45&quot; (68-114 cm)</td>
<td>6'2&quot;-7&quot; (188-213 cm)</td>
<td>Whitaker (1997)</td>
</tr>
<tr>
<td>Mule deer</td>
<td>3'-3'5&quot; (90-105 cm)</td>
<td>3'10&quot;-7'6&quot; (116-199 cm)</td>
<td>Whitaker (1997)</td>
</tr>
<tr>
<td>Pronghorn</td>
<td>2'11&quot;-3'5&quot; (89-104 cm)</td>
<td>4'1&quot;-4'-9&quot; (125-145 cm)</td>
<td>Whitaker (1997)</td>
</tr>
<tr>
<td><strong>Models</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feral horse</td>
<td>4'8&quot;-5' (142-152 cm)</td>
<td></td>
<td>Whitaker (1997)</td>
</tr>
<tr>
<td>Quarter horse</td>
<td>4'11&quot;-5'4&quot; (150-163 cm)</td>
<td></td>
<td>UHS (2007), Wikipedia (2007)</td>
</tr>
<tr>
<td>Llama</td>
<td>3'-3'11&quot; (91-119 cm)</td>
<td></td>
<td>Llamapaedia (2007)</td>
</tr>
<tr>
<td>Goat</td>
<td>25&quot;-30&quot; (64-76 cm)</td>
<td></td>
<td>ADM Alliance Nutrition Inc (2011)</td>
</tr>
<tr>
<td>Sheep</td>
<td>25&quot;-50&quot; (63-127 cm)</td>
<td></td>
<td>Minnesota Zoo (2011)</td>
</tr>
</tbody>
</table>

Table 3. Body weight of wildlife target species and horses, llamas, goats and sheep.

<table>
<thead>
<tr>
<th>Species</th>
<th>Weight male</th>
<th>Weight female</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target species</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moose</td>
<td>900-1400 lbs (400-635 kg)</td>
<td>700-1100 lbs (315-500 kg)</td>
<td>Whitaker (1997)</td>
</tr>
<tr>
<td>Elk</td>
<td>600-1089 lbs (272-494 kg)</td>
<td>450-650 lbs (204-295 kg)</td>
<td>Whitaker (1997)</td>
</tr>
<tr>
<td>White-tailed deer</td>
<td>150-310 lbs (68-141 kg)</td>
<td>90-211 lbs (41-96 kg)</td>
<td>Whitaker (1997)</td>
</tr>
<tr>
<td>Pronghorn</td>
<td>90-140 lbs (41-64 kg)</td>
<td>75-105 lbs (34-48 kg)</td>
<td>Whitaker (1997)</td>
</tr>
<tr>
<td><strong>Models</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Llama</td>
<td>250-450 lbs (113-204 kg)</td>
<td></td>
<td>Llamapaedia (2007)</td>
</tr>
<tr>
<td>Goat</td>
<td>110-225 lbs (50-101 kg)</td>
<td>160-264 lbs (72-119 kg)</td>
<td>ADM Alliance Nutrition Inc (2011)</td>
</tr>
<tr>
<td>Sheep</td>
<td>100-350 lbs (45-160 kg)</td>
<td>100-225 lbs (45-100 kg)</td>
<td>Wikipedia (2008)</td>
</tr>
</tbody>
</table>
Table 4. Body size and weight of the horses, llamas, and sheep used in the experiment (Pers. com. Lethia Olson, livestock supplier). The measurements were taken in November 2010.

<table>
<thead>
<tr>
<th>Individual</th>
<th>Height at shoulder</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horse 1 (Bubba)</td>
<td>5’ (152 cm)</td>
<td>1130 lbs (513 kg)</td>
</tr>
<tr>
<td>Horse 2 (Buster)</td>
<td>5’2’’ (157 cm)</td>
<td>1450 lbs (659 kg)</td>
</tr>
<tr>
<td>Llama 1 (Sparkle)</td>
<td>3’9’’ (114 cm)</td>
<td>350 lbs (159 kg)</td>
</tr>
<tr>
<td>Llama 2 (Cocoa)</td>
<td>3’9’’ (114 cm)</td>
<td>470 lbs (213 kg)</td>
</tr>
<tr>
<td>Sheep 1</td>
<td>2’4’’ (71 cm)</td>
<td>170 lbs (77 kg)</td>
</tr>
<tr>
<td>Sheep 2</td>
<td>2’5’’ (74 cm)</td>
<td>225 lbs (101 kg)</td>
</tr>
</tbody>
</table>

Test periods

In 2009 and 2010 there were four ten day test periods with animals:

- Test period 1: Start on November 19, 2009 (at midnight), end on November 28, 2009 (end at midnight).
- Test period 2: Start on December 17, 2009 (at midnight), end on December 26, 2009 (end at midnight).
- Test period 3: Start on July 30, 2010 (at midnight), end on August 8, 2010 (end at midnight).
- Test period 4: Start on September 2, 2010 (at midnight), end on September 11, 2010 (end at midnight).

For each test day (24 hours), the researchers selected three random one-hour-long sections of video for review (stratified random). This resulted in a total of 30 hours during which the reliability of the system was investigated for each test period, and 120 hours for the four test periods combined. The images from the time periods that were analyzed were all saved on DVD. Time periods that were not analyzed were not saved.

In addition, there were two ten day test-periods without domesticated animals present in the enclosure:

- Test period 1: Start on December 7, 2009 (at midnight), end on December 16, 2009 (end at midnight).
- Test period 2: Start on January 5, 2010 (at midnight), end on January 14, 2010 (end at midnight).

The detection data from these two periods were screened for the potential presence of detections (which may indicate false positives), and extreme environmental conditions (based on weather data from a nearby meteorological station). The researchers selected 10 hours from this ten day period for review. These hours were non-randomly selected based on potential suspicious detection patterns (i.e., detections were reported while there are no domesticated animals present), and extreme environmental conditions.

Reliability Parameters

The time periods reviewed were analyzed for valid detections, false positives, false negatives, and intrusions in the detection area. These terms are defined below (see Huijser et al. 2009b for more details).

- **False positives** – A false positive was defined as “when the system reported the presence of an animal, but there was no animal in the detection zone.” Thus, each incident in which a system’s data logger recorded a detection, but there was no animal present in the detection zone of that system, was recorded as a false positive. The date and time were recorded for all false positives.
- **False negatives** – A false negative was defined as “when an animal was present but was not detected by the system.” However, due to animal behavior and the design of some detection systems (i.e., some systems are desensitized by the continuous presence of an animal), there are several ways for a false negative to occur. Therefore, various types of false negatives were distinguished and these were recorded separately.
- **Intrusions in detection area** – An intrusion was defined as “the presence of one or multiple animals in the detection zone.” An intrusion began when one or more animals entered the detection zone and ended when all animals left the detection zone.
We compared the reliability data to the recommended performance requirements that were obtained through interviews with three stakeholder groups (Huijser et al. 2009b).

RESULTS

The percentage of false positives (i.e., a detection is reported by a system but there is no large animal present in the detection zone) was relatively low for both systems (Magal Senstar: 0%; STS: 0.41%). However, the percentage of false negatives (i.e., an animal is present in the detection zone but a system failed to detect it) differed substantially (Magal Senstar: 1.9%; STS: 16.8%). The percentage of intrusions (i.e., animal intrusions in the detection area) that were detected also varied substantially (Magal Senstar 99.5%; STS: 88.6%). A comparison of the reliability data to the recommended performance requirements that were obtained through interviews with three stakeholder groups (Huijser et al. 2009b) showed that the Magal Senstar system met the recommended requirements, while the STS system did not (Table 5).

<table>
<thead>
<tr>
<th>Manufacturer and system name</th>
<th>Meets false positives (yes/no)</th>
<th>Meets false negatives (yes/no)</th>
<th>Meets intrusions detected (yes/no)</th>
<th>Meets overall recommended norms (yes/no)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magal Senstar (Perimitrax®)</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>STS (RADS III)</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>

DISCUSSION AND CONCLUSION

The results of the reliability tests showed that the percentage of false positives was low for both systems. The percentage of false negatives was higher than the recommended minimum norm for the STS system though. The STS system also did not meet the suggested minimum norm for detection intrusions in the detection zone. The Magal Senstar system met all of the recommended performance requirements for reliability. However, experiences with installation, operation and maintenance with this system along Hwy 160 near Durango, Colorado, showed that this system may still have problems with the integration of different system components (Huijser et al. 2011). The robustness of this and other animal detection systems (see e.g. Huijser et al. 2009b) may have to be improved before the systems can be deployed on a large scale.

BIOGRAPHICAL SKETCHES


Tiffany Allen received a MSc in ecology at Montana State University in Bozeman, MT in 2011, a BSc in fish and wildlife management from Montana State University in Bozeman, MT in 2006, and a BM in music theory from Furman University in Greenville, SC in 2004.

Matt Blank is an assistant research professor at the Western Transportation Institute and the Department of Civil Engineering at Montana State University. Matt earned his Master of Science and Ph.D. in Civil Engineering at Montana State University. He earned his Bachelor of Science in Geological Engineering at the University of Wisconsin-Madison. His research focuses on the interactions of roads and riparian corridors with an emphasis on aquatic connectivity.
Mark Greenwood is a tenured Associate Professor of Statistics in the Department of Mathematical Sciences at Montana State University in Bozeman, MT. He received a PhD in Statistics from the University of Wyoming in 2004. His research involves nonparametric and nonlinear statistical methods with applications in geosciences, ecology, neuroscience, and economics.

Mr. Shaowei Wang was a Research Engineer at WTI through 2010, where he focused on systems and software engineering, data mining and statistical analysis for transportation safety and road weather management, Geographic Information Systems (GIS), software, web, and multimedia development, and cost benefit analysis for engineering applications. He has extensive skills in system architecture design, prototyping, simulation, and modeling. Mr. Wang holds a Master's Degree in Industrial and Management Engineering from Montana State University. He is also a member of the International Council on Systems Engineering.

Larry Hayden has more than 20 years’ experience as a Senior Design Engineer, specializing in telecommunications, radio frequency and microwave circuitry. He has a strong background in mechanical engineering issues, and excellent troubleshooting skills. He has extensive experience in private industry product development, including eight years at Ball Aerospace, where he developed components for telecommunications satellites. At the Western Transportation Institute, he has applied his technical expertise to the development of communication solutions for transportation research facilities, special events, transportation safety and a virtual traffic management center. Currently, Mr. Hayden serves as a Research Associate at the Western Transportation Institute where he focuses on the analysis and development of telecommunications systems for transportation applications.

Mr. Mohammad (Ashkan) Sharafsaleh is a Senior Research and Development Engineer with California PATH Program of UC Berkeley. He has multiple advanced degrees in engineering and has worked as a consultant in private sector as well as the assistant City Traffic Engineer for the City of Berkeley prior to joining PATH in 2002. At PATH, he has managed a variety of projects including Performance Measurement System (PeMS), ITS Decision Website, Construction of PATH’s Intelligent Intersection Test-Bed, and Evaluation of Animal Warning System effectiveness. He has also contributed to a number of other PATH projects throughout the years. The examples of these projects include Intersection Decision Support, Vehicle-Infrastructure Integration, and Cooperative Intersection Collision Avoidance Systems. He has also vast experience dealing with cities, counties, and state institutions for deployment and field collection efforts.

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LITERATURE CITED


