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II. Road Ecology Seminar

ROAD AND VEHICLE SYSTEM

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Abstract

Road ecology principles are superimposed on an immense, dominant and seemingly essential road and automobile lifestyle. The road-vehicle system in America has evolved to dominate travel and freight. More than 89% of all trips made by Americans in 1999 were made in motor vehicles.

Public roads and their right-of-ways cover about 1.5% of U.S. land area. The road system includes 3.9 million center lane miles and 8.2 million total lane miles. Local roads, that provide direct access to land, comprise nearly 70% of all linear miles of roads, but carry only about 13% of traffic, while the Interstate Highway System which is only 1.2% of U.S. road miles carries nearly 23% of all vehicle traffic.

This large road system has been shaped by U.S. political history and regional land use patterns, as well as road designs for modern vehicles. The road network in the Eastern United States was built along footpaths and natural lines. Roads in the Midwest were often developed along surveyed section lines to which sixty-six foot right of ways were assigned. Roads in the West have often been built to connect major population centers across relatively unpopulated areas.

Over 75% of roads, measured as center lane miles, are in rural areas, and about one half of rural roads are unpaved. Surprisingly, most of the linear rural road miles in America were already here at the turn of the century, before automobiles, linking land parcels to rails, markets and cities. However, few miles of this system were paved. The rapid adoption of automobiles and trucks after WWI lead to the systematic paving of the road system and eventually led to the addition of an interstate freeway system after WWII. In part, the federal government promoted the interstate system for defense purposes to carry heavy equipment and armament to ports. American cities also successfully lobbied to be an integral partner in the Interstate System. However, the most significant impact of the Interstate System has been to link American regions and facilitate car and truck use. The Interstate Highway System was completed in 1990. Since 1990 the Federal Government has shifted its focus to maintenance of the current system and increased funding of transit, bike paths and better integration of rail and other modes of travel to the car-road system. New freeway building has slowed in recent decades; most new building is either local roads and arterials in sub-urban developments or additional lane miles to existing corridors. More significant than road building are increasing congestion, fuel use, noise and urban sprawl effects. While some forms of transit will grow and air travel will increase, these are a small percentage of overall travel, and automobile travel will continue to grow in the near future faster than population and GNP.

The heavy use of this road and vehicle system is a source of a wide range of problems, including air pollution (including greenhouse gases), ground water pollution, noise, and creating a physical barrier to other types of movements such as walking and bikes, accidents, as well as increasing dependence on petroleum imports. Transportation researchers are now focused on making the system less harmful and more energy efficient. Over the last few decades automakers have made good progress in making vehicles cleaner, pushed by air quality standards. Most recently car makers and regulators have begun to work on improving the efficiency of

cars to reduce CO_2 emissions. A range of new technologies are emerging including efficient electric drive vehicles, especially hybrid-electric vehicles, and dedicated compressed natural gas vehicles. These vehicles will have lower tailpipe and cold soak emissions, reduce CO_2 emissions and in most cases use less coolants and lubricants, and in some cases are quieter.

In summary, the road vehicle system is a mature and essential system that is unlikely to be replaced in the near future. It will not grow much on a percentage basis in the future but will have increased numbers of technical improvements to vehicles, surfaces, design and control systems to increase the flow and decrease the unwanted impacts of vehicles and roads on ecosystems, quality of life and national security.

Biographical Sketch: Tom Turrentine is a Research Scientist with the Institute for Transportation Studies at UC-Davis. Dr. Turrentine studies the role of travel and movement in the evolution of culture, society and lifestyle. He focuses on understanding automobile-based lifestyles, applying anthropological methods and theories to explore potential responses of car users to new technologies and policies aimed at mitigating the negative impacts of automobile infrastructure and use. He has studied consumer responses to electric vehicles, alternative fueled vehicles, micro-vehicles, station car systems, advanced traveler information, and other intelligent transportation systems. Dr. Turrentine also studies travel behavior and road systems in environmentally sensitive areas, focusing on Yosemite National Park and the Sierra Nevada region in California.

ROADSIDES AND VEGETATION

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Abstract

A huge area, equal to 100,000 football fields in every state of the U. S., is devoted to roadsides. Most travelers see nothing there...a boring void. Yet looking closely reveals a set of plants different from those in adjacent land. Vegetation zonation across the roadside, together with patches scattered over it, is conspicuous. And like a movie film, the sequence of vegetation along the road often changes markedly. Despite these distinctive patterns, ecologists see more problems than benefits. Indeed, roadsides represent an enormous opportunity for new thinking and approaches by the transportation community, science and society.

Road construction normally is a process of moving, homogenizing, molding and smoothing earth to produce a safe, efficient and hydrologically stable road. Roadsides begin without their inherent natural heterogeneity. Soil, vegetation, and animal communities thus become relatively monotonous and impoverished. The earth forms...including road shoulder, ditch, outer roadside, cutbank and fillslope...are somewhat novel habitats in the landscape, especially with traffic effects superimposed on them. Soil erosion and its control mechanisms are a major issue, and establishing natural plant communities on roadsides remains a challenge.

At least two dozen chemical constituents of pollutants emanate from road systems and probably have significant ecological effects (FHWA 1996). Four-fifths of the chemicals come from vehicles, with a wide variety of sources: oil, grease, hydraulic fluids, engine and parts wear, metal plating and rust, tire wear, brake lining wear, and fuel and exhaust. Non-vehicular sources include sanding and de-icing agents, roadbed and road surface wear, and herbicide and pesticide use. Pollutant levels in road runoff often correlate poorly with traffic volume, though several pollutants seem to correlate with traffic volume during storms. With a high diversity of pollutants and sources, mitigation or best-management-practice solutions for pollutants in road runoff are difficult.

The total diversity of roadside plants along a road tends to be quite high, largely because of the many non-native species added (Harper-Lore 1999). In contrast, plant diversity is often low at a specific spot or site. The spread of non-natives along roads is favored by ditching, road salt, vehicle transport, vehicle-caused wind, and habitat homogenization in road construction. Native rare species are present in roadsides though little studied. Rock outcrops, bridges, culverts, other concrete structures (with calcareous conditions), and blocked-drainage spots may provide microhabitats for rare species. In intensively altered landscapes such as for agriculture, roadsides may harbor some of the rare species and natural communities remaining, and thus be of considerable conservation interest. Although roadsides often contain numerous non-native species, and non-natives invade ranchland, cultivated land, parkland and natural areas, little is known about how important roadsides are in these invasions.

Road-shoulder vegetation subject to vehicle disturbance, numerous pollutants and road maintenance differs sharply from ditch vegetation with much more water and sediments. Ditch vegetation differs in turn from the outer-roadside plant community with usually well-drained soil, less vehicular and maintenance disturbance, and more intense influence of adjacent land. Disturbance-induced early successional stages may be of conservation importance in areas of mature vegetation. Roadside natural strips (road reserves) in intensive agricultural landscapes of Australia are an impressive example of protecting relatively natural communities along roads. Creating roadsides as a mosaic strip, e.g., of successional communities, rare-species habitats, shrubland, savanna and forest for carbon sequestration and/or wood products, could contribute to many of society's goals.

Maintenance, mowing and management occur in countless combinations, with highly diverse ecological effects (Aanen et al. 1991). For instance, vegetation can be mowed at different times and different frequencies, as well as in alternating strips of varying size, located either along the road or laterally across the roadside. Wildflower patches may be planted, tree saplings maintained or removed, wildlife encouraged or discouraged, wet spots protected or drained, and so forth. In effect, the nature of roadsides is strongly determined by road managers and workers.

The ecology of visual quality is especially important in the many miles of roadsides along which the average American spends several hours a week. In the U. S. the perception of high-visual-quality roadsides has gradually changed from neatness to an increasing emphasis on beautification, followed by ecological conditions, and more recently cultural dimensions including a sense of place. The consequent ecological changes in roadsides are equally diverse. Ecological characteristics such as biodiversity, wildlife movement, vegetation type, erosion, water flows and water quality of high-visual-quality roadsides usually differs sharply from those of low-visual-quality roadsides.

In conclusion, the huge area devoted to roadsides offers few ecological benefits, but with new approaches, nature's heterogeneity and richness could be reestablished, and roadsides could provide many resources and uses to society. Chemical pollutants from road systems are highly diverse, suggesting the absence of a "magic bullet" and the need for diverse solutions. The abundance of rare species in roadsides and the roles of non-native species remain little known. Finally, maintenance, mowing and management offer an enormous opportunity to enhance both roadsides and the landscapes surrounding us.

Biographical Sketch: Richard T.T. Forman is Professor of Advanced Environmental Studies in Landscape Ecology at Harvard University's Graduate School of Design, where he teaches ecological courses and conducts research on landscape and regional ecology. Forman is particularly interested in the linking of scientific principles with spatial dimensions to discover compatible patterns for nature and people. Forman received his B.S. from Haverford College, his Ph.D. from University of Pennsylvania, an honorary M.A. from Harvard University, an honorary doctorate from Florida International University, as well as an honorary Doctor of Humane Letters from Miami University.

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ANIMAL POPULATIONS AND ROADS

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Abstract:

The purpose of this paper is to summarize what is known about the effects of roads on persistence of wildlife populations and to highlight areas requiring further research. By definition, populations decline before they go extinct. Small populations are known to be more susceptible to extinction (Wilcox and Murphy 1985). Therefore, the question "how do roads affect persistence of wildlife populations?" is equivalent to the more tractable question "how do roads reduce wildlife populations?" Figure 1 summarizes the ways in which roads reduce wildlife population sizes and thereby reduce population persistence.

Roads directly reduce population size through mortality (Fahrig et al. 1995) and habitat loss (Forman 2000). Habitat loss is further reduced for species that avoid habitats near roads (Reijnen et al. 1996). In addition to these direct effects on population size, roads reduce movement of animals through the landscape, which can fragment populations, thus reducing their sizes. Reduced movement can also restrict access of individuals to required resources. This limited access may result in death (e.g., through starvation) or lack of reproduction (e.g., inability to access a mate), both of which can ultimately reduce population sizes.

An important question is "what is the relative importance of habitat loss, resource inaccessibility, habitat fragmentation, and road mortality on population persistence?" This question has important implications for determining what mitigation measures should have priority. For example, Jaeger and Fahrig (2001) suggest that direct road mortality generally has a larger and more immediate effect than reduced movement on population persistence. This suggests that, when a species has a high risk of mortality from a road, fencing the road is a good interim measure until proper mitigation structures such as overpasses or underpasses (Clevenger 2001) can be built.

The relative effects of the four factors depend to a large extent on knowledge about species responses to roads. Animals with low reproductive rates, low density and high space requirements will be susceptible to all road effects. Animals that avoid roads and require several different kinds of habitats will be susceptible to the effects of habitat inaccessibility. Highly vagile animals that are habitat generalists (Carr and Fahrig 2001) and species that are attracted to roads (e.g., reptiles for basking) will be particularly susceptible to traffic mortality. Species with high road avoidance and forest interior specialists (Ortega and Capen 1999) will be more susceptible to habitat loss and fragmentation effects.

Although the linkages in Figure 1 seem logical, in many instances there is little or no actual research to provide evidence or estimate the magnitude of the effect. For example, although there are a large number of studies documenting numbers of animals killed by roads, very few studies document an effect of this mortality on population size (van der Zee et al. 1992; Fahrig et al. 1995; Vos and Chardon 1998). The degree of road avoidance is a critical piece of information required for accurately estimating habitat loss due to roads and possible effects of roads on population fragmentation. Relatively little information is available on road avoidance. Reduced population densities near roads do not necessarily indicate road avoidance, since they could also result from road mortality. Radio-telemetry studies have been conducted on large animals (e.g., Mace et al. 1996), but more such studies are needed on a wide range of species to determine the extent of road avoidance and how this depends on traffic volume. Documentation of the effects of roads on resource inaccessibility will require studies comparing population densities near roads in situations where both resources are available on the same side of the road vs. situations were required resources are available only on opposite sides of the road. Studies are also needed to determine whether population densities in areas

surrounded by (fragmented by) roads are actually lower than densities where roads do not fragment the landscape.

In summary, roads can affect population persistence through their effects on population density. There are several mechanisms for this effect. Research is needed to document the hypothesized linkages and to estimate their relative magnitudes.

Biographical Sketch: Dr. Lenore Fahrig, a Professor at Carleton University in Ottawa, studies the effects of landscape structure on abundance, distribution and persistence of organisms. In her research, Lenore uses spatial simulation modeling to formulate and test predictions using a range of different organisms. Her current work on road system ecology includes empirical studies of road impacts on small mammal and amphibian populations and movements, as well as generalized simulation modeling of population responses to road networks. Lenore obtained her Ph.D. in 1987 from the University of Toronto, Canada. Her postdoctoral fellowship was performed at the Virginia Coast Reserve LTER (University of Virginia, U.S.A.); she also previously worked as a Research Scientist in the Canadian Department of Fisheries and Oceans in Newfoundland, Canada.

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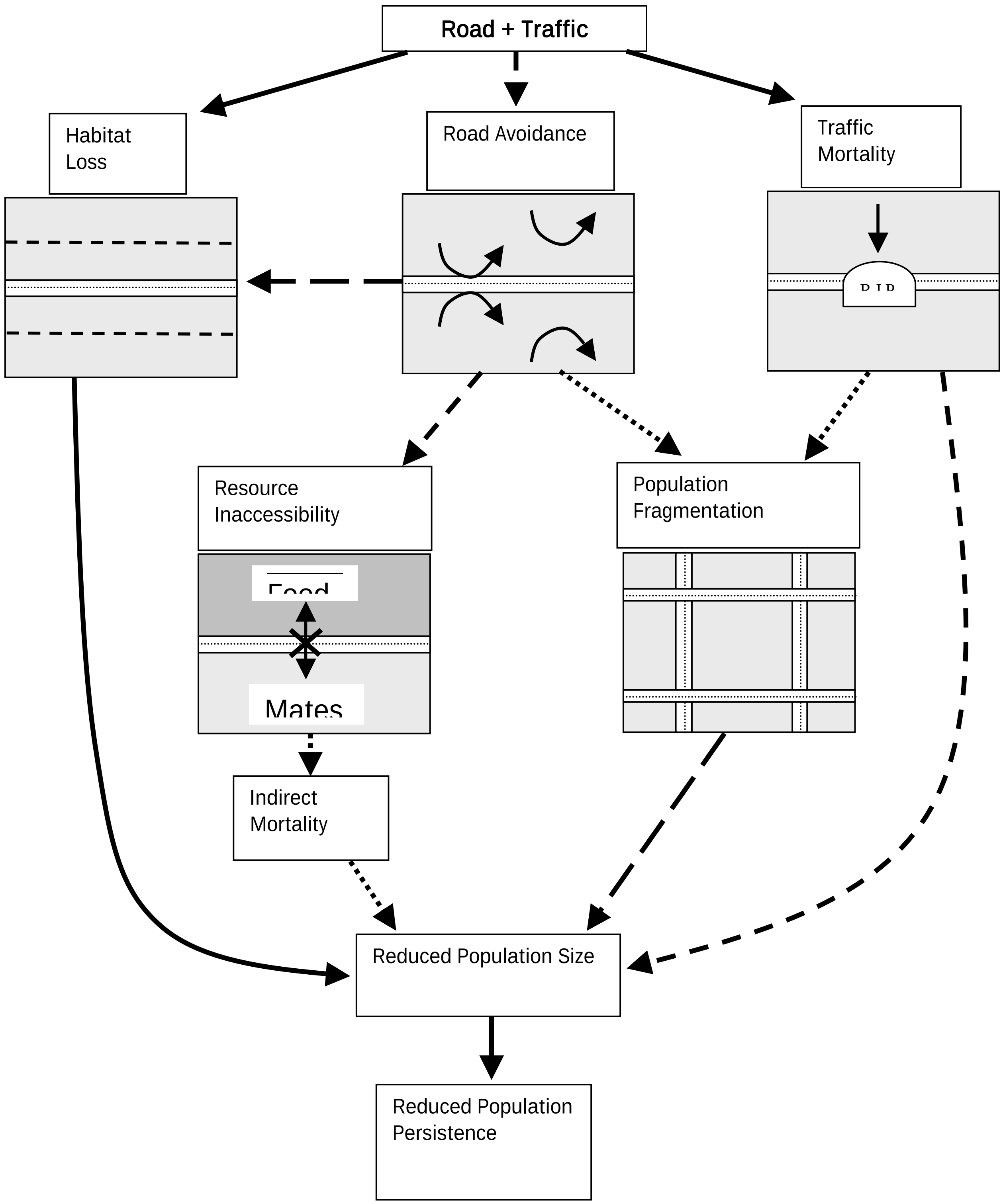

Fig. 1. Effects of roads and traffic on persistence of animal populations.
Solid lines represent good evidence for the effect, dashed lines moderate evidence for the effect and dotted lines represent weak evidence, i.e., areas where further research should be a priority.

MITIGATION FOR IMPACTS OF ROADS ON WILDLIFE

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Abstract

The previous section described the ways roads can impact wildlife populations (Fahrig, this volume). The aim of this summary is to describe the measures used to mitigate the effects of mortality, barrier effects and habitat loss on animal populations, report on current performance evaluations of the measures, and lastly, identify the principles emerging from our knowledge of road effects on wildlife populations and the measures designed to reduce them.

Many techniques have been used to reduce mortality of wildlife on roads and nearly all designed for large animals. Romin and Bissonette (1996) identified 11 mitigation measures used by 42 state transportation agencies to reduce deer-vehicle collisions. They concluded that few rigorous performance evaluations had been carried out, yet measures were still being used by the agencies. Evaluations often times were based solely on opinion and not data collected from monitoring effectiveness. Of the techniques reviewed, fencing and wildlife crossing structures were believed to be the most effective in reducing collisions. Fencing alone tends to reduce accidents but it also may force animals to cross at fence ends, thus solving one problem but creating another. Fencing also effectively fragments habitat and limits movement within a population. The combination of fencing and crossing structures, however, are proven measures to reduce road-kills and maintain habitat connectivity (Child 1998, Clevenger et al. 2001). For combined fencing and crossing structures to be functional fences have to been maintained and surveyed frequently. Other collision-reducing techniques have been tested but are largely ineffective in reducing deer-vehicle collisions. However, novel and mobile signage may be a promising technique (Hindelang et al. 1999). The measures designed to mitigate road mortality consist of either changing the behavior of motorists (warning, calming, improving visibility, managing traffic) or animals (modifying movements or access by fencing, gates, passages, altering habitat quality).

Wildlife passages are used to mitigate barrier effects and fast becoming standard measures in road construction and upgrade projects. However, few rigorous evaluations have been conducted to assess their efficacy (Romin and Bissonette 1996). Monitoring and performance evaluations are essential, enabling us to determine whether passages are meeting criteria for success, if retrofitting or landscape enhancements are needed, and more importantly, what design features might be critical for passage construction in the future. Wildlife passages come in all shapes and sizes. Amphibian tunnels, ecopipes, ecoculverts, and talus tunnels are some examples for small fauna. Large passages generally consist of underpass and overpass structures.

We summarized 17 published studies evaluating wildlife passages and identified the several knowledge gaps and deficiencies, the most critical being the lack of rigorous studies, most evaluations being based on observed passage without considering expected passage, and currently little is known about means of determining passage placement.

Measuring passage effectiveness is a complex task. Few criteria have been developed to assess wildlife passage effectiveness. Judging success needs to take into account both the goal of reducing road-related mortality and the goal of maintaining habitat connectivity. Managers and scientists may have different criteria for evaluating effectiveness. Further, animals need time to adapt to new structures and populations need even more time, possibly decades. Answering some of the complex ecological questions around roads and long-lived wildlife, like grizzly bears, may require research timeframes of up to 10-20 years.

There are two means of mitigating for habitat loss or quality. Compensation is used when road construction projects cannot avoid sensitive habitats or reduce impacts at problematic spots with mitigation measures. Compensation implies that for road developments there is a no-net-loss of natural processes and biodiversity. The creation or enhancement of habitat near roads is another way of mitigating for habitat loss. The construction of ponds, wetland habitat or vegetated earth berms along right-of-ways are some examples.

Some principles have emerged from our knowledge of how roads affect wildlife populations and means of mitigating those impacts. The ecological impact of roads is not confined to the road itself. We know little about the factors influencing road-kills. For wildlife populations to remain viable roads must be permeable to their movements. There is a lag-time between an effect occurring and when the effect may impact a population. There are many unknowns regarding the effectiveness of mitigation measures and few performance criteria developed. Finally, highway mitigation is most economical if built into new highway or lane upgrade, but not by retrofitting an existing highway.

Biographical Sketch: Anthony Clevenger is currently directing a 5-year research project addressing the ecological effects of roads on wildlife populations in the Central Canadian Rocky Mountains. The investigation focuses primarily on the Trans-Canada highway in Banff National Park, it's permeability for wildlife, and effects in terms of wildlife mortality, movements, and habitat connectivity in the Bow River Valley. The study will be completed in April 2002.

Anthony Clevenger received a B.Sc. degree in Conservation of Natural Resources from the University of California, Berkeley, a M.Sc. degree in Wildlife Ecology from the University of Tennessee, Knoxville, and a Ph.D. in Zoology from the University of León, Spain. He has been an adjunct assistant professor at the University of Tennessee, Knoxville since 1989 and the University of Calgary since 1998. In August 2001, he has become a member of the U.S. National Academy of Sciences, National Research Council committee to study the effects of highways on natural communities and ecosystems.

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WATER, SEDIMENT, AND CHEMICAL FLOW RELATED TO ROADS

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Introduction

The presence and movement of water affects roads, and roads affect the movement of water and the material transported by water. A few of the ways water can affect roads include; (1) flooding, (2) destruction of bridges and culverts, (3) erosion of unpaved roads and the shoulders of paved roads, (4) inducing landslides onto roads or sliding of the road itself, (5) deterioration of road surfaces through the freeze/thaw cycle in some climates, and (6) groundwater discharge, which can cause road beds to be unstable.

Roads can be responsible for transporting water and its various loads through watersheds in many ways. A road segment may act as (1) a source of water when water runs off of a road, especially paved roads. (2) a sink for water when water accumulates on a road, (3) a barrier to the flow of water down a hillside, or (4) a corridor for the flow of water when water runs down ruts and depressions in the road surface. In these ways, roads can disrupt natural flows of surface water and groundwater, create new routes for the flow of water, and (or) serve as sources of chemicals and sediment that are introduced into surface water and groundwater. Although the surface of the earth is complex, it is useful to look at the interactions of roads and water for two basic landforms – sloping terrain and flat terrain.

Roads on Sloping Treads

With respect to roads on slopes, water can erode cutslopes and fillslopes, wash out culverts and sections of roads, erode ditches into gullies, and trigger landslides that cover roads or remove road segments. Roads on slopes also affect the movement of water because they block natural flow paths. Examples of some of the interactions of roads and water on hillsides are provided by forest roads in the Cascade Mountains in the Pacific Northwest (Wemple et al. 2001). Contaminants from roads on hillsides can readily move into streams and quickly travel long distances. Because of the dominance of surface flow on hillsides, contamination of groundwater generally is only local in extent because of the shallow subsurface flow paths on hillsides. However, if a road is near the base of a hillside, contaminants associated with roads can contaminate nearby surface water, such as lakes and wetlands. An example is Mirror Lake, at the lower end of the Hubbard Brook valley in New Hampshire. The lake has had increasing concentrations of sodium and chloride since Interstate Highway 93 was constructed through the eastern part of its watershed during 1969-1971. The highway cut across the lower end of the stream draining the watershed east of the lake, thereby intercepting most of the water that would normally drain to the lake from that side. To prevent road runoff from reaching the lake, at the time the freeway was constructed, a diversion berm was constructed across the east inlet stream between the highway and the lake. However, data collected prior to and following road construction indicated that the sodium and chloride concentrations in the lake started to increase a few years after the road was completed, and have continued to increase to the present. A recent study designed to determine the hydrologic pathway of the road salt found that most salt-laden runoff was diverted by the berm, but that some of it was seeping beneath the berm and was then carried to the lake via the east inlet stream (Rosenberry et al. 1999). The study also revealed that groundwater in the fractured crystalline bedrock beneath the highway was contaminated to a depth of at least 123 m (ca 400 ft).

Roads in Flat Terrain

Roads in flat terrain are affected by water largely through flooding and occasional washouts. Roads in such settings can be a barrier to encroachment of floodwater, or they can prevent floodwater from returning to a stream after a flood peak has subsided. In addition, roads in flat terrain commonly transect shallow water bodies. Examples of the latter are provided for two greatly different ecosystems - Great Salt Lake in Utah and some prairie pothole wetlands in North Dakota.

Great Salt Lake in Utah receives most of its fresh water from streams flowing into the southern part of the lake. A railroad trestle was constructed in an east-west direction across the entire lake in 1903, but in 1959 a rock-fill causeway was constructed to replace the trestle. The trestle permitted water to circulate freely throughout the lake, but the causeway was built with only two 15-foot culverts and a 290-foot breach. This design severely restricted water movement between the northern and southern parts of the lake and the two parts quickly took on different characteristics. Before the causeway was constructed, and only the trestle crossed the lake, the dissolved solids concentration of the lake in the northern and southern parts were about equal. A recent study indicated that by 1972 salt concentration in the northern part was about 200 grams per liter greater than in the southern part, and by 1998 it was 250 grams per liter greater (Loving et al. 2000).

Two small prairie lakes near Crystal Springs in North Dakota were transected by an Interstate highway, U.S. highway, county highway, and a railroad. In their natural condition, these two lakes received water and dissolved chemicals from groundwater, which were then circulated freely throughout the lakes. Disruption of the circulation pattern of the lakes by the roadbeds resulted in each of the individual pools having substantially different chemical and biological characteristics because some no longer received the constituents brought in by groundwater. The pools that continued to receive groundwater input following road construction, Crystal Springs Lake north of the railroad and pool F of Stink Lake, remained the freshest. Crystal Springs Lake continued to support game fish. Because the fresh groundwater input to pool F of Stink Lake could no longer circulate throughout the lake after road construction, the main body of Stink Lake and pools A and B of Stink Lake reached specific conductances of 20,000 S/cm or greater. Stink Lake itself became habitat for brine shrimp (Swanson et al. 1988).

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ROAD SYSTEMS INTERACTING WITH THE LAND

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Abstract:
Road networks with traffic flows are embedded in, and intensively interact with, the land. Thus road systems affect surrounding landscapes by altering river systems, fragmenting habitats, disrupting wildlife movements, and widely distributing numerous exotic plants. Conversely, the land affects road systems by washing out road segments and harboring large animals involved in auto accidents. Of course, some road-system-and-land interactions are positive, such as the pleasure of viewing landscapes. In short, the mosaic of natural ecosystems and land uses composing a landscape tends to be permeated by roads and vehicles, which produce myriad effects. Fortunately, landscape ecology, focusing at exactly the same scale as road systems, offers great promise in transportation, conservation and planning (Forman 1995, National Research Council 1997).

Land-use patterns set the structure of road networks. A sampling of landscape areas on the scale of 1000 km^2 generally contains two components of road systems---a coarse-grained network of highways connecting population centers, and a fine-grained intensive network of roads serving local land uses. The grain of the local network is strongly determined by the size of the local patches of land-use activities served. Residential lots in suburbs, farm fields in agricultural landscapes, and viewpoints in parklands commonly create the grain size of the landscape or mesh size of the road network.

Road density (km of road length per km^2 of land area) and traffic volume are major determinants of the effects of road systems on the land. Typically average road density ranges from about 40 km/km^2 in urban centers to nearly zero in wilderness. Road density progressively and curvilinearly decreases from urban center to suburbia to rural residential (or sprawl) area to mountain forestry land to agricultural landscapes (U. S. Central Plains) to arid grazing land to parkland and to wilderness. Traffic volume follows a similar curvilinear change across these landscape types.

Rectilinear networks tend to characterize flat areas, wavy or irregular rectilinear networks in topographically varied areas, and dendritic-like networks in rugged terrain, especially with forestry activity. Many structural properties of rectilinear networks and of dendritic networks appear to be ecologically important. The hierarchy of highway-and-road sizes, the mesh size of enclosed patches, overall network connectivity, circuitry (the frequency of alternative routes), total road surface area, and habitat fragmentation due to roads are examples. In addition, traffic flows exhibit a hierarchy in the network.

Change in road systems also determines interactions with the landscape. Traffic volume changes significantly and cyclically over three time scales, diurnal (commuter flows), weekly (weekend movements), and seasonally. Traffic also generally changes non-cyclically over years. In addition, road networks evolve over time, manifesting changes in most of the structural and functional network properties. Thus ecological effects of the network on the land, and vice versa, tend to be dynamic.

Road effects extend different distances from a roadway depending both on the landscape type and the ecological factor considered. For example, heavy metals and herbicides tend to exert significant effects only meters or tens of meters from a road surface, whereas some avian communities and large mammals are affected for hundreds of meters. Thus for a typical road density in a sprawl or agricultural landscape the network-caused effect of these chemicals covers little of the land, whereas the effect on the vertebrates covers much of the land.

Indeed, the form of road networks is a better indicator of road effects or naturally functioning ecosystems in a landscape than is road density. Countless network forms can have the same average road density. But for instance, only those with a large natural-vegetation patch would likely support key interior species or an unpolluted aquifer.

In steep wet landscapes, such as in the Pacific Northwest, road networks strongly interact with dendritic stream networks. Here roads divert groundwater flows to surface water in ditches that deliver water to streams, which in turn may lead to more downstream flooding. Also some bridges and culverts are inadequate to permit passage of water, sediment and wood during major floods, which may lead to landslides and road blockages. Thus the placement of road networks in the landscape, especially relative to stream networks, is a key challenge for road planners and land-use managers.

Landscape type is, of course, a major indicator of the interaction of road systems and land. For example, in suburban landscapes, pollutants in storm-water drainage from the road network often have a major effect on groundwater and stream water quality. In intensive agricultural landscapes roadsides may contain many of the uncommon plant and butterfly species in the landscape. And in dry landscapes road systems probably generate a significant portion of the airborne particulate matter.

In conclusion, three road system characteristics may provide the handle for understanding ecological interactions between road systems and the land: (1) total road surface area; (2) form of the road network; and (3) traffic volume. Integrating the spatial patterns and movements of organisms and materials across landscapes with the spatial patterns and changes in roads and traffic represents a challenge for science, transportation and society. It is also at the core of a future where safe and efficient transportation and protection of ecological flows and biodiversity are highlighted together.

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ALIGNING ROAD ECOLOGY, PROFESSIONALLY AND SCIENTIFICALLY

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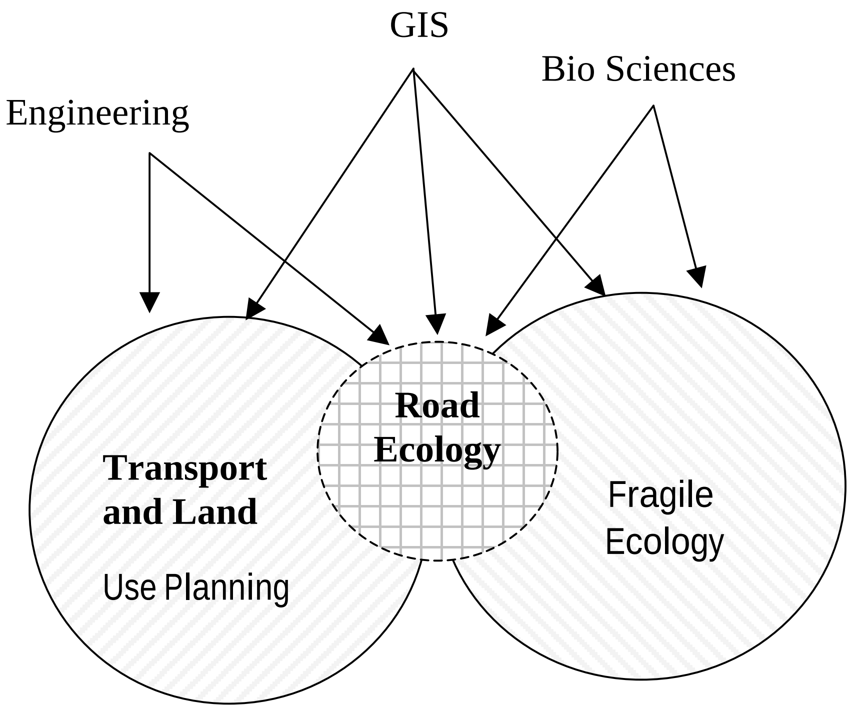
Abstract
What is "Road Ecology"? How does it relate to existing professional and scientific groupings? What role might it play and how? It is my belief that it should focus on the metropolitan fringe – where population growth is most rapid, and most new roads are likely to be built in the foreseeable future.

Consider the schematic below (inspired by discussions with Professors Richard Forman and Martin Lee-Gosselin).



This simple schematic may be viewed on two levels. From a spatial perspective, it suggests that road ecology lies at the intersection of metropolitan-focussed land use and transport planning, and rural-focused ecologists. The latter have historically dealt with large parks and low-volume roads. Land use and transport planners are focused on the built environment, while ecologists deal largely with sensitive areas with a minimal human population.

On a professional level, the two groups are quite distinct. Land use and transport planners employ a large set of transport network and travel forecasting models. These professionals are part of a deeply entrenched and institutionalized process responsible for allocating transportation funds. Park and rural ecologists, in contrast, are rooted in the biological sciences, and their activities are not nearly as codified or institutionalized. They deal with wildlife, plant life, aesthetics, aquatic hydrology, and so on.

Is road ecology simply the intersection of the two groups? At present, the answer is probably yes. But it could be much more, as suggested by the schematic; it could assume a larger scientific and professional presence, building synergies and strong interactive ties with the other two groups.

Key Research and Policy Issues

- Road ecology addresses the relationship between roads and the surrounding environment. The relationships are complex and many. They are not well understood. Below are research and policy issues and actions that would be part of an initiative to create a scientific and professional field of road ecology.
- To what extent should road ecology focus spatially on the metropolitan fringe, as a profession and scientific discipline?
- A base of knowledge needs to be created that integrates the many fragments of knowledge into a coherent whole. The book project launched by Professor Richard Forman and myself is a first step in synthesizing ad documenting what is known (R. Foreman and D. Sperling, *Road Ecology: Science and Solutions*, Island Press, forthcoming)
- Focus on accumulating knowledge relevant to ecological impacts of roads at the urban fringe. Most ecological inquiry has been focused on large parks and remote, ecologically fragile areas – where few people live and impacts are remote.
- Develop methods and tools that are relevant to analyzing impacts of infrastructure and its use. Such tools are virtually non-existent. In contrast, consider the three decade long institutionalization of travel demand models in metropolitan areas, and the long time use of air quality and vehicle emissions models for air quality planning purposes. Note that these models and methods were mandated by federal rules for regions desiring federal transport funds (which is all regions).
- Related to the above issue is the glaring lack of expertise in road ecology issues in small cities and other political entities at the urban fringe -- yet this is where the needs are greatest.
- What is important to people? Which impacts are of greatest concern, or might be? Sophisticated survey research and contingent valuation studies are needed to provide some sense to policy makers of relative priorities.
- How severe are the impacts of light suburban development and roads at the urban fringe, compared to other uses such as intensive agriculture? Are roads and light development better or worse than intensive agriculture? Is that the central question? At the margin, what happens and what should be done? How effective and how costly are mitigation strategies and alternative land use strategies and development patterns?

Biographical Sketch: Daniel Sperling is Professor of Civil Engineering and Environmental Science and Policy, and founding Director of the Institute of Transportation Studies at the University of California, Davis. He is also co-director of UC Davis's Fuel Cell Vehicle Center and New Mobility Center. Sperling is recognized as a leading international expert on transportation technology assessment, energy and environmental aspects of transportation, and transportation policy.

Prior to obtaining his Ph.D. in Transportation Engineering from the University of California, Berkeley, Sperling worked two years as an environmental planner for the U.S. Environmental Protection Agency and two years as an urban planner in the Peace Corps in Honduras. He has an undergraduate degree in engineering and urban planning from Cornell University. During 1999-2000, he was on leave as a visiting scholar at OECD (European Conference of Ministers of Transport).