

Making America's Highways Safer for Drivers and Wildlife

Wildlife-Vehicle Collision Reduction Study

REPORT TO CONGRESS



U.S. Department of Transportation
Federal Highway Administration

FHWA-HRT-08-034
August 2008

FOREWORD

America's highways allow people and products to travel to every corner of our nation. Along the way, these roads cut across the habitat of many native wildlife species. When these paths cross, collisions occur, and in greater numbers than most people realize. This presents a real danger to human safety as well as wildlife survival. State and local transportation agencies are looking for ways to find a balance among travel needs, human safety, and conserving wildlife.

This national study details the causes and impacts of wildlife-vehicle collisions and identifies potential solutions to this growing safety problem. This Report to Congress focuses on tools, methods, and other measures that reduce the number of collisions between vehicles and large wildlife, such as deer, because these accidents present the greatest safety danger to travelers and cause the most damage.

Michael F. Trentacoste
Director, Office of Safety
Research and Development

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| 16. Abstract Under the SAFETEA-LU Congressional Bill, the Secretary of Transportation was directed to conduct a national wildlife-vehicle collision (WVC) reduction study. The study was to advance the understanding of the causes and impacts of WVCs and identify solutions to this growing safety problem. This report contains the findings of this study, beginning with estimates on the current magnitude and trend for WVCs in the United States. Based on several national datasets, the study found that there are between one and two million WVCs annually in the United States and that the number is increasing. Estimates are provided for the costs associated with WVCs, and the impact of direct road mortality is described for 21 federally listed threatened and endangered species. The core of the report is an in-depth review of over 34 WVC mitigation methods assembled from information obtained from hundreds of literature sources (both published and "gray" literature). Each mitigation measure is described in detail, and information including case studies, benefits, costs, undesirable effects, and design guidelines is provided. The report also covers planning and design considerations and provides cost-benefit analyses for the mitigation methods that had sufficient data available to support these analyses. A working group of seven national experts provided input and evaluated the effectiveness of the mitigation methods, categorizing them as either recommended for implementation, recommended for future research, or not recommended for future research or implementation. A summary of their evaluation is included in this report. Recommendations for implementation of effective measures and for further investigation of promising mitigation measures are provided. | | | |
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| SI* (MODERN METRIC) CONVERSION FACTORS | | | | |
|--|-----------------------------|-----------------------------|-----------------------------|---------------------|
| APPROXIMATE CONVERSIONS TO SI UNITS | | | | |
| Symbol | When You Know | Multiply By | To Find | Symbol |
| LENGTH | | | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| AREA | | | | |
| in ² | square inches | 645.2 | square millimeters | mm ² |
| ft ² | square feet | 0.093 | square meters | m ² |
| yd ² | square yard | 0.836 | square meters | m ² |
| ac | acres | 0.405 | hectares | ha |
| mi ² | square miles | 2.59 | square kilometers | km ² |
| VOLUME | | | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| ft ³ | cubic feet | 0.028 | cubic meters | m ³ |
| yd ³ | cubic yards | 0.765 | cubic meters | m ³ |
| NOTE: volumes greater than 1000 L shall be shown in m ³ | | | | |
| MASS | | | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| TEMPERATURE (exact degrees) | | | | |
| °F | Fahrenheit | 5 (F-32)/9 or (F-32)/1.8 | Celsius | °C |
| ILLUMINATION | | | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/m ² | cd/m ² |
| FORCE and PRESSURE or STRESS | | | | |
| lbf | poundforce | 4.45 | newtons | N |
| lbf/in ² | poundforce per square inch | 6.89 | kilopascals | kPa |
| APPROXIMATE CONVERSIONS FROM SI UNITS | | | | |
| Symbol | When You Know | Multiply By | To Find | Symbol |
| LENGTH | | | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| AREA | | | | |
| mm ² | square millimeters | 0.0016 | square inches | in ² |
| m ² | square meters | 10.764 | square feet | ft ² |
| m ² | square meters | 1.195 | square yards | yd ² |
| ha | hectares | 2.47 | acres | ac |
| km ² | square kilometers | 0.386 | square miles | mi ² |
| VOLUME | | | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| m ³ | cubic meters | 35.314 | cubic feet | ft ³ |
| m ³ | cubic meters | 1.307 | cubic yards | yd ³ |
| MASS | | | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| TEMPERATURE (exact degrees) | | | | |
| °C | Celsius | 1.8C+32 | Fahrenheit | °F |
| ILLUMINATION | | | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/m ² | candela/m ² | 0.2919 | foot-Lamberts | fl |
| FORCE and PRESSURE or STRESS | | | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/in ² |

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS FOR COLLISIONS WITH ANIMALS

| | |
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| AVC | Animal-vehicle collisions. Collisions with wild and domestic animals in cases where domestic animals could not be separated from the dataset. |
| WVC | Wildlife-vehicle collisions. Collisions with all species of wild animals. |
| DVC | Deer-vehicle collisions. WVCs that involve only deer. A separate term is used for deer and no other specific type of animal because deer account for a majority of WVCs when data are available. When information is specific to one type of animal other than deer, no abbreviation is used (e.g., moose-vehicle collision). |

ABBREVIATIONS

| | |
|---------|---|
| ADT | Average daily traffic, is defined as the total volume during a given time period (in days), greater than 1 day and less than 1 year, divided by the number of days in that time period. ⁽¹⁾ In this report the time period is always 1 year. |
| AASHTO | American Association of State Highway and Transportation Officials |
| ADOT | Arizona Department of Transportation |
| BTS | Bureau of Transportation Statistics of the U.S. Department of Transportation |
| CaMg | Chemical formula for calcium magnesium acetate, a common alternative to road salt for deicing. |
| CSD/CSS | Context-sensitive design/context-sensitive solutions, is a planning and/or design strategy that attempts to consider scenic, aesthetic, historic, environmental, and community values. |
| DOT | see State DOT |
| DMS | Dynamic message signs, also referred to as variable message signs |
| FARS | Fatal Accident Reporting System, is a national dataset that includes all crashes with a human fatality. |
| FHWA | Federal Highway Administration |
| GES | General Estimates System, is a dataset that enables estimates of national crash numbers based on a national sample. |
| GIS | Geographic Information Systems, which relates to spatial data standards and in some cases, sets of spatial data. |
| GPS | Global Positioning System |

| | |
|------------|---|
| HSIS | Highway Safety Information System, is a dataset that includes all reported crashes from Washington, California, Illinois, Maine, Michigan, Minnesota, North Carolina, Ohio, and Utah. |
| IUCN | International Union for Conservation of Nature and Natural Resources |
| km/h | Kilometers per hour |
| LED | Light-emitting diode, a technology used for, among other things, lighted signs and flashers. |
| MNDOT | Minnesota Department of Transportation |
| mi/h | Miles per hour |
| MUTCD | <i>Manual on Uniform Traffic Control Devices</i> , which provides national guidance and standards for, among other things, warning signs and signals. |
| NaCl | Chemical formula for sodium chloride (salt), a common deicing chemical |
| NCHRP | National Cooperative Highway Research Program |
| NPS | National Park Service |
| NYSDOT | New York State Department of Transportation |
| ROW | Right of way, refers to the area owned by the transportation agency, including the roadside. |
| SAFETEA-LU | Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users, which is the primary congressional bill for surface transportation programs, signed by President George W. Bush in August 2005. |
| State DOT | State department of transportation in general (i.e., not a specific state) |
| USDOT | U.S. Department of Transportation |
| USFWS | U.S. Fish and Wildlife Service |
| VMT | Vehicle miles traveled |

SYMBOLS

| | |
|-------|--|
| \$ | Followed by a numerical value refers to dollar value. Unless otherwise specified, reported values are in U.S. dollars. |
| Can\$ | Followed by a numerical value refer to Canadian dollars. |
| € | Followed by a numerical value refers to Euros. |

EXECUTIVE SUMMARY

America's highways allow people and products to travel to every corner of our nation. Along the way, these roads cross through the habitat of many native wildlife species. When these paths intersect, collisions can occur, and in greater numbers than most people realize. Based on the results of this study, there are an estimated one to two million collisions between cars and large animals every year in the United States. This presents a real danger to human safety as well as wildlife survival. State and local transportation agencies are looking for ways to meet the needs of the traveling public, maintain human safety, and conserve wildlife.

Under Section 1119 (n) of the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), the U.S. Congress directed the Secretary of Transportation to conduct a national wildlife-vehicle collision (WVC) study. This study details the causes and impacts of WVCs and identifies potential solutions to this growing safety problem. The report focuses on mitigation methods that reduce the number of collisions between vehicles and large wildlife, such as deer, because these accidents present the greatest safety danger to travelers and cause the most damage (figure ES1).

This summary of the full report highlights the major findings and serves as an introduction to the issue of WVCs. Major findings include:

- WVCs are a growing problem and represent an increasing percentage of the accidents on our roads.



Figure ES1. Photo. A collision with a white-tailed deer can result in extensive property damage (copyright: Marcel Huijser).

- WVCs have significant impacts on drivers and wildlife. For motorists, WVCs present a safety danger and can result in significant costs from vehicle damage. For animals, WVCs often kill the individual animals and can even pose a threat to the very survival of

certain species. This study identified 21 federally listed threatened or endangered animal species in the United States for which road mortality is documented as one of the major threats to their survival.

- There are no simple solutions to reducing WVCs. In this study, the research team reviewed 34 mitigation techniques, a number of which are effective in reducing WVCs, show promise, or are considered good practice, including integrated planning efforts, wildlife fencing and wildlife crossing structures, animal detection systems and public information and education (figure ES2 through figure ES4).



Figure ES2. Photo. Standard deer warning sign along Montana Highway 83 (copyright: Marcel Huijser).



Figure ES3. Photo. Seasonal deer migration sign in Utah (copyright: Marcel Huijser).



Figure ES4. Photo. Wildlife warning and advisory speed limit reduction signs triggered by an animal detection system in ‘t Harde, The Netherlands (copyright: Marcel Huijser).

- A major challenge that must be addressed before WVCs can be systematically reduced is improving the consistency and precision of data collection on WVCs. Inconsistent and imprecise data make it difficult to identify and prioritize road sections that require mitigation.

This document concludes with recommendations for further action. Policymakers who are interested in reducing WVCs can begin by considering the following actions:

- Incorporate WVC reduction into the early stages of planning and design for transportation projects.
- Develop and implement guidelines and standards for collecting data on and reporting WVCs.
- Develop and implement guidelines for evaluating mitigation methods.
- Evaluate the effectiveness of mitigation methods that have been recommended for further research.
- Implement (or install) proven mitigation measures where appropriate.
- Develop and apply wildlife population models to assist with locating and designing mitigation methods.

- Conduct technology transfer to State departments of transportation, resource agencies, and other transportation professionals regarding the findings of this study. A handbook and training course on WVC reduction techniques will be developed by August 2008, which will help in making this information available to practitioners.

WILDLIFE-VEHICLE COLLISIONS: A GROWING PROBLEM ON U.S. ROADS

Isn't This Just a Rural Problem?

According to data from national crash databases, 89 percent of all WVCs (2001–2005) were on two-lane roads. This might lead some people to conclude that WVCs are only a problem in remote, rural locations, but two-lane roads and WVCs are also prevalent in areas where many people live and commute to work in nearby cities. Such two-lane highways are critical travel corridors, and, in the United States, drivers use two-lane roadways for the majority of the total highway miles they travel. Therefore, WVCs are a challenge in every state and for almost all drivers across the country.

How Many Accidents Are There?

Estimates of the total number of WVCs are based on several sources, including crash statistics (from police and highway patrol report information), roadside carcass counts, insurance industry claims information, and interviews with the public.

National crash databases estimate the total number of reported collisions at 300,000 per year. However, most researchers believe that WVCs are substantially under-reported for a number of reasons. Crash databases typically exclude accidents that have less than \$1,000 in property damage, not all drivers report collisions with animals, and not all law enforcement, natural resource, or transportation agencies have the resources to collect detailed information on WVCs. Furthermore, many animals that are injured wander away from the road before they die and are never found.

Using a combination of carcass count data, insurance industry information, police-reported crashes, and interviews with the public, this study estimates that there are between one and two million collisions between vehicles and large animals in the United States every year. Almost all animal-vehicle collisions (AVCs) resulted in no human injury (95.4 percent). Collisions with moose and other large animals can have a higher likelihood of resulting in harm to the vehicle occupant (figure ES5 and figure ES6).

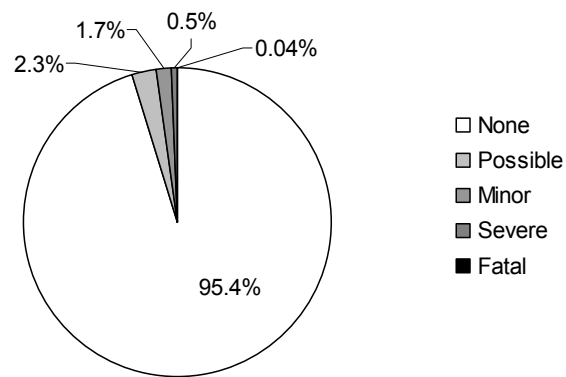


Figure ES5. Graph. Human injury from AVCs (primarily deer).

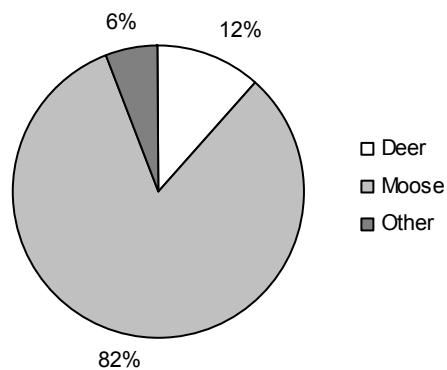


Figure ES6. Graph. Animal species involved in fatal (to human) collisions, Maine.

Is the Number of Accidents Increasing?

National trends were studied in a review of several sources of crash data. Figure ES7 and figure ES8 illustrate that from 1990 to 2004, the number of all reported motor vehicle crashes has been holding relatively steady at slightly above six million per year. By comparison, the number of reported AVCs (includes wildlife and domestic animals) has increased by approximately 50 percent over the same period, from less than 200,000 per year in 1990 to a high of approximately 300,000 per year in 2004. Looking at the data another way, AVCs now represent approximately 5 percent (or 1 in 20) of all reported motor vehicle collisions.

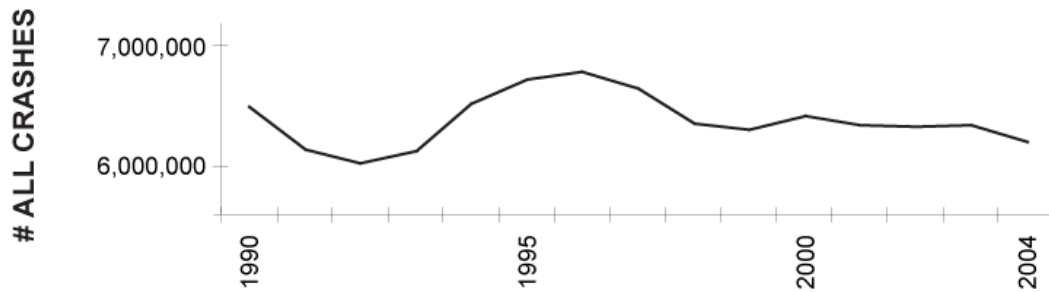


Figure ES7. Graph. Total vehicle crashes.

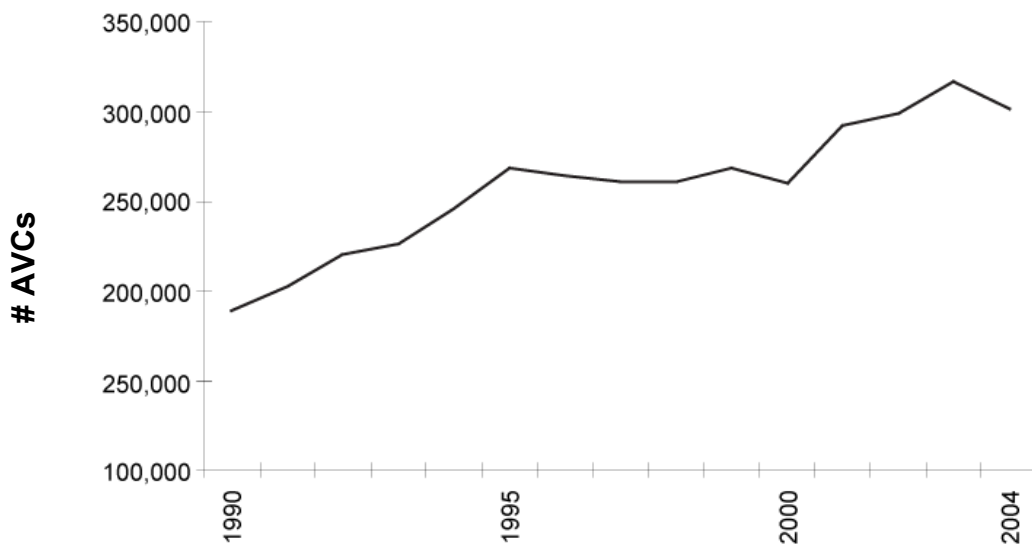


Figure ES8. Graph. Total AVCs (including wildlife and domestic animals).

The increase in WVCs appears to be associated with an increase in vehicle miles traveled (VMT) and an increase in deer population sizes in most regions in the United States. The occurrence of WVCs, however, is associated with many more factors, as reflected by their characteristics, which include:

- More than 98 percent of WVCs are single-vehicle crashes.
- 89 percent of WVCs occur on two-lane roads.
- WVCs occur more frequently on low-volume roads.
- Compared to all motor vehicle collisions, WVCs occur more frequently on straight roads with dry road surfaces.

- WVCs occur more frequently in the early morning (5–9 a.m.) and evening (4 p.m.–12 a.m.), when deer are more active and traffic volume is relatively high.
- WVCs occur more frequently in spring and especially in fall, when animals move around more due to migration, mating, or hunting seasons.
- The vast majority (as high as 90 percent in some states) of reported WVCs involve deer.
- White-tailed deer-vehicle collisions are associated with diverse landscapes with abundant edge habitat (transitions from cover to more open habitat) and riparian habitat.

WHAT ARE THE CONSEQUENCES? THE COSTS AND IMPACTS TO DRIVERS AND ANIMALS

WVCs can have a broad range of consequences for both motorists and animals. Though human injuries and fatalities resulting from WVCs are relatively rare, they do occur and are a serious consequence. More common results are vehicle damage, secondary motor vehicle crashes, emotional trauma, and less direct impacts such as travel delays. WVCs can also require the assistance of law enforcement personnel, emergency services, and road maintenance crews for potential repairs and carcass removal. For animals, WVCs present an immediate danger to their individual survival, and certain threatened and endangered species are faced with a further reduction in their population survival probability.

Impacts on Travelers

Safety Risk

Collisions with large animals pose a safety risk to humans as well as wildlife (figure ES9). Based on research from various states, roughly 4–10 percent of reported WVCs involving large animals result in injuries to drivers and their passengers. While this may not appear to be a large percentage, this translates into approximately 26,000 injuries per year that are attributable to these accidents.



Figure ES9. Photo. A mule deer is hit by a vehicle in Big Bend National Park, TX (copyright: Marcel Huijser).

Similarly, only a very small proportion of crashes with large animals result in human fatalities. Nonetheless, an estimated 200 people die from WVCs in the United States every year. From 2001 to 2005, an average of 38,493 fatal crashes occurred.⁽²⁾ Hence WVCs represent roughly 0.5 percent of fatal crashes.

Direct Monetary Impacts

For vehicle owners, the most common direct cost incurred from a WVC is damage to their vehicle. Most research indicates that more than 90 percent of collisions with deer result in damage to the driver's car or truck. Nearly 100 percent of collisions with larger animals—such as elk or moose—end with substantial vehicle damage.

Due to the size and weight of the animals, damage to the vehicle can be costly. Based on numerous studies, the average cost of repairing a vehicle after colliding with a deer was estimated at \$1,840. For collisions with elk and moose, the averages increase to \$3,000 and \$4,000, respectively.

Drivers may incur other direct costs if they must have their vehicle towed after the accident. If an injury occurs, drivers and passengers may face expenses from medical care and possibly lost wages from missed work.

WVCs have financial implications for public agencies as well. Law enforcement agencies face direct costs of investigation and traffic control following a collision. Transportation agencies typically are responsible for carcass removal and disposal costs and infrastructure repair costs, if necessary. Public agencies may incur some financial losses based on the monetary value of the animal itself, value associated with its hunting or license fees or recreational attraction for wildlife viewing.

The best estimate of the total annual cost associated with WVCs, based on available data, is calculated to be \$8,388,000,000. Collisions with deer constitute the single largest collision category involving human and vehicle costs. The average costs from a collision with a deer include the following:

- \$1,840 in vehicle repair costs.
- \$2,702 in medical costs.
- \$125 in towing and law enforcement services.
- \$2,000 for the monetary value of the animal.
- \$50 for carcass removal and disposal.
- Costs can increase substantially if a car collides with a larger animal (such as an elk or moose).

Indirect Impacts on Travelers

WVCs can have other impacts on travelers that are more difficult to quantify in fiscal terms. Accidents involving large animals can lead to travel delays or secondary accidents for subsequent motorists if the vehicle or animal lies in the right of way. Some drivers also experience emotional trauma as a result of the danger they experienced and the killing of a large animal.

Impacts on Wildlife

WVCs are a serious safety risk for animals. In most cases, an animal that has been hit by a vehicle dies immediately or shortly after a collision. Clearly, these deaths affect the immediate survival of many individual animals. However, they also represent a serious conservation issue. For some species, the long-term survival of a local or regional population may be threatened, especially in combination with other factors such as habitat loss due to agriculture and urbanization.

This study identified 21 federally listed threatened or endangered animal species in the United States for which road mortality is among the major threats to the survival of the species. These species include birds such as the Hawaiian goose (figure ES10), reptiles such as the desert tortoise (figure ES11), mammals such as the San Joaquin kit fox (figure ES12), and amphibians such as the California tiger salamander.



Figure ES10. Photo. Hawaiian goose warning sign (copyright: Haleakala National Park, National Park Service).



Figure ES11. Photo. Desert tortoise (copyright: Marcel Huijser).



Figure ES12. Photo. San Joaquin kit fox (copyright: Brian L. Cypher, California State University, Stanislaus, Endangered Species Recovery Program).

THREATENED AND ENDANGERED SPECIES

This study identified 21 federally listed threatened or endangered species in the United States for which road mortality is among the major threats to the survival of the species:

Mammals

Lower Keys marsh rabbit, Key deer, bighorn sheep (peninsular California), San Joaquin kit fox, Canada lynx, ocelot, Florida panther, red wolf

Reptiles

American crocodile, desert tortoise, gopher tortoise, Alabama red-bellied turtle, bog turtle, copperbelly water snake, eastern indigo snake

Amphibians

California tiger salamander, flatwoods salamander, Houston toad

Birds

Audubon's crested caracara, Hawaiian goose, Florida scrub jay

Note that other factors such as habitat loss due to agriculture and urbanization also impact these species and that a substantial reduction in WVCs may not automatically result in viable populations.

CAN THE NUMBER OF COLLISIONS BE REDUCED? METHODS FOR PREVENTING COLLISIONS

For this study, 34 different techniques aimed at reducing the number of WVCs were identified and reviewed. This section presents only some examples of the mitigation measures aimed at reducing WVCs; other measures are described and evaluated in the main text of the report. The measures are grouped into four major categories: efforts to change or influence the behavior of wildlife, efforts to reduce wildlife population size, efforts to change or influence a driver's behavior, and planning and design approaches. It should be noted that the Federal Highway Administration (FHWA) is not recommending these measures by including them in this report.

Influencing Wildlife Behavior

WVCs can be reduced by influencing the behavior of animals. These efforts either attempt to deter animals from approaching the roadway or direct the animals toward a safer location to cross the road.

Wildlife fences that separate animals from the roadway have a successful record of reducing WVCs and are now used extensively. Wildlife fences typically consist of wire mesh fence material that is 2 to 2.5 m (6.5 to 8 ft) tall, running parallel to the roadway (figure ES13). Numerous studies in the last 20 years have demonstrated that wildlife fencing, with or without wildlife crossing structures, can reduce collisions with deer and other large animals by 87 percent on average (80–99 percent).



Figure ES13. Photo. Wildlife fencing along Interstate 90 near Bozeman, MT (copyright: Marcel Huijser).

While correctly installed wildlife fencing is highly effective in reducing collisions, it must be carefully applied to avoid unintentional effects such as creating an absolute barrier that keeps animals from accessing habitat on the other side of the road. In addition, animals are more likely to break through the wildlife fencing if safe crossing opportunities are not provided or if these opportunities are too few, too small, or too far apart. Therefore wildlife fencing is usually combined with safe crossing opportunities, such as wildlife underpasses (figure ES14 and figure ES15) and overpasses. In addition, wildlife jump-outs are usually integrated with wildlife fencing. These features allow animals that do manage to cross the fence to escape from the fenced road and right of way.



Figure ES14. Photo. Wildlife underpass in southern Florida that allows for ecosystem process (hydrology) as well as wildlife use, including the Florida panther (copyright: Marcel Huijser).

Wildlife underpasses and overpasses provide safe road crossing opportunities for a wide array of species, allowing them to continue to move across the landscape. These structures are typically used in combination with wildlife fences that keep the animals from entering the roadway and that funnel the animals toward the overpasses and underpasses. In some cases wildlife underpasses and overpasses have no or very limited wildlife fencing, making them the primary measure to reduce WVCs on short road sections. The location, type, and dimensions of wildlife crossing structures must be carefully planned with regard to the species and surrounding landscape. For example, grizzly bears, deer, and elk tend to use wildlife overpasses to a greater extent than wildlife underpasses, while black bears and mountain lions use underpasses more frequently than overpasses. In addition, different species use different habitats, influencing their movements and where they want to cross the road. Other factors that should be considered are the vegetation in the direct vicinity of the crossing structure, co-use by humans, and the time it

takes for animals to learn the location of the structures and to learn that they are safe to use. Although wildlife overpasses are more common in Europe than North America, some of the best studied examples are located in Banff National Park in Canada, and multiple large overpasses are planned in the United States.



Figure ES15. Photo. Large culvert with vegetative cover and fencing on Highway 1 in Canada (copyright: Tony Clevenger).

Large boulders parallel to the road can be an alternative to wildlife fencing, especially if landscape aesthetics are a concern. Preliminary data suggest that hoofed animals are reluctant to walk across large boulders. Smaller rocks have also been used at fence ends to discourage hoofed animals from wandering in between the fences.

Long tunnels (or landscape bridges) are tunnels that are at least several hundreds or thousands of yards long (figure ES16). Long bridges (or elevated road sections) are bridges that span a similar distance. Long tunnels and bridges are primarily constructed because of the nature of the terrain (e.g., through a mountain, across a floodplain), but in some cases they are constructed to avoid areas that are ecologically very sensitive and where no alternatives are available. If the nature of the terrain permits, animals can move freely over long tunnels or under long bridges, and because the animals are physically separated from traffic, WVCs are eliminated. However, long tunnels or bridges are rarely specifically designed to reduce WVCs.



Figure ES16. Photo. Long bridge on Arizona Highway 260 constructed in such a way as to minimize the impact to soil and vegetation (copyright: Marcel Huijser).

Reducing Wildlife Population Size

Wildlife culling involves a substantial reduction in the population size of a particular species in a certain area. When used, this measure is typically applied to deer. Culling is sometimes done by recreational hunters through increased deer quotas and sometimes it is accomplished by hiring professionals. The elimination of does (females) is more effective than the killing of bucks (males) because there is a greater impact on the reproductive potential of a population. Culling efforts are more likely to result in a substantial reduction in deer population size if the herd size is relatively small to begin with and if it is a closed population that does not allow influx of animals from nearby places. Data on the effect of culling on deer-vehicle collisions (DVCs) are scarce. One field test in Minnesota showed that a deer population reduction program reduced winter deer densities by 46 percent and DVCs by 30 percent. Sharpshooting by professionals using bait was deemed to be the most effective and adaptable culling method in an urban setting, as opposed to controlled hunts in large parks and refuges or opportunistic sharpshooting by professionals. The effort will have to be repeated periodically, as the deer population will return to the same levels if the habitat conditions remain similar; culling is not a one-time-only measure. In addition, the effort involved for population size reduction programs increases disproportionately with higher population size reduction goals, and substantial reductions (for example ≥ 50 percent) may be hard to obtain, perhaps capping the potential reduction in DVCs at 50 percent. Finally, wildlife culling can meet with strong public opposition.

Modifying Driver Behavior

Efforts aimed at helping motorists avoid collisions depend on providing the driver with information. The driver may then take action, for example, by choosing when or where to drive, remaining alert, or lowering vehicle speed (figure ES17).



Figure ES17. Photo. Permanently flashing Florida black bear warning signs in the Ocala National Forest, FL (copyright: Marcel Huijser).

Animal detection systems use sensors to detect large animals that approach the road. Once a large animal is detected, warning signals are activated to inform drivers that a large animal may be on or near the road at that time. Such systems have been installed at over 30 locations in North America and Europe. Limited data exist on the effectiveness of animal detection systems, but a Swiss study showed that collisions with large hoofed animals were reduced by 82 percent on average for seven different locations. While these data are encouraging, animal detection systems should still be regarded as experimental, as more data on their effectiveness is needed. Animal detection systems applied over long road sections do not restrict animal movements. Animal detection systems may also be applied at gaps in a wildlife fence or at fence ends. This mitigation measure still allows large animals to be on the roadway, and the posts, sensors, and other equipment associated with the system may pose a safety hazard of their own.

Public information and education programs aim to increase motorists' awareness of the impacts, causes, and high risk locations of WVCs. These campaigns may also offer advice on how to avoid crashes with animals or how to reduce their severity. Dissemination of this information is often targeted to drivers at specific high risk locations or during seasons of high wildlife movement. Little research has been conducted to conclude whether these efforts are effective on their own; therefore, they are generally integrated with other mitigation measures.

Planning and Design Methods

Integration of transportation planning and wildlife management on a regional or statewide level can help to reduce WVCs. These efforts do not generally reduce WVCs in a direct or easily quantifiable manner. However, by working together, planners from transportation, resource, park, and other agencies find opportunities to share information and make planning decisions that help prevent or reduce WVCs. Examples include:

- Avoidance of key habitat. Some states have chosen to avoid impacts in the most sensitive areas, for example by choosing an alternative route for a new road. This may avoid increased WVCs.
- Identification and prioritization of WVC problem areas. Some transportation agencies use roadkill data, animal movement data, aerial photos, and mapping tools to identify habitat linkage zones (areas of high animal movement) and WVC locations. With this information, transportation agencies can focus limited resources on mitigating high priority locations. Having such information available also allows for the early integration of these WVC reduction measures with road building or road upgrading plans. This increases the probability that mitigation measures will be implemented and that WVCs will be reduced.
- Data collection. Planners need good data regarding the magnitude and trends of WVCs so that they can identify and prioritize areas that may require mitigation. In addition, these data help in evaluating the effectiveness of potential mitigation measures. Some states have established data standards; others are developing methods to make it easier to collect detailed and accurate information (figure ES18). Having good data increases the probability that mitigation measures will be implemented and that WVCs will be reduced.
- Consideration of geometric and roadside design features can reduce WVCs:
- Steeper fill slopes may not allow drivers to see deer approaching the roadway until the animals leap over the guardrail. If a steeper side slope is unavoidable, a landing area may allow drivers to see animals before they jump over the guardrail.
 - At locations where the roadway crosses drainages, known migration corridors, or known animal habitat, avoid curves, steep side slopes, and narrow clear zones, which may make animals visible to drivers.
 - At locations where culverts or bridges are installed, culverts and bridges can possibly be widened to include opportunities for animals to cross under the road.
 - Drainage features can be designed to minimize wildlife attraction and influence wildlife movement. Avoid creating pooled water in the right of way which increases vegetation and attracts wildlife. Some wildlife will avoid crossing rip-rap (large boulders). If rip-rap funnels animals to an undesirable crossing location, consider filling gaps in the rip-rap with sand and gravel (which may make it more

conductive to animals crossing) or extend the rip-rap to a more suitable crossing location.

- When considering seeding mixes for the roadside, consider unpalatable species. Also consider plants that do not grow so tall as to visually obscure animals approaching the roadway.
- Concrete median barriers may cause wildlife to pause at the barrier or turn around, increasing their time in the roadway.

Which Methods Are Most Effective?

There is no single, low-cost solution for WVCs that can or should be applied everywhere. A successful mitigation strategy requires a detailed, location-specific analysis of the problem and often involves a combination of different types of mitigation measures. Nonetheless, wildlife fences, with or without wildlife crossing structures, animal detection systems, and long tunnels or bridges, reduce or may reduce WVCs substantially (≥ 80 percent). Of these mitigation measures, wildlife fences, with or without wildlife crossing structures and animal detection systems, are among the most cost-effective measures.

ARE WE MAKING PROGRESS? CHALLENGES FACED BY TRANSPORTATION AGENCIES

With several successful WVC mitigation methods available, why hasn't more progress been made toward reducing the number of WVCs? This study identified several challenges that currently prevent a systematic, nationwide approach to WVC reduction.

Gaps in Knowledge, Insufficient Information, and Lack of Data

There are no standards or guidelines for the collection of data on WVCs. Data are collected inconsistently and often haphazardly, and methods vary between states and agencies. Some transportation agencies do not collect this type of data at all. Without reliable, consistent data, it is difficult to identify road sections where mitigation methods may be required, to select an appropriate mitigation measure, or to evaluate whether that effort is making a difference. Future analyses should also include additional statistical methods to analyze the data.



Figure ES18. Photo. Roadkill observation collection system (ROCS), a GPS-enabled PDA for animal carcass data collection (copyright: Amanda Hardy, WTI).

Research and Evaluation of Mitigation Measures

While several mitigation methods show promise, transportation agencies need data that show the effectiveness of different types of mitigation measures to justify their deployment. Additional research and field demonstration of WVC reduction techniques (figure ES19) help advance the state of the practice as results depend on the type of problem, the species involved, and local circumstances. Long-term monitoring of the effectiveness of the mitigation measures is needed, as WVC numbers are highly variable in nature. In addition, wildlife use of crossing structures tends to increase over time, as animals need time to learn their locations and learn that they are safe to use.

Training

While many transportation agencies are interested in reducing WVCs, their staff may not have the knowledge or experience to select effective methods. DOT planners and design engineers need training and guidance materials before they can begin to implement WVC reduction plans.



Figure ES19. Photo. Animal detection system along U.S. Highway 191 in Yellowstone National Park, MT (copyright: Marcel Huijser).

WHERE DO WE GO FROM HERE? OPPORTUNITIES AND NEXT STEPS

This study has provided an opportunity to document the central issues related to WVCs on America's highways: the magnitude and trend of the problem, the dangers posed to both drivers and animals, successful and promising methods for reducing the number of collisions, and challenges that lie ahead.

More importantly, the findings of this study can help policymakers make informed choices regarding future efforts to reduce WVCs. Policymakers who wish to take the lead in advancing effective WVC safety measures can begin by considering the following recommendations:

- Incorporate WVC reduction into the early stages of planning and design for transportation projects.
- Develop and implement standards and guidelines for the collection of data on and reporting of WVCs.
- Develop and implement guidelines for the evaluation of mitigation measures.
- Evaluate the effectiveness of mitigation measures that have been recommended for further research.
- Conduct additional analysis of the data and conduct research to further develop and improve existing mitigation measures (figure ES20).

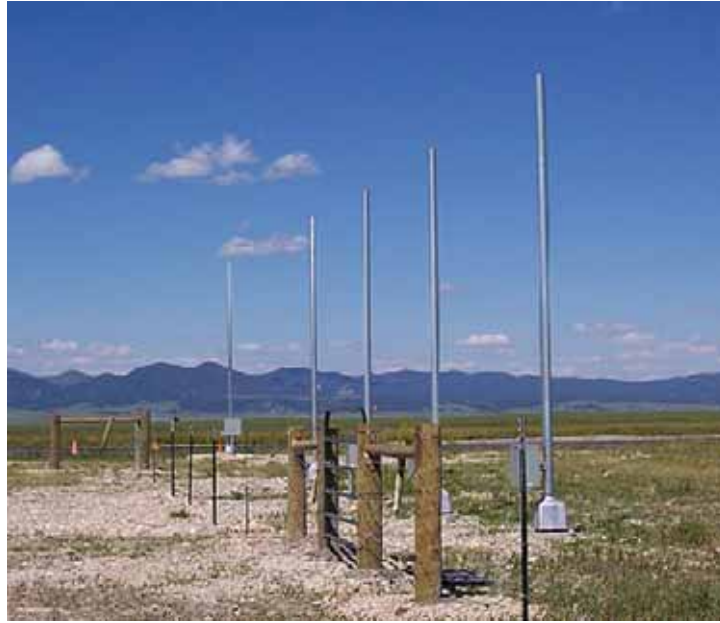


Figure ES20. Photo. Animal detection test-bed used to test the reliability of multiple animal detection systems, Lewistown, MT (copyright: Marcel Huijser, WTI).

- Implement (or install) proven mitigation measures where appropriate.
- Develop and apply wildlife population viability models to assist with locating and designing mitigation measures.
- Conduct technology transfer to state DOTs, resource agencies, and other transportation professionals regarding the findings of this study. A handbook and training course on WVC reduction techniques will be developed by 2008, which will help in making the information available to practitioners.

CHAPTER 1. INTRODUCTION

In the recently enacted transportation bill, the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU Public Law 109-59), the U.S. Congress directed the Secretary of Transportation to conduct a national WVC study. In response, FHWA sponsored a WVC study aimed at reviewing methods to reduce collisions between motor vehicles and wildlife. The Study will advance the understanding of the causes and impacts of WVCs and identify solutions to this growing safety problem. This Study is a unique opportunity to synthesize current knowledge from the United States, Canada, Europe, and elsewhere to promote the expertise, coordination, and effectiveness of transportation agencies in addressing WVCs and, ultimately, reduce WVCs on U.S. roadways.

Approximately 300,000 reported collisions between cars and large animals (i.e., animals capable of causing substantial property damage upon impact) occur every year in the United States, and the number is steadily increasing. Including unreported collisions, the total number is more likely between one and two million WVCs annually. The increasing trend is expected to continue as both traffic volumes and deer populations continue to increase nationwide. Of the reported crashes, approximately 26,000 resulted in human injuries and 200 resulted in human fatalities per year. This study identified 21 federally listed threatened or endangered animal species in the United States for which road mortality was documented as a major threat to their survival.

The remainder of this report provides information relating to WVCs and associated mitigation measures based on the literature review. The primary sections are listed below:

- **Causes and Characteristics** of WVCs provides an overview of what is known about WVCs. It includes those issues documented in the literature and provides an analysis of national crash datasets. This section is primarily focused on large animals.
- **Economic Impacts of Wildlife-Vehicle Collisions** summarizes the known costs of WVCs nationally. This section is also primarily focused on large animals.
- **Impacts to Wildlife** provides a list and discussion of endangered species that are known to be impacted by WVCs directly. This report does not include issues relating to habitat loss, habitat fragmentation, or other impacts of roadways on wildlife.
- A broad range of **Mitigation Methods** are discussed in several sections (organized into major categories). For each mitigation method, the report provides, if available, (1) a general description, (2) case studies (with contacts), (3) benefits and drawbacks, (4) costs, and (5) design guidelines. The major mitigation categories considered are as follows:
 - Methods that aim to influence driver behavior.
 - Methods that aim to influence animal behavior with no or minimal structures on/over the road or in the right of way.
 - Methods that seek to reduce the wildlife population size.

- Methods that aim to physically separate animals from the roadway.
- Planning considerations.
- Results are summarized for an **Evaluation of Mitigation Methods by a Technical Working Group** of national experts.
- **Gaps in Current Knowledge** provides a summary of topics related to WVCs that require further research and investigation.
- **Cost-Benefit Analyses** provides an overview of the costs and benefits of the different mitigations.
- A brief **Conclusion** ends the report.

This document reports on Tasks 1–3 of the study, which include a literature review and technical working group meeting. Other elements of this project, which will be covered in later separate deliverables, include the following:

- Best Management Practices Manual.
- Training Course.

In this document three terms are used to describe collisions with animals. Animal-vehicle collisions (AVCs) refer to collisions with wild and domestic animals in cases where domestic animals could not be separated from the dataset. WVCs include all species of wild animals. Deer-vehicle collisions (DVCs) include WVCs that involve only deer (*Odocoileus* sp.). The reason a separate term is used for deer and no other specific type of animal is that deer account for a majority of WVCs when data are available. When information is specific to one type of animal other than deer, no abbreviation is used (e.g., moose-vehicle collision).

CHAPTER 2. CAUSES AND CHARACTERISTICS OF WILDLIFE-VEHICLE COLLISIONS

The primary method of investigating the causes and characteristics associated with WVCs is to analyze data on previous collisions. This chapter provides a summary of current knowledge about WVCs, based on information from the literature and an update from national crash databases. After discussing data sources and evaluation methods, this chapter investigates the following characteristics of WVCs:

- Total magnitude.
- Growth rate.
- Temporal distribution by:
 - Time of day.
 - Time of year.
- Severity of human injuries and fatalities.
- Roadway facility type.
- Traffic density and speed.
- Weather conditions.
- Animal species.
- Landscape adjacent to roads.
- Number of vehicles involved.
- Deer population density.
- Driver characteristics.

DATA SOURCES

Numbers and factors related to WVCs have been reported extensively in the literature. Possibly the most commonly quoted statistic is that there are over one million WVCs with large animals annually in the United States. This number originally comes from a survey of states completed by Romin and Bissonette.⁽³⁾ States responded to this survey with a mix of crash record numbers, carcass counts, and estimates. Approximately 500,000 DVCs were reported by 35 states. Conover and others estimated that DVCs are underestimated by at least 50 percent, so most researchers increase this number to one million or more to include the missing states and unreported crashes.⁽⁴⁾

There are three common sources of data for WVCs: carcass counts, the insurance industry, and police-reported crashes. The first source, carcass counts, includes counts of dead animals on the side of the roadway that likely died from collisions with a vehicle. Sometimes these data include more detail than just the species (e.g., sex, age, size, etc.). Unlike the two other sources discussed

below, carcass counts are not always focused on safety and can include smaller animals since conservation concerns are also a reason to collect carcass data. This source of data may be sufficient for corridor or regional studies, but the lack of consistency in reporting methods limits evaluation on a statewide or national level. However, it is often thought that carcass counts are the most comprehensive data available since the following two sources tend to underreport the total number of WVCs.

Another source of information on WVCs is data from the insurance industry, which is based on reported claims. Claims typically relate to major damage, and major damage is typically associated with relatively large animals (e.g., deer size and up). State Farm Insurance estimated the number of claims for collisions with deer, elk, and moose and then estimated the total number nationally based on the company's proportion of market share of insurance policies.⁽⁵⁾ This estimate is questionable. The number may underreport total collisions, since it only includes vehicles with comprehensive insurance; accidents with uninsured vehicles are not reported to the insurance industry. On the other hand, it could be overestimating crashes, since people may be likely to say they hit a deer when they actually hit something else in an attempt to keep their insurance rates low. As shown in figure 1, there are approximately one million WVC insurance claims annually (years are shown as fiscal years, July 1–June 30). This source of data typically does not contain detailed information about each crash.

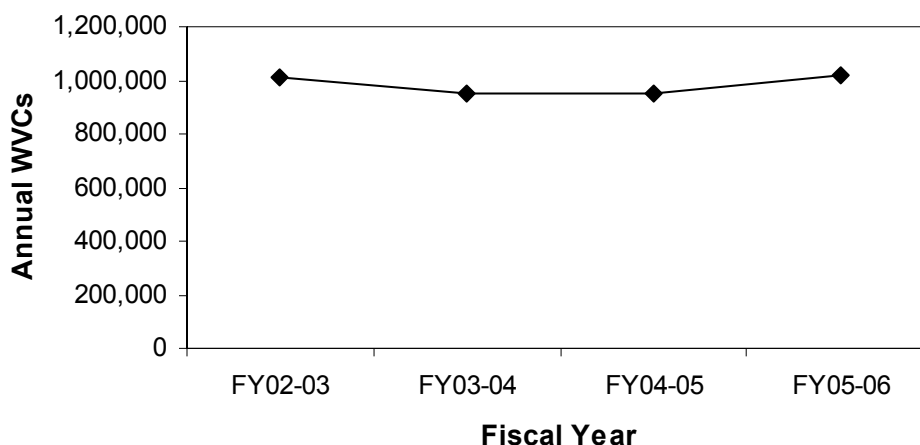


Figure 1. Graph. Annual WVCs estimated by insurance industry.⁽⁵⁾

The third source of WVC information is police reports of total crashes of all types (including WVCs). These reports are more effective for analyzing data nationally, because there is more consistency in their collection. The transportation industry expends considerable effort collecting and cleaning up these data for accurate analysis. However, this data set also has its limitations. These data only include crashes on public roads. In addition, these reports only include data for accidents that incurred a certain level of damage to the vehicle (each state has its own reporting threshold). Finally, the data may not include information on animal species, because these reports are focused on safety in general and are not specific to WVCs. In fact, the crashes may

only be categorized as AVCs (not separating domestic and wild animals). Three national police report-based datasets were used in this review as described below.

NATIONAL CRASH DATABASES

Each state maintains its own database of crash records with different reporting thresholds, different variables describing the contributing factors, and different database structures. WVCs were analyzed from three sources:

- Fatal Accident Reporting System (FARS) includes all crashes nationally that involve a human fatality. The data from this system are likely the most consistent nationally since more detail and effort goes into reporting a fatal crash. However, the dataset is small with typically fewer than 200 AVC fatal crashes annually. From 2001 to 2005, an average of 38,493 fatal crashes occurred.⁽²⁾ Hence AVCs represent roughly 0.5 percent of fatal crashes.
- The Highway Safety Information System (HSIS) includes all reported crashes from Washington, California, Illinois, Maine, Michigan, Minnesota, North Carolina, Ohio, and Utah. This is a useful source of data since some of these states report more detail on the species of animal involved in a crash. Although it contains all crashes reported, it is only for the selected states.
- The General Estimates System (GES) is a true national sample. A small random sample of police accident reports is collected from each sampling unit. A sampling unit contains one or more police jurisdictions. The values from these police reports are aggregated up to determine national estimates. Although the collection methods are rigorous to ensure randomness, this is still only a sample of all crashes, so these are estimates of national values, not true national values.

Throughout the rest of this chapter, numbers are reported from each of these three datasets. General issues and methods for analyzing these datasets are discussed here. It should be noted that national figures are analytically attractive because there is a much larger dataset, but they may mask significant differences in WVCs between local areas.

Fatal Accident Reporting System

Fatal Accident Reporting System (FARS) data include those crashes where at least one person died within 30 days of the collision from collision-related injury. Data were collected from 2001 to 2005. AVCs were identified when a crash's "first harmful event" was an animal. Note that for these events, the "most harmful event" was not always an animal. Data were downloaded from the FARS Web site (<http://www-fars.nhtsa.dot.gov/>)(accessed November 27, 2006). The first harmful event is the first event during a crash that causes injury or property damage. The most harmful event causes the most damage and is not always the same as the first harmful event.

Highway Safety Information System

HSIS data contain police-reported accidents for Washington, California, Illinois, Maine, Michigan, Minnesota, North Carolina, Ohio, and Utah. HSIS was developed and is maintained

by FHWA. Information can be found at <http://www.hsisinfo.org> (accessed January 24, 2007). This database includes all police-reported crashes for these states; therefore, it has a larger sample than the random sample in the GES dataset, but it does not contain data beyond these states. A strength of this dataset is that some of the detail collected by individual states is maintained. For example, Maine divides its AVCs into deer, bear, moose, and other.

HSIS states have different data availability. The most recent 5 years of data from each state were analyzed (table 1). Also shown in table 1 are the reporting thresholds for each state.

Table 1. Summary of HSIS data characteristics from different states.

| State | Years | Thresholds | Animal Categories |
|----------------|-----------|---|--|
| California | 1998–2002 | Differ by municipality: from \$500 to \$1,000 or injury only. | Deer, livestock, other animal (except in 2001) |
| Illinois | 1999–2003 | \$500 or injury | Deer, other animal |
| Maine | 2000–2004 | \$1,000 or injury | Deer, bear, moose, other animal |
| Minnesota | 2000–2004 | \$1,000 or injury | Deer, other animal (except 2000–2002) |
| Michigan | 1993–1997 | \$400 or injury | Animal only |
| North Carolina | 2000–2004 | \$1,000 or injury | Animal only |
| Utah | 1996–2000 | \$750 or injury | Wild or domestic animal |
| Washington | 2000–2004 | \$750 or injury | Large domestic, small domestic, wild animal |

The manner in which animals are categorized also varies between states (table 1). Some states simply have a single general category of “animal” for all AVCs. One category for all animals is similar to the GES and FARS animal categorization, which can include domestic animals. When reporting on HSIS data as a whole, domestic animals were excluded (unless otherwise stated) for those states that differentiated. As such, HSIS results refer to WVCs, even though some of the states may include domestic animals within their animal classification.

Crash data can sometimes be misleading when a clear and detailed explanation of the reported value is not provided. For example, from the same source of data one could state that there were 100 crashes, or that 200 vehicles were involved in a crash (i.e., there were 100 crashes, each involving two vehicles). In this report, unless otherwise stated, crash numbers refer to number of crashes (not number of vehicles or people). When referencing the vehicle attribute, it refers to the vehicle that struck the animal (almost all crashes were single-vehicle crashes). When referencing the person attributes, it refers to the driver of that vehicle.

To compare data from states with vastly different numbers of collisions (range = 176,793 to 890,215), proportions of collisions were compared instead of raw numbers. Further, rather than using the sum of all collisions with certain characteristics (which would bias the total towards states with more collisions), the proportion of collisions within each state was summed and divided by the number of states.

General Estimates System

GES is a stratified random sample. There are actually two strata. The first stratum is geographic. There are four regions (Northeast, Midwest, South, and West) that are further categorized into 1,195 primary sampling units, each containing one or more police jurisdictions. Within these geographic areas, crash reports are sampled randomly. The second stratum is crash type (mostly in terms of severity). Crash types are divided into the following categories:

- An occupant of a vehicle that was towed after the collision is killed or severely injured—no medium or heavy trucks.
- An occupant of a vehicle that was towed after the collision is injured—no medium or heavy trucks.
- A passenger vehicle is towed after the collision (no fatalities or injuries)—no medium or heavy trucks.
- A medium or heavy truck that resulted in a vehicle being towed or an injury report.
- No vehicles were medium or heavy trucks, no vehicles were towed, and at least one person was injured.
- No person was injured.

The total number of crash reports (including those not sampled) is also known for each geographic and crash type sampling unit. Based on these sampling units, rates are determined such that each crash record is given a weight that is an estimate of the number of crashes it represents. When comparing across the crash strata mentioned above or considering total AVC numbers, the weighting factors were used. Since these weighting factors have not been published for 2005, these numbers represent 2000–2004 data. When considering variables within the AVC subsample (e.g., time-of-day distributions), straight proportions were used assuming there were random samples across nonsampling unit variables. For these numbers, 2001–2005 GES data without weights were used. The assumption regarding these proportions was not validated. Future analysis should include the most recent available data and include the weighting factors. GES data were downloaded from <ftp://ftp.nhtsa.dot.gov/ges/> (accessed January 24, 2007).

Total Vehicle Miles Traveled

Researchers collected data on vehicle miles traveled (VMT) for each state. This information, coupled with the crash data described above, allowed for determination of crash rates. These rates are expressed as crashes per million VMT unless otherwise stated. These values allow researchers to compare crashes both geographically and over time to see if there is an increase in the exposure rate. VMT files were downloaded from the U.S. Department of Transportation, Bureau of Transportation Statistics (BTS) Web site at <http://www.bts.gov/> (accessed January 24, 2007). Annual national VMT were available through 2004.

EVALUATION METHODOLOGIES

The goal of the remainder of this section is to summarize how WVCs (or AVCs when crash data could not be separated into domestic and wild animal) are unique from other crashes. It is difficult to normalize for all the secondary factors that may cause a certain distribution of WVCs for a given variable. The best method is to compare WVCs with non-WVCs. A proportional *t*-test or chi squared test can be completed to confirm a statistically significant difference. In the case of all reported differences, they were statistically significant.

TOTAL MAGNITUDE

Based on the HSIS data, Table 2 shows the WVCs for each of the eight states analyzed. The proportion of crashes that were WVCs in a given state ranged from 0.6 to 14.6 percent. The total number of WVCs in these eight states was 251,619 for a 5-year period (about 50,000 per year). Consider that these states comprise 16 percent of the total land area in the 50 United States and 22 percent of the rural VMT in 2004. Considering the HSIS data represent about one-fifth of the United States, the national number of reported crashes is likely to be around five times the amount reported in the HSIS states (i.e., 50,000 per year). Extrapolating the HSIS data would yield an estimate of about 250,000 WVCs per year in the United States.

GES estimates the national average of AVCs at 292,000 annually (2001–2004). This value represents 4.6 percent of all crashes annually. Based on FARS data, the total number of fatal crashes involving AVCs nationally averages 179 per year (2001–2005). From 2001 to 2005, an average of 38,493 fatal crashes occurred for all crash types.⁽²⁾ Hence AVCs represent, on average, less than 0.5 percent of all fatal crashes.

Table 2. Five-year crash totals for HSIS states.

| State | WVCs | All Collisions | WVCs (%) |
|----------------|---------|----------------|----------|
| California | 5,580 | 890,215 | 0.63 |
| Illinois | 29,038 | 664,263 | 4.37 |
| Maine | 21,599 | 176,793 | 12.22 |
| Michigan | 103,962 | 711,482 | 14.61 |
| Minnesota | 21,621 | 415,118 | 5.21 |
| North Carolina | 51,764 | 637,994 | 8.11 |
| Utah | 12,449 | 240,381 | 5.18 |
| Washington | 5,606 | 207,133 | 2.71 |
| Totals | 251,619 | 3,943,379 | 6.38 |

As mentioned previously, carcass counts have been extrapolated to a national estimate of over one million per year. Additionally, as shown previously in figure 1, the estimated number of insurance claims per year averages about one million. Table 3 summarizes the WVC counts from these various sources.

Table 3. Total annual magnitude of WVCs from various sources.

| Source | Annual WVCs |
|------------------|-------------|
| HSIS | 250,000 |
| GES | 292,000 |
| Insurance claims | 1,000,000 |
| Carcass counts | 1,000,000 |

Marcoux conducted a survey in Michigan and found that of the people involved in a DVC, only 52 percent reported it to their insurance company.⁽⁶⁾ This finding implies that the estimated WVCs are underreported. The carcass counts are also not likely to include all WVCs, since they are extrapolated from a mix of reported collisions and carcass counts as well as from 35 to 50 states. Considering all of these figures and the previously discussed potential underreporting, the authors recommend the following two numbers be used when discussing the magnitude of WVCs with large animals:

- The total count of WVCs each year is between one and two million.
- The number of WVCs that are reported to police and have enough property damage to warrant tracking in crash databases (e.g., greater than \$400–1,000 depending on the state) totals 300,000 per year.

Keep in mind that each of these numbers represent WVCs with large animals since they are based on reported crashes or carcasses. The total magnitude of WVCs with small animals is likely much larger.

IS THE PROBLEM GROWING?

Is the number of WVCs increasing or decreasing? A previous study of HSIS data found that WVCs increased 69 percent from 1985 to 1991.⁽⁷⁾

Since GES data are likely the best source of national numbers, trends were examined using this data source, extending back to 1990. As shown in figure 2 and figure 3, the number of all crashes is holding relatively steady at slightly above six million, while the number of AVCs is increasing. This increase could be due to a number of different factors discussed later in this chapter such as an increase in deer population and changes in traffic volumes and speeds.

To analyze WVC trends over time, three linear regression models were used, with the independent variable being the year and the dependent variable being either the total number of WVCs, the proportion of WVCs to total crashes, or the total crash rate. An important statistic is the *t*-statistic for the coefficient of the slope, which describes the relationship between the dependant and independent variables. If the *t*-statistic is greater than two, it can be confidently concluded ($\alpha = 0.05$ or 95 percent confidence) that the slope is not zero (i.e., the rate of WVCs changing through time). Statistically a linear regression line on the total annual AVCs shows an increasing slope of 6,769 AVCs per year ($t = 7.8$, R -squared = 0.81). In addition, the proportion of AVCs to total crashes has a positive slope of 0.11 percent per year ($t = 9.4$, R -squared = 0.86).

Note that a higher R -squared value (which ranges from zero to one) indicates there is a linear relationship. An R -squared value of one results from a perfect linear relationship.

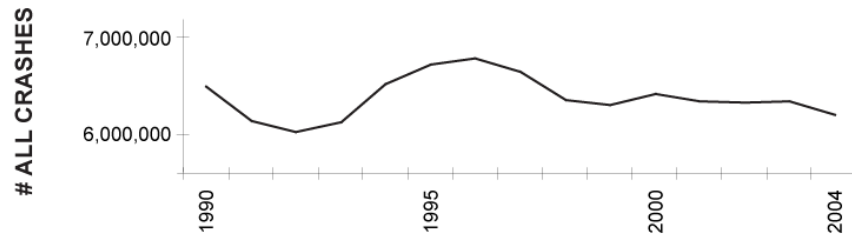


Figure 2. Graph. Total vehicle crashes.

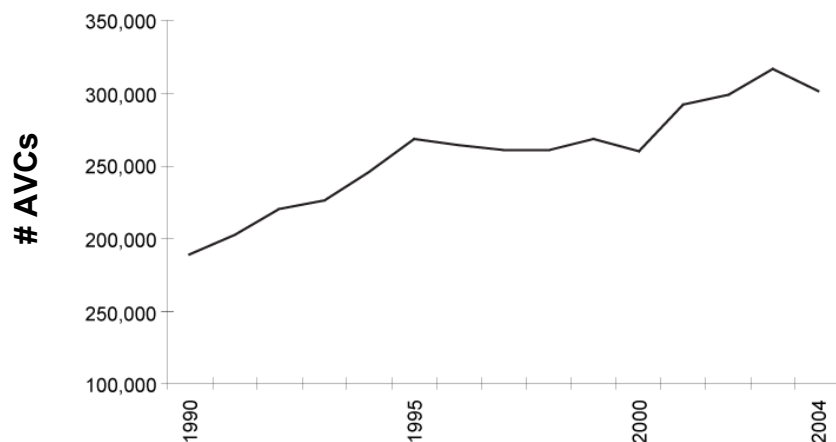


Figure 3. Graph. Total AVCs (including wildlife and domestic animals).

To ensure that the increase in WVCs over time was not due only to increases in the amount of travel (i.e., VMT), the crash rate was investigated. Figure 4 shows the crash rates each year determined by dividing GES annual numbers by VMT. The linear regression of crash rate over time has a positive slope of 0.00072 crashes per million VMT per year ($t = 2.2$, R -squared = 0.27). The linear relationship is weak as indicated by a low R -squared value. The t -statistic shows that the crash rate increase is statistically significant.

Statistical analysis beyond linear regression models will be considered in future stages of this topic to further assess relationships.

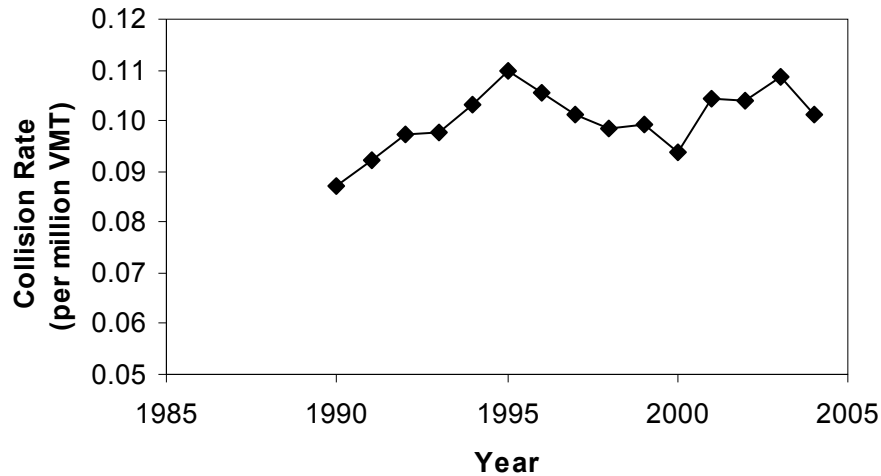


Figure 4. Graph. Annual crash rate for AVCs (GES and VMT data).

TEMPORAL DISTRIBUTIONS

For some species, there are clearly certain times of the day and times of the year when WVCs occur more frequently. For large mammals, numerous studies have shown that WVCs occur more frequently in the morning (5–8 a.m.), the evening (4 p.m.–12 a.m.), in the fall (October and November), and in the spring (May–June).^(8,9,10) The peak in the spring is generally not as high as that in the fall. The daily peaks are typically explained by the fact that deer and other large animals are moving around dusk and dawn, which, combined with relatively high traffic volume in the early morning and late afternoon, results in a peak in collisions in the early morning and late afternoon and evening. The fall peak is typically explained as being related to mating season, migration, and hunting season, all of which cause animals to move around more.⁽¹¹⁾ The spring peak is explained by distribution of young and migration.

Figure 5 shows the annual AVC distribution for the three reported crash datasets. The HSIS- and GES-based AVC distributions are very similar in magnitude and shape. The FARS data do not have the sharp peak in AVCs observed in November in the other two datasets. Note that for the HSIS data most of the states followed the same basic trend. Five of the eight states had substantial peaks in proportion of AVCs in November, while two states (California and Washington) had a larger peak in October and a smaller peak in November. Utah had the least overall difference in WVCs by time of year. All states except North Carolina and Utah had minor peaks in WVCs in spring, generally in June.

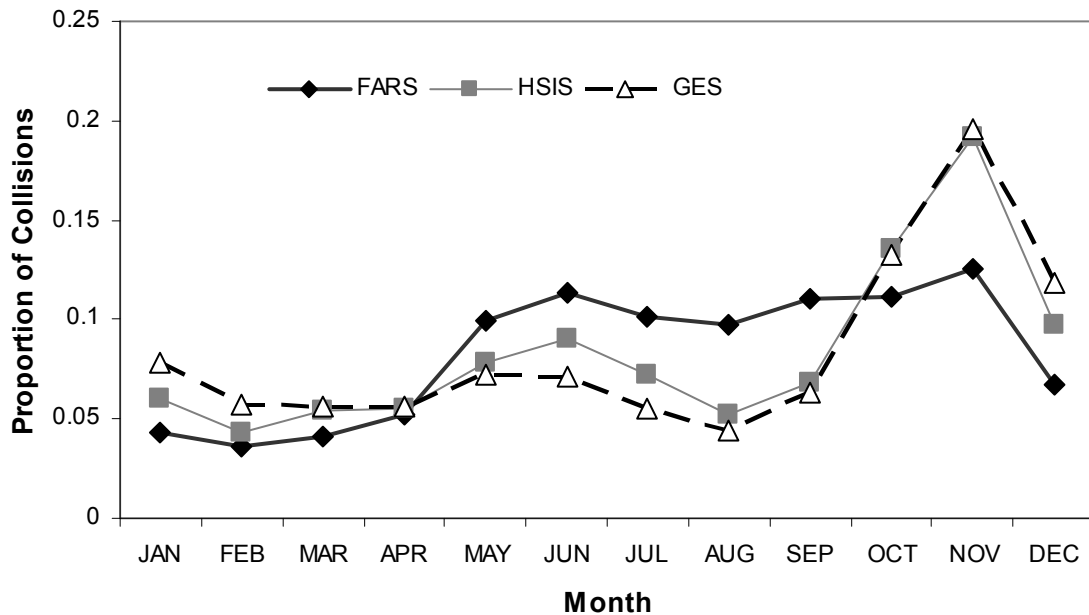


Figure 5. Graph. Annual distribution of AVCs.

Some HSIS states separated deer from other animals (WA, ME, IL, UT, and CA). For the “other animal” or domestic classifications the distribution is much more uniform throughout the year (figure 6).

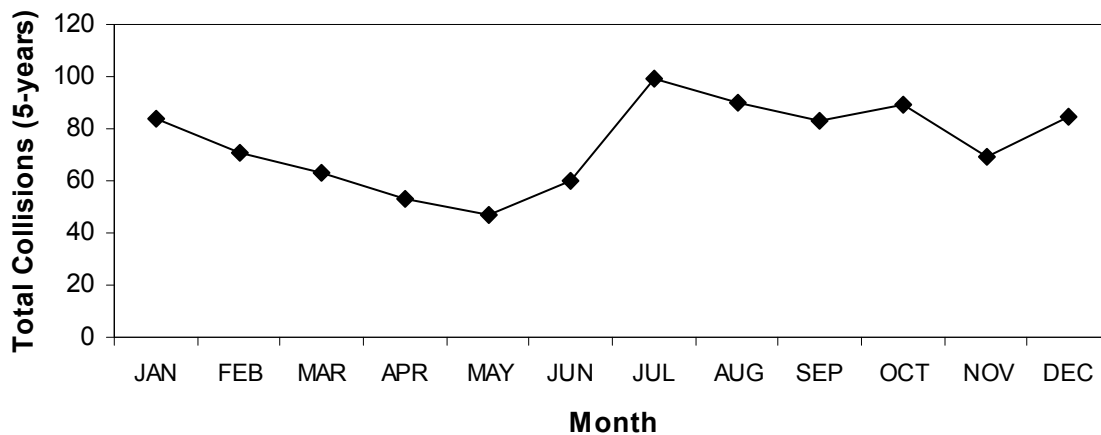


Figure 6. Graph. Annual distribution for other/domestic animal-vehicle collisions in CA, WA, IL, ME, and UT (HSIS data).

Maine was the only HSIS state to list specific wild species other than deer. For Maine, the annual distributions for bear- and moose-vehicle collisions (figure 7) do not have the major peak in November like deer (note AVCs reported in figure 5 are primarily deer). Bear-vehicle collisions are fairly uniform in the summer and nonexistent in the winter during their hibernation period.

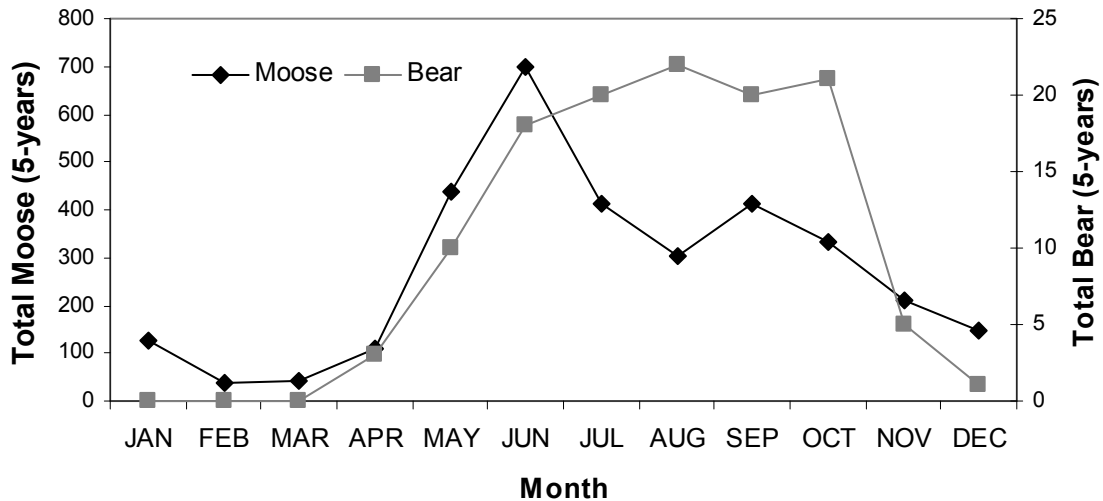


Figure 7. Graph. Annual distributions for moose and bear collisions in Maine (HSIS data).

Seasonal distributions appear to be somewhat dependent on specific geographic area. For example, in Teton County, Wyoming, WVCs were most frequent in summer months, especially in Grand Teton National Park, which has much higher traffic volumes in the summer.⁽¹²⁾ These numbers contrast sharply with the more regional trends presented in figure 5.

For time of day, the three data sources all show the expected peaks at early morning and evening (figure 8). Wildlife, especially deer, typically move around more at dusk and dawn.

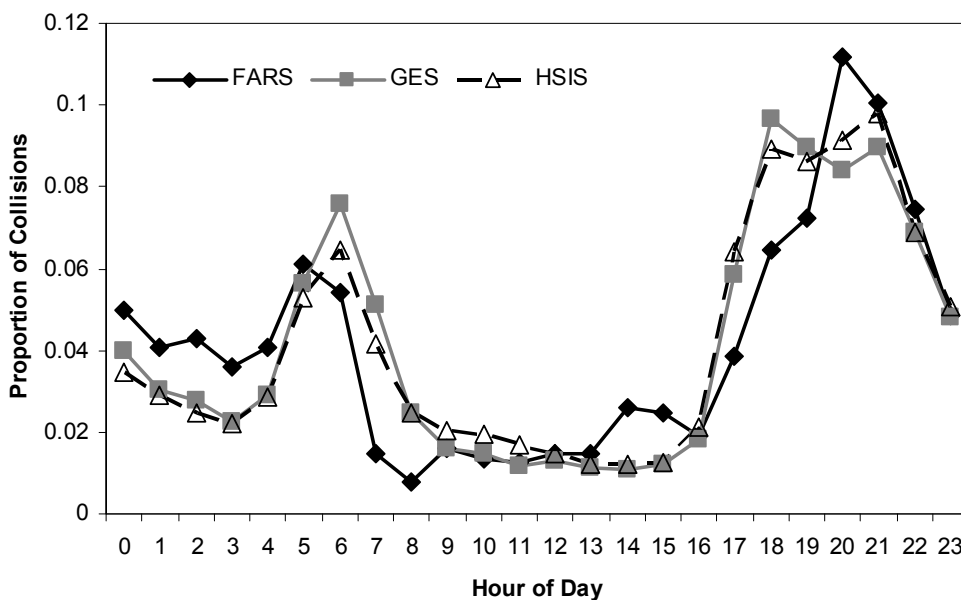


Figure 8. Graph. Time-of-day distribution.

SEVERITY

Williams and Wells looked at 147 fatal WVCs from nine different regions and found that the most common types were (1) a motorcyclist striking an animal and falling off the vehicle followed by (2) a passenger vehicle striking an animal, going off the road, and striking a fixed object or overturning. Safety measures (i.e., helmets and seat belts) were not used in 60–65 percent of the cases.⁽¹³⁾ Jones also reported most fatal crashes involved motorcycles.⁽¹⁴⁾ This conclusion was confirmed by the FARS data. On average, 30 percent of the fatal crashes involving animals also involved motorcycles. Conn and others investigated 22,498 emergency room visits where a motor vehicle collision with a large animal was identified as the cause.⁽¹⁵⁾ Of these, more than one-third (8,508) were people ages 15 to 24.

In general, WVCs are less severe than other crashes. Compared to all crashes, the datasets show the proportion of crashes involving human injury is much less for WVCs. GES-based estimates of crash severity over 5 years are shown in figure 9 and figure 10 for AVCs and all crashes, respectively. Almost all AVCs resulted in no human injury (95.4 percent). This figure is consistent with the HSIS data that show 92.3 percent of crashes resulted in no human injury. There was some variability in severity values between the HSIS states, likely due to the different reporting thresholds. California showed only 87.4 percent of DVCs resulted in no injury. GES estimated fatal crashes at 608 in a 5-year period, compared to 895 in the FARS data. However, the upper confidence interval of the GES data is 1,956 fatal crashes. Note that for all crashes in this same 5-year period, FARS shows 192,463 fatal crashes.

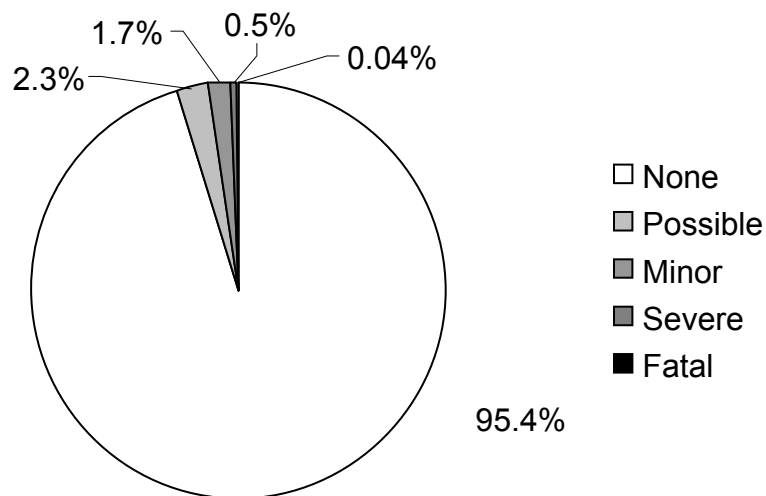


Figure 9. Graph. Severity distribution for AVCs (GES data).

Often collisions with moose and other larger animals are thought to be more fatal to humans than collisions with deer. In Newfoundland, Joyce and Mahoney found that among moose-vehicle collisions, 0.6 percent were fatal crashes and 26 percent were injury crashes.⁽⁸⁾

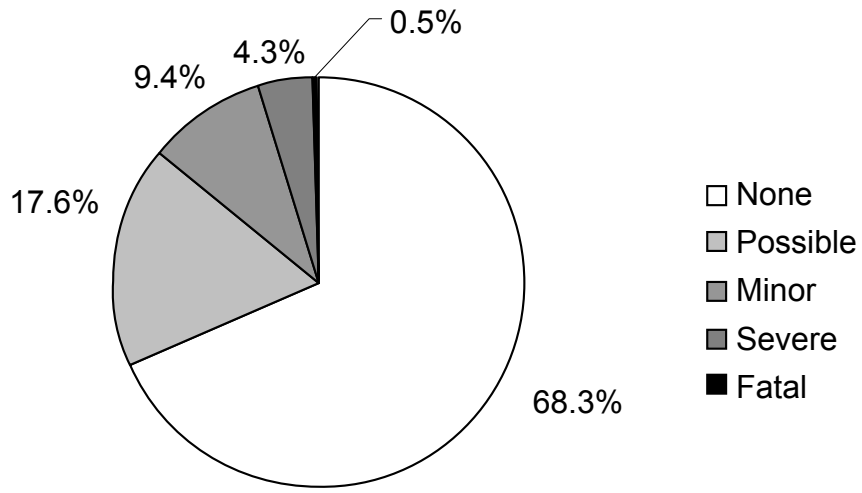


Figure 10. Graph. Severity distribution for all crashes (GES data).

From the HSIS data, domestic, livestock, and other animals had a slightly higher severity rate than WVCs, with 79.2 percent of crashes resulting in no human injury, which is lower than the 92.3 percent value for all AVCs, but still higher than the 68.3 percent value for all crashes. Moose-vehicle collisions from the Maine HSIS data show a severity profile more similar to that of all collisions (figure 11).

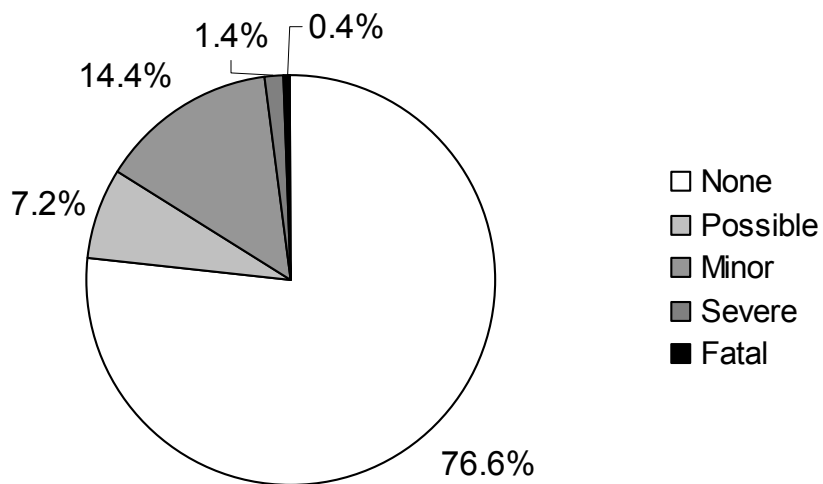


Figure 11. Graph. Severity distribution of moose-vehicle collisions in Maine (HSIS data).

FACILITY TYPE

Most studies that look at the types of roadways where WVCs occur report that they are most common on rural two-lane roads.⁽⁷⁾ However, these results should be used with caution since a large majority of highway miles are rural, two-lane roadways.

For the GES records with number of lanes and facility types, 89.7 percent of AVCs occurred on two-lane roads. In comparison, 52 percent of all crashes occur on two-lane roads (figure 12). This is not to say that upgrading all two-lane roads would reduce WVCs. Reilly and Green found that the upgrade from two to four lanes in constructing Interstate 75 in Michigan initially resulted in a 500 percent increase in DVCs.⁽¹⁶⁾ With time, the number of DVCs did steadily decrease. The initial increase could have been due to deer being unfamiliar with the new character of the roadway.

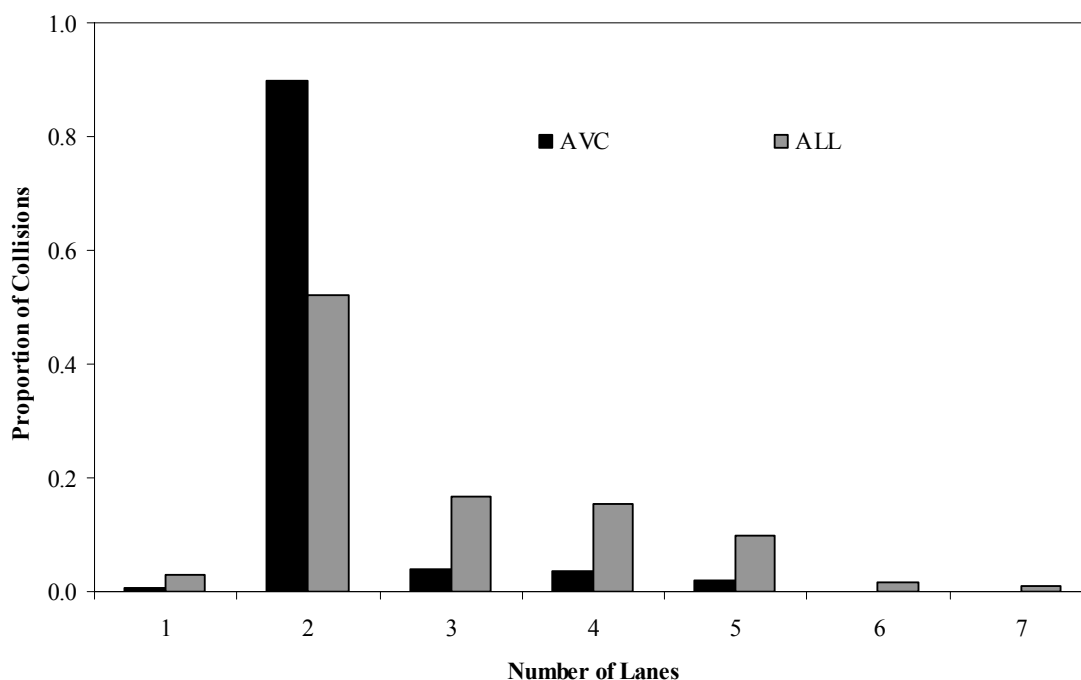


Figure 12. Graph. AVCs by number of lanes (GES data).

The majority of AVCs (91.7 percent) occurred on straight sections of roadways, compared to 85.8 percent for all crashes, according to the GES data. However, these results vary by region. In the West Region, 74.8 percent of AVCs occurred on straight roads, compared to 82.7 percent of all collisions.

TRAFFIC DENSITY AND SPEED

The impact of traffic density and speed on WVCs is complex. Predictive models of DVCs for Kansas and also for Iowa positively correlated the number of DVCs per year per mile to the number of roadway lanes and/or traffic volume.^(17,18) Using traffic flow theory, Langevelde and Jaarsma modeled the probability of successful wildlife road crossings based on relevant species,

road and traffic characteristics.⁽¹⁹⁾ Traffic volume has a large effect on this probability, especially for slow-moving species.⁽¹⁹⁾

Lower traffic volumes do not necessarily equate with fewer roadkills.⁽²⁰⁾ In fact, WVCs actually decrease when traffic volume increases to a high enough level that it is, in effect, a barrier (i.e., animals do not attempt to cross).^(20,21,22) Several researchers have hypothesized a relationship similar to that shown in figure 13.^(22,23,24)

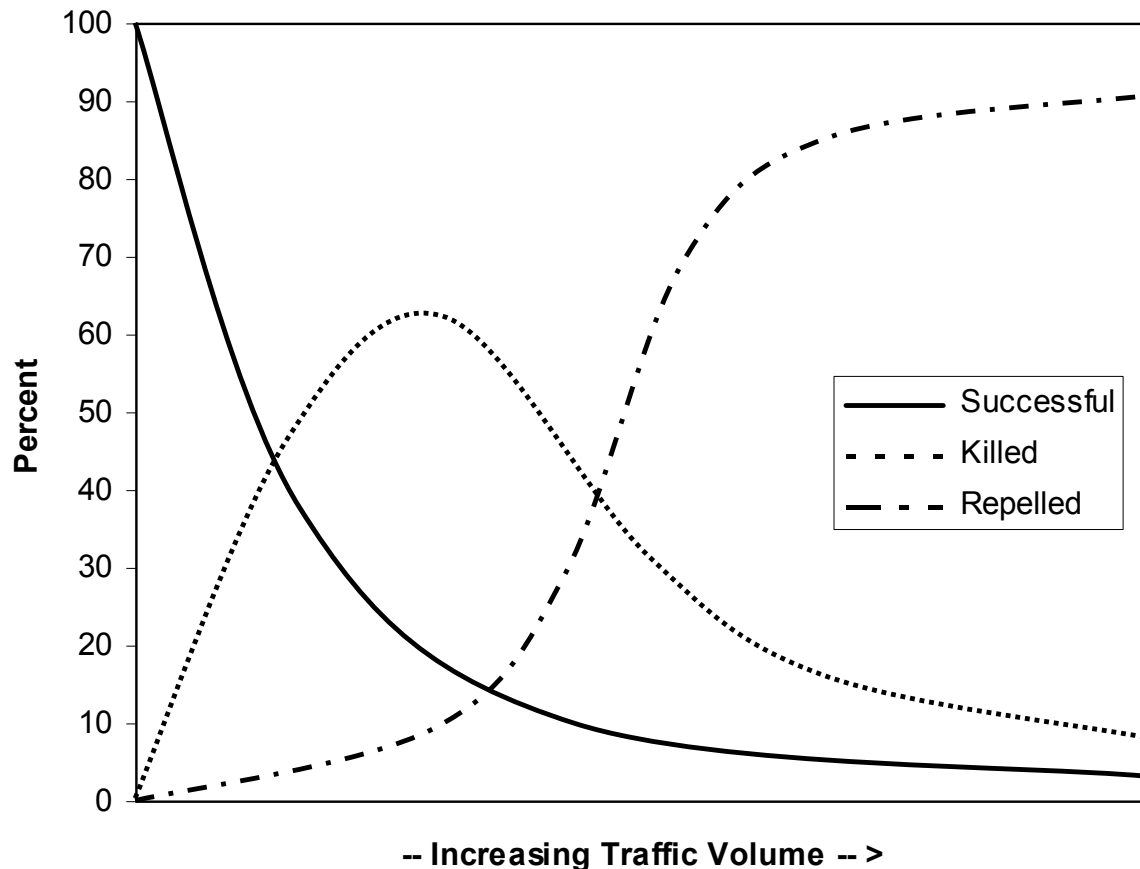


Figure 13. Graph. Theoretical relationship between traffic volume, successful wildlife crossings, and road mortality (adapted from Seiler).⁽²³⁾

When analyzing the national crash data, AVCs are more likely to occur on low volume roads, as shown in figure 14. Almost one-half of WVCs in the HSIS states occurred on roadways with less than 5,000 average daily traffic (ADT).

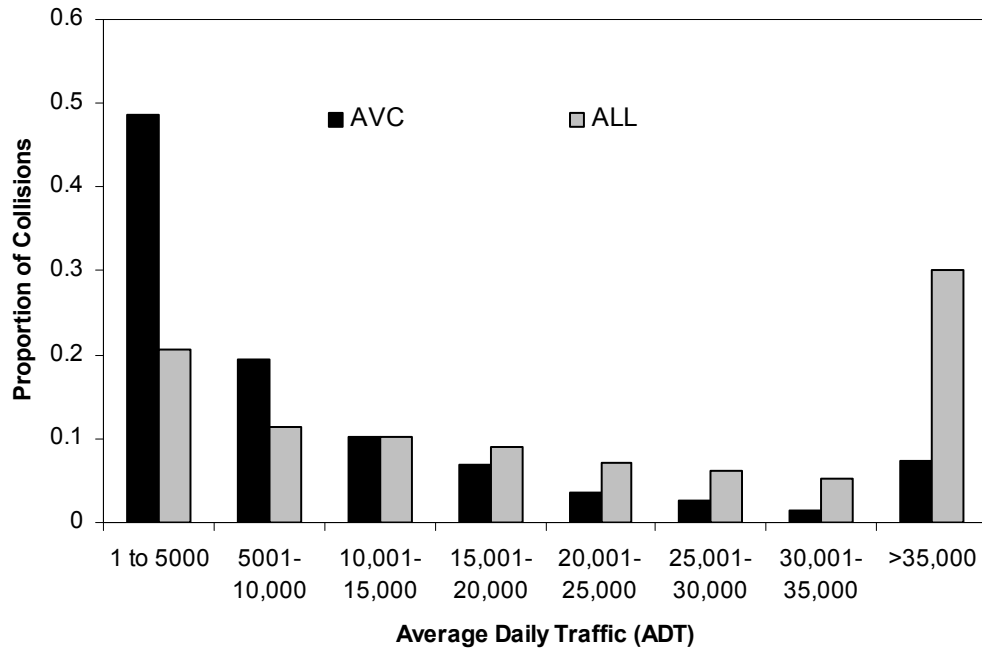
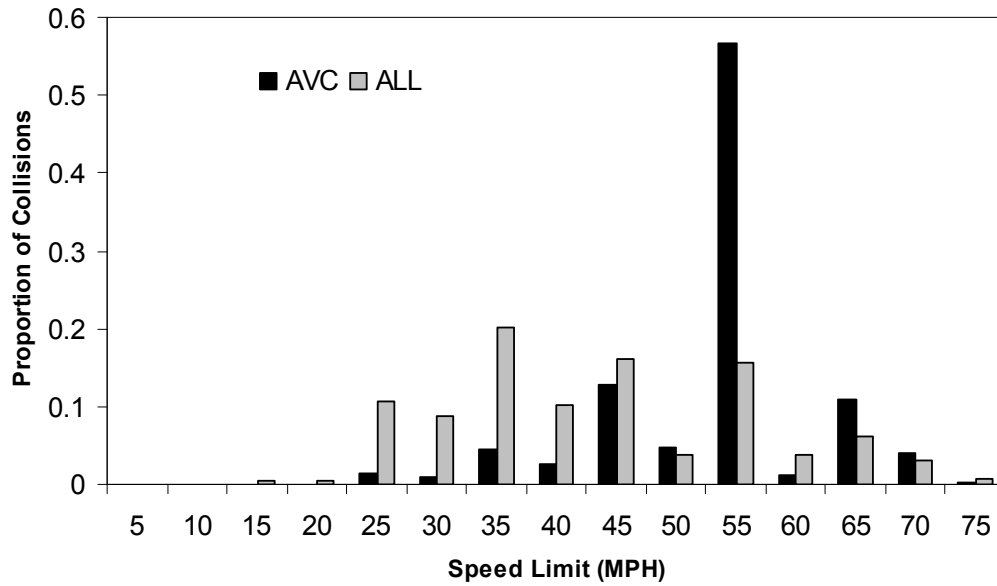


Figure 14. Graph. Crashes by ADT (HSIS data).

There are numerous reports that attempt to correlate increasing speed to increasing WVCs. Such correlations can be misleading if the author is not clear on what is being compared and what the results can suggest. For example, figure 15 indicates that AVCs occur less frequently on low-speed roadways. The initial conclusion could be that if the posted speed limit is lowered, the number of WVCs will decrease. However, the high number of AVCs on 88 km/h (55 mi/h) roadways (nearly 60 percent) is more likely a result of higher populations of wildlife on rural two-lane roadways with this design speed, rather than the 88 ki/h (55 mi/h) design speed in and of itself.

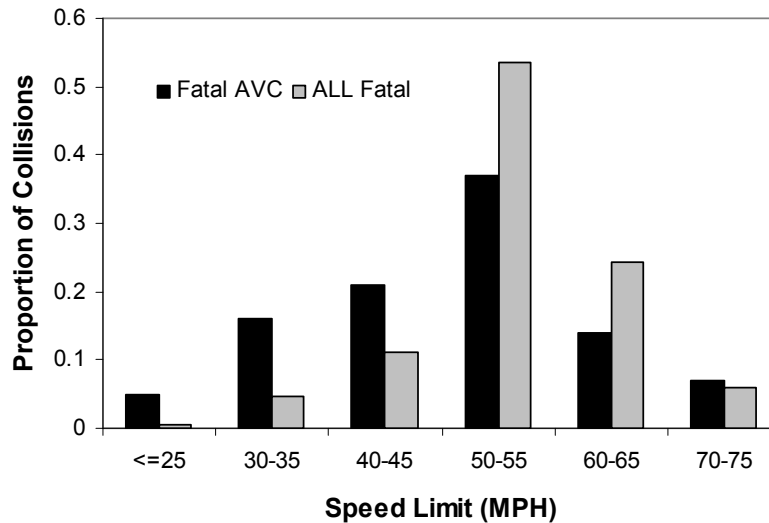


1 mi/h = 1.61 km/h

Figure 15. Graph. Distribution by posted speed limit (GES data).

Seiler found a similar trend with moose in Sweden. Moose-vehicle collisions peaked on roads with speed limits of 90 ki/h (56 mi/h) and declined at higher speeds.⁽²⁵⁾ Although an old study, Cottam found that collisions with birds also occurred more frequently on higher-speed roadways.⁽²⁶⁾ Cramer and Portier found that Florida panther WVCs increased with an increase in posted speed and traffic flow.⁽²⁷⁾

As shown in figure 16, the likelihood of fatal AVCs occurring on 88 ki/h (55 mi/h) roadways is lower than the likelihood of a non-AVC fatal crash on a roadway with the same speed limit. This relationship is opposite of the distribution for all AVC crashes discussed above. There are numerous possible explanations for this. One hypothesis is that motorcycles, which account for a large proportion of fatal AVC crashes, typically travel on lower-speed roadways. However, there has been insufficient research to verify what accounts for the difference in the distribution of speeds for fatal AVCs.



1 mi/h = 1.61 km/h

Figure 16. Graph. Distribution of fatal crashes by posted speed limit (FARS data).

WEATHER

WVCs are more likely to occur in dry weather, perhaps due to the fact that animals are less likely to move around during inclement weather. Carbaugh found there were fewer deer sightings during precipitation.⁽²⁸⁾ Ninety-five percent of fatal AVCs occurred during clear weather compared to 88 percent of all crashes. The proportion of accidents in clear weather is similar for GES (92 percent AVC and 85 percent all) and HSIS (92 percent of WVCs 83 percent of all).

These results reinforce those of other research that show collisions with large animals typically occur on straight, dry roads.⁽²⁹⁾

ANIMAL SPECIES

Data regarding animal species affected by WVCs vary considerably by state. Williams and Wells characterized 147 fatal WVCs from nine states in different regions of the United States between 2000 and 2002.⁽¹³⁾ Seventy-seven percent of these WVCs involved deer; other types of animals included cattle, horse, dog, bear, cat, and opossum.

Of the eight HSIS states, six differentiated WVCs by some categorization scheme based on animal type (table 1). Illinois and Minnesota recorded DVCs and “other animal” collisions, although Minnesota only made this differentiation in 2003 and 2004. In both these states, deer made up more than 90 percent of the WVCs. California differentiated among deer, livestock, and other, except in 2001, when the species were not recorded. Using 1998–2000 and 2002 data only, deer represented 54 percent of AVCs (figure 17). Livestock are clearly not wild, but “other animal” could be wild or domestic. Non-animal represents WVC collisions in which an animal was involved but not struck (i.e., the driver swerves to avoid a deer and collides with a guardrail).

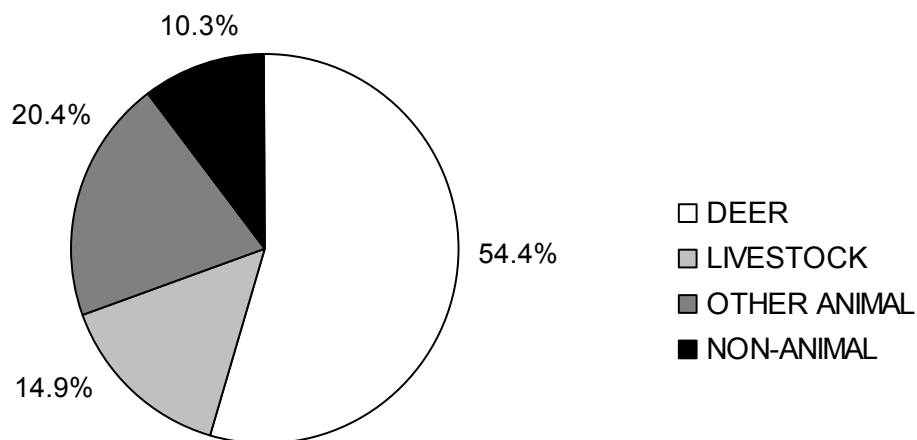


Figure 17. Graph. Animal species involved in collisions in California (HSIS data).

In Maine, 81 percent of AVCs were attributable to deer and 15 percent attributable to moose (figure 18). Maine also recorded whether collisions occurred with bears and other animals.

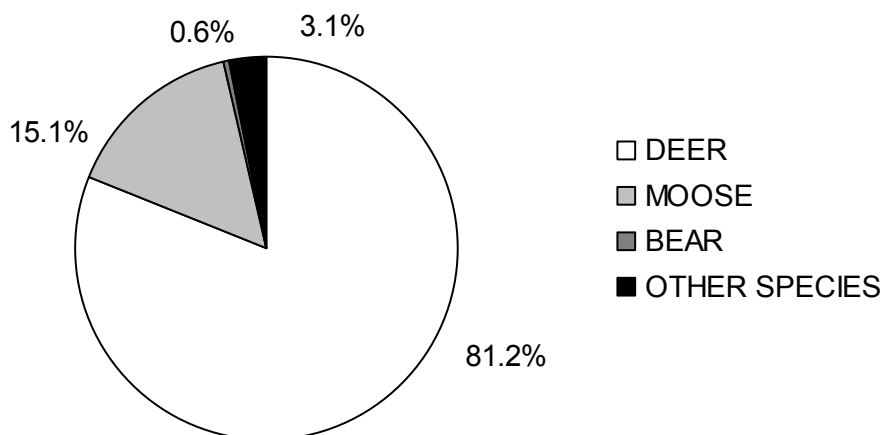


Figure 18. Graph. Animal species involved in collisions in Maine (HSIS data).

Rather than differentiating by species, Utah and Washington divided their reported AVCs into wild and domestic species. Washington further divided domestic species into large (cattle, horses, etc.) and small (dog, cat, etc.) domestics (figure 19). Washington reported a preponderance of collisions with wild animals. In Utah, over the five years of study, 84 percent of all AVCs were due to collisions with wild animals rather than domestic animals, a slightly lower percent of wild animal collisions than reported in Washington.

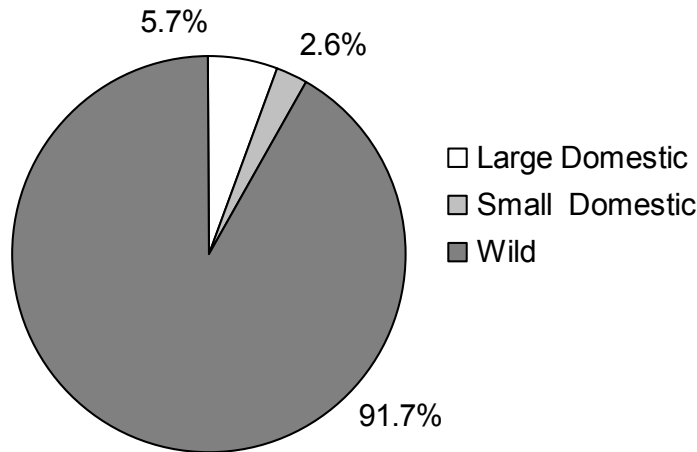


Figure 19. Graph. Animal species involved with collisions in Washington (HSIS data).

LANDSCAPE ADJACENT TO ROADS

Of all recorded accidents in the United States, the vast majority involve deer, especially white-tailed deer (*Odocoileus virginianus*). While deer and DVCs may be widespread, their occurrence is not randomly distributed across the landscape. White-tailed deer-vehicle collisions are typically associated with mixed landscapes that provide cover (forests, shrub land) as well as food (more open areas with grasses, herbs, crops, but also young trees).^(30,31) A high heterogeneity and diversity of the landscape, proximity to cover, and the occurrence of edge habitat (transitions from cover to more open habitat), riparian habitat, and shrub land are strongly associated with the presence of white-tailed deer and white-tailed deer-vehicle collisions. (See references 30, 31, 32, 33, 34, 35, 36, 37, and 38.)

Research results are mixed on the relationship between building density and WVCs, showing either a negative or positive association. In general there are fewer collisions when the density of buildings increases. (See references 25, 28, 31, 37, 39, and 40.)

Mule deer (*Odocoileus hemionus*)-vehicle collisions are sometimes associated with seasonal migration corridors.^(41,42,43) Seasonal migration of mule deer typically occurs in mountainous and heavy snowfall areas.⁽⁴⁴⁾ Furthermore, mule deer-vehicle collisions have been associated with large drainages and heavy cover.^(45,46) Mule deer tend to avoid sites with human disturbance and deep snow.^(47,48) Nonetheless, mule deer can adapt to an urban or suburban environment.^(46,49)

The relationship between slopes and DVCs is uncertain. Carbaugh found that deer favored steep declines and inclines and rarely used level areas.⁽²⁸⁾ By contrast, Malo and others found that lateral embankments, especially with guardrail, negatively correlated with DVCs.⁽³⁹⁾ Alexander and Waters found that slopes less than five degrees were optimal for wildlife movement, but that west to south facing slopes were also indicative of locations with wildlife movement.⁽⁵⁰⁾ Pellet found that on a section of Interstate 90 near Bozeman, MT, as the absolute mean slope increased up to 19.5 percent, ungulate vehicle collisions decreased; while further increases in slope led to an increase in collisions.⁽⁵¹⁾

NUMBER OF VEHICLES AND COLLISION TYPE

Almost all WVCs are single-vehicle crashes (HSIS 98.5 percent, GES 99 percent). However, FARS data indicated a slightly lower percentage than the HSIS and GES data sources; only 85.6 percent of fatal AVCs were single-vehicle crashes. The proportion of FARS AVCs is lower than the other datasets (which include nonfatal crashes); however, this value is still much higher than the proportion for all FARS crashes, of which 56.9 percent are single-vehicle crashes. From the FARS data it can be seen that aside from collisions with animals, the two highest collision types for AVCs were hitting another vehicle or overturning (figure 20), which reinforces the hypothesis that swerving to avoid a WVC may result in a higher-severity collision.

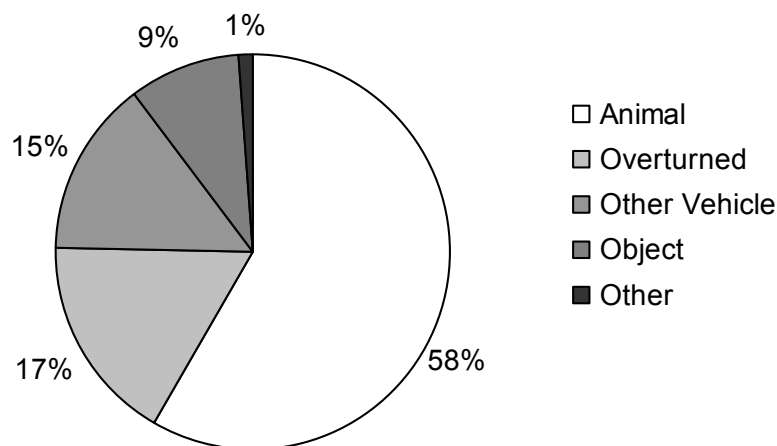


Figure 20. Graph. Fatal AVCs by collision type (FARS data).

DEER POPULATION DENSITY

A relationship between deer population density and DVCs has been documented in several studies.^(52,53,54) Over the last century deer population size has increased strongly in most regions in the United States.⁽⁵⁵⁾ For example, in Virginia the white-tailed deer population size increased from an estimated 25,000 animals in 1931 to 900,000 by the early 1990s.⁽⁵⁵⁾ In Wisconsin, pre-hunting population size estimates for white-tailed deer increased from 1,152,000 in 1993 to 1,643,000 in 2004, but the estimated population size varied strongly between 1993 and 2004.⁽⁵⁶⁾ In Iowa population size estimates for white-tailed deer increased from 500–700 in 1936 to 360,000 in 2004.⁽⁵⁴⁾ In Wisconsin, the deer population estimates between 1993 and 2004 were poorly correlated with the number of DVCs.⁽⁵⁶⁾ In Iowa, deer population indices were closely correlated to the number of road-killed deer, both increasing by about a factor of 2.3 between 1985 and 2004.⁽⁵⁴⁾ The increase has been especially strong since the 1960s.^(55,57) The increase in deer abundance is correlated with the number of DVCs, at least across relatively large areas, but this correlation has not been analyzed at a national level.^(53,54,58)

The relationship between deer population density and the number of DVCs seems intuitive, but this is not necessarily the case.^(59,60) A comprehensive review by Knapp, Putman and suggests that a reduction of the population size across a relatively wide area can be effective in reducing DVCs. (See references 52, 53, 54, 58, 61, and 62.) On the other hand, a reduction in population

over a large area does not necessarily result in a decrease in DVCs, and the reduction in population can be difficult to achieve and maintain, as is discussed further in chapter 7. Very few data exist on the effectiveness of population reduction programs in reducing WVCs, but one field test showed that a deer population reduction program in Minnesota reduced winter deer densities by 46 percent and DVCs by 30 percent.⁽⁵²⁾

DRIVER CHARACTERISTICS

GES and HSIS data showed very little difference in the proportion of male drivers involved in WVCs versus all crashes. According to the FARS data, however, 81.8 percent of drivers involved in AVCs were male, compared to 74.8 percent in all crashes.

The national rate of alcohol involvement in all collisions was 7.76 percent (GES crashes where alcohol involvement was known and recorded). Comparatively, only 0.4 percent of AVCs involved alcohol. This observation does not, of course, mean that being intoxicated decreases a driver's chance of being involved in an AVC. This observation is likely due to some correlation between alcohol-related crashes and some other factor.

Probably the most unexpected finding in comparing crash distributions of WVCs to all crashes was the difference in accident distribution by driver age (note that the same trend was found with FARS and GES data, but only HSIS data are shown in figure 21). The peak in the number of crashes (all types combined) for younger drivers (i.e., age 16–25), seen in figure 21, is typically explained by inexperience and more risky driving behavior. Specific attributes of younger drivers include less skill at detecting hazards, less ability to conduct some driving tasks automatically, being easily distracted, less skill in performing emergency maneuvers, less perception of risk, and overestimation of driving abilities.⁽⁶³⁾ For middle-age drivers, the chances of being involved in a crash are fairly constant across this age group but less than that of younger age groups (figure 21). As driver age increases, the number of drivers decreases, resulting in reduced exposure (in terms of VMT), explaining the reduction in the total number of crashes (figure 21).

The unexpected finding is that, in contrast to the distribution for all crashes, WVC crashes have no pronounced spike for young drivers (figure 21). This suggests that the chance of being involved in a WVC does not decrease with experience. Another possible explanation is that young drivers drive less on the types of roadways where WVCs occur (i.e., low flow, two lane), resulting in relatively few WVCs for this age group.

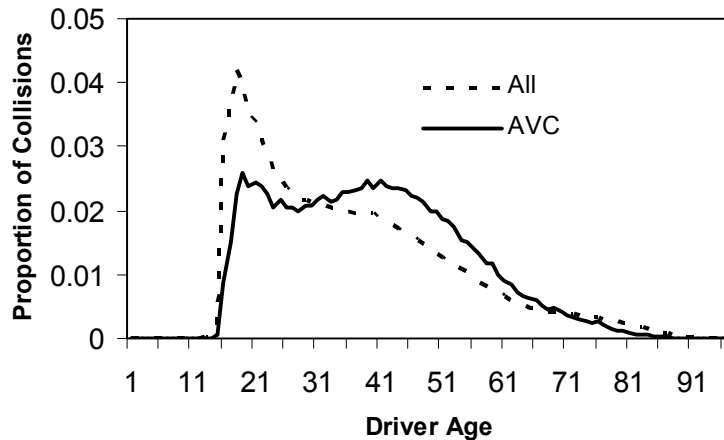


Figure 21. Graph. Age distribution for all crashes and AVCs (HSIS data).

To further investigate the relationship between age and WVCs, the National Household Travel Survey and U.S. Census data were combined to estimate a VMT breakdown by age group.^(64,65) This VMT was used to determine a crash rate by age category for the GES data. Young drivers (age 15–19) had a crash rate 3.7 times higher than middle-age drivers (age 25–54) for all crashes. For AVCs, younger drivers still had a higher crash rate than middle-age drivers (2.1 times as high), but it is clearly not as large an increase as for the typical crash.

It should be noted that although age may not play as much of a role in being involved in a WVC, it does play a role in being injured. As noted previously, Conn and others found that persons between ages 15 and 24 were by far the highest category of emergency room injuries attributed to WVCs.⁽¹⁵⁾

SUMMARY

This review of the national crash databases showed that AVCs have become more important, in both absolute and relative numbers. The total number of WVCs is increasing at a rate of approximately 6,800 more WVCs per year. Deer populations have also continued to increase in many areas within the United States. The review of reported crashes for large animals showed that WVCs are more commonly or typically as follows:

- On rural, two-lane, low-flow, high-speed roadways.
- During early morning and late evening hours.
- Within spring and fall months.
- Lower-severity crashes (high-severity WVCs are more commonly motorcycle crashes).
- Comparative in proportion of crashes for the younger and medium-age driver categories.
- In locations with high wildlife populations, especially deer.

- With deer (mule deer and white-tailed deer combined).
- In areas with many transitions from cover to more open habitat, riparian habitat, shrub land (for white-tailed deer) and large drainages and known seasonal migration corridors (for mule deer).
- Near forested cover and drainages.
- On dry, straight roadways.
- Single-vehicle collisions.

This review also showed that the availability of consistent and detailed WVC data is limited, the data do not always distinguish between species or species groups, and the data suffer from severe underreporting. Furthermore, reliable WVC data for small or medium size species or threatened or endangered species do not exist on a national level.

CHAPTER 3. ECONOMIC IMPACTS OF WILDLIFE-VEHICLE COLLISIONS

This chapter describes the costs associated with WVCs. It focuses on impacts that can be converted to monetary values. There are other impacts associated with WVCs that may not be easily quantifiable. Nonetheless, the cost estimates that are presented are an important component in justifying potential mitigation measures to reduce WVCs.

METHODS

Western Transportation Institute (WTI) researchers estimated the costs for WVCs in two ways. First, they estimated the costs for the average WVC based on property damage, human injuries and human fatalities. Secondly, they estimated the costs for species-specific WVCs for deer, elk, and moose-vehicle collisions (*Alces alces*). For this second analysis, the parameters included were vehicle repair costs, costs associated with human injuries and fatalities, towing, accident attendance and investigation, the monetary value of the animal that was killed in the collision (based on hunting fees and other recreational values), and the cost of disposal of the animal carcass.

AVERAGE ANIMAL-VEHICLE COLLISION

The total estimated cost of the average AVC based on property damage, human injuries, and human fatalities is \$6,126 (table 4). More than 95 percent of all AVCs result in property damage only (table 4), at an average cost over all collisions of \$2,451. While human injuries and fatalities occur in less than 5 percent of all collisions, their associated costs per collision are substantially higher, driving up the cost of the average AVC to the \$6,126 value.

For the analyses described above, 1994 USDOT estimates of motor vehicle accident costs were used, corrected for the Gross Domestic Product Deflator through the fourth quarter in 2006.^(66,67) The 1994 USDOT cost estimates relate to all types of motor vehicle accidents, including, but not exclusively, AVCs. The severity categories for human injuries, including a “possible human injury” are based on police reports at the scene of the accident. The 1994 USDOT cost estimates factor in that some of these “possible human injuries” later show to be injuries indeed, while others are not. The distribution of AVCs across the maximum severity categories is based on the data presented in figure 9 in chapter 2 of this report and specifically relates to AVCs.

Table 4. Estimated costs for property damage, human injuries, and human fatalities for the average AVC.

| Maximum Severity | Cost (\$) | Distribution of Collisions (%) | Contribution to Cost of Average AVC (\$) |
|------------------------------------|------------------|---------------------------------------|---|
| Property damage only | 2,570 | 95.37 | 2,451 |
| Possible human injury | 24,418 | 2.34 | 572 |
| Evident human injury | 46,266 | 1.75 | 809 |
| Incapacitating/severe human injury | 231,332 | 0.47 | 1,083 |
| Human fatality | 3,341,468 | 0.04 | 1,210 |
| Total | | 1.00 | 6,126 |

DEER-, ELK-, AND MOOSE-VEHICLE COLLISIONS

Based on a review of the literature, the probability that a collision with a deer, elk, or moose would result in property damage, a human injury, and a human fatality was estimated. In addition, estimates were made of the amount of property damage (vehicle repair costs) as a result of a collision with these three species.

The species-specific cost estimates were made using the same base cost estimates and categories for human injuries as in table 4. Since it was not possible to distinguish among the three injury categories when calculating the species-specific probabilities that a collision would result in a human injury, the relative frequency of each of the three injury categories was determined using the values in table 4. This approach produced the following values: 51.4 percent of all human injuries involved possible human injuries, 38.4 percent of all human injuries involved evident human injuries, and 10.3 percent of all human injuries involved incapacitating or severe human injuries.

VEHICLE REPAIR COSTS

In Nova Scotia, the percentage of collisions involving white-tailed deer that resulted in property damage was estimated at 90.2 percent—3,524 collisions with property damage out of 3,905 collisions.⁽⁶⁸⁾ In Utah this percentage was estimated at 94 percent.⁽³⁾ There were no similar data available for elk or moose. For this analysis the percentage of collisions resulting in property damage was assumed to be 92 percent for collisions with deer, 100 percent for collisions with elk, and 100 percent for collisions with moose. Property damage (repair costs for vehicles) has been estimated by a number of studies:

- Romin and Bissonette estimated the value at \$1,200 (\$1,881 for deer in Utah and Vermont) in 1992.⁽³⁾

- In British Columbia, the costs for deer collisions with passenger vehicles were estimated at Can\$1,222.⁽⁶⁹⁾
- The cost for deer collisions on average for different regions in the United States in 1993 were estimated at \$1,577.⁽⁴⁾
- In New Mexico, the average vehicle repair cost of an elk-vehicle collision was estimated at \$3,448, based on seven collisions.⁽⁷⁰⁾
- Vehicle repair costs resulting from a collision with a moose in north central British Columbia can be as high as Can\$25,000, but they averaged Can\$5,150 in 1999.⁽⁷¹⁾
- In British Columbia, the estimated average claim for a DVC was Can\$1,222 and a moose-vehicle collision was Can\$3,358.⁽⁶⁹⁾
- Other studies in British Columbia estimated moose-vehicle collisions at Can\$2,200 in 2000 and Can\$2,800 in 2001.^(68,72)
- An average value of \$2,300 was reported for the United States in 2002.⁽⁷³⁾

Based on these various values, it was assumed for this analysis that the average vehicle repair costs as a result of AVCs were \$2,000 for deer, \$3,000 for elk, and \$4,000 for moose. Combined with the percentage chance that a collision indeed results in property damage (see earlier), the vehicle repair costs for an average AVC with each species were estimated at \$1,840 (deer), \$3,000 (elk), and \$4,000 (moose).

HUMAN INJURIES

AVCs can cause human injuries. (See references 4, 15, 29, 68, and 74.) In the United States, AVCs were estimated to result in 26,647 human injuries per year (average for 2001–2002).⁽¹⁵⁾ An estimated 22,498 of these human injuries resulted from collisions with larger animals, mostly with deer (86.9 percent). An estimated 12.2 percent were the result of collisions with horses (*Equus* sp.) and bovines (*Bos* sp.). Elk, moose, and bear (*Ursus* sp.) accounted for the remaining 0.8 percent.⁽¹⁵⁾

The percentage of white-tailed deer-vehicle collisions resulting in human injuries was estimated at 1.3 percent in Finland; 3.8 percent in the U.S. Midwest; 4 percent in Ohio, 4 percent across the U.S., 7.7 percent in Ohio; and 9.7 percent in Nova Scotia. (See references 4, 53, 62, 68, and 75.)

The percentage of moose-vehicle collisions resulting in human injuries was estimated at 9.9 percent in Finland, 11.2 percent in Sweden, 18 percent in Newfoundland and Labrador, 21.8 percent in Newfoundland, 23 percent in Maine (figure 11, chapter 2), 20 percent in rural Alaska, and 23 percent in Anchorage, AK. (See references 68, 75, 76, 77, 78, and 79.) The ratio of moose-vehicle collisions to human injuries was estimated at 1:0.201 in Newfoundland and 1:0.304 in Anchorage, AK.^(79,80) The ratios are higher than the percentages, because more than one person may be present in a car, and multiple people may be injured as a result of one collision. For this analysis it was assumed that an AVC resulted in an average of 0.05 human

injuries for deer, 0.10 human injuries for elk, and 0.20 human injuries for moose. When these proportions are combined with the relative frequency for each of the three injury categories (51.4 percent for possible human injuries, 38.4 percent for evident human injuries, and 10.3 percent for incapacitating or severe human injuries), it results in the cost estimates for human injuries by species presented in table 5. The costs of human injuries by species type are \$2,702 (deer), \$5,403 (elk), and \$10,807 (moose) for each collision. Note that the costs in table 4 and table 5 cannot be directly compared. The costs in table 4 are for all AVCs, regardless of the species, while the costs in table 5 relate to specific wildlife species. In addition, for table 4 the chances that a reported AVC results in a human injury are based on GES data (table 8), while for table 5 these chances are based on a species-specific review of the literature.

Table 5. Costs for types of human injuries for the average deer-, elk-, and moose-vehicle collision.

| Type of Human Injury | Deer | Elk | Moose |
|-----------------------------|----------------|----------------|-----------------|
| Possible | \$627 | \$1,254 | \$2,508 |
| Evident | \$887 | \$1,775 | \$3,550 |
| Incapacitating/severe | \$1,187 | \$2,374 | \$4,749 |
| Total | \$2,702 | \$5,403 | \$10,807 |

HUMAN FATALITIES

While rare, AVCs can cause human fatalities. (See references 4, 13, 68, and 74.) The percentage of white-tailed deer-vehicle collisions resulting in human fatalities was estimated at 0.009 percent in Ohio (14 collisions with human fatalities from 143,016 collisions), 0.029 percent in North America, 0.03 percent in the U.S. Midwest (33 collisions with human fatalities from 125,608 collisions), and 0.05 percent in Nova Scotia (2 collisions with human fatalities from 3,905 collisions).^(53,62,68)

White-tailed deer are the most common species involved in fatal WVCs. A study that used data from nine states (Colorado, Georgia, Minnesota, Missouri, North Carolina, Ohio, Pennsylvania, South Carolina, and Wisconsin) showed that 77 percent of these fatal accidents involved white-tailed deer.⁽¹³⁾

The percentage of moose-vehicle collisions resulting in human fatalities was estimated at 0 percent in Anchorage, AK (0 fatalities from 519 collisions), 0.26 percent in Newfoundland (14 fatalities from 5422 collisions), 0.36 percent in Newfoundland (6 collisions with human fatalities from 1662 collisions), 0.45 percent in Newfoundland (3 fatalities from 661 collisions), 0.43 percent in Maine (figure 11, chapter 2); 0.5 percent in Sweden, and 0.50 percent in rural Alaska. (See references 8, 68, 76, 78, 79, and 80.)

For this analysis it was assumed that an AVC resulted in an average of 0.0005 (deer), 0.0020 (elk), and 0.0040 (moose) human fatalities. When these proportions are combined with the cost listed in table 4, it results in a cost estimate for human fatalities of \$1,671 (deer), \$6,683 (elk), and \$13,366 (moose) for each collision. Note that these estimates cannot be directly

compared with those in table 4. The costs in table 4 are for all AVCs, regardless of the species, while the cost estimates in this paragraph relate to specific wildlife species. In addition, for table 4 the chances that a reported AVC results in a human fatality are based on GES data (table 8), while the chances for the cost estimates in this paragraph are based on a species-specific review of the literature.

TOWING, ACCIDENT ATTENDANCE, AND INVESTIGATION

Not all WVCs require the towing of a vehicle and attendance or investigation by medical personnel, fire department personnel, or police. When they do, the cost for these efforts was estimated to vary between Can\$100 and 550.⁽⁶⁹⁾ Note that the cost for the actual medical assistance is included in the cost estimates for human injuries calculated earlier. For this analysis it was assumed that the cost of towing and accident attendance or investigation is \$500, but these services are only required in 25 percent (deer), 75 percent (elk), and 100 percent (moose) of the collisions. These assumptions result in an average cost for towing, accident attendance, and investigation of \$125 (deer), \$375 (elk), and \$500 (moose) per AVC.

MONETARY VALUE OF ANIMALS

Animals usually die immediately or shortly after having been hit by a vehicle. In Michigan, Allen and McCullough estimated that a minimum of 91.5 percent of all white-tailed deer that were hit by a vehicle died at the scene or shortly thereafter.⁽⁸¹⁾ In Newfoundland, 88.5 percent of all moose collisions resulted in the death of the animal (4,800 moose fatalities out of 5,422 collisions). For this analysis, it was assumed that an AVC always resulted in the eventual death of the animal, regardless of the species.

The monetary value of wildlife has many different components, including license fees, costs associated with hunting (e.g., materials, transport, lodging, meals), and recreational wildlife viewing. Hunting license fees in British Columbia were Can\$15–125 for deer, Can\$25–200 for elk, and Can\$25–200 for moose, for residents and non-residents, respectively.⁽⁷²⁾ The net return to the economy of British Columbia from hunting was estimated at Can\$1,270–7,450 for deer, Can\$3,250–3,290 for elk, and Can\$1,250–1,680 for moose.⁽⁷²⁾ The total net return to the economy of British Columbia from recreational wildlife viewing was estimated at Can\$174,000,000 per year.⁽⁷²⁾ There were an estimated 681,000 large mammals present in British Columbia, including black bears (*Ursus americanus*), grizzly bears (*Ursus arctos*), caribou (*Rangifer tarandus*), mule deer, and black-tailed deer (*Odocoileus hermionus columbianus*), white-tailed deer, elk, moose, and bighorn sheep (*Ovis canadensis*).⁽⁷²⁾ From this information, an average value for recreational wildlife viewing per large mammal was estimated at Can\$255.

In New Mexico, the minimum estimated income to the state as a result of hunting was estimated at \$250 for each deer and \$500 for each elk, excluding hunter expenditures and associated economic benefits.⁽⁷⁰⁾ In Utah, Romin and Bissonette estimated the economic value of a deer at \$1,313 in 1992.⁽³⁾ Bissonette and Hammer estimated the value of deer in Utah in 1999 at \$2,420.⁽⁸²⁾ Based on this information, it was assumed that the total monetary value of each animal was \$2,000 (deer), \$3,000 (elk) and \$2,000 (moose).

REMOVAL AND DISPOSAL COSTS OF DEER CARCASSES

In Canada, the clean-up, removal, and disposal costs for animal carcasses were estimated at Can\$100 for deer, Can\$350 for elk, and Can\$350 for moose.⁽⁷²⁾ In Pennsylvania, the average for deer carcass removal and disposal in a certified facility was \$30.50 per deer for contractors and \$52.46 per deer for the Pennsylvania Department of Transportation in 2003–2004 (Jon Fleming, Pennsylvania Department of Transportation, personal communication). For this analysis, it was assumed that the removal and disposal costs of animal carcasses were \$50 (deer), \$100 (elk), and \$100 (moose).

OTHER COSTS

Examples of costs that are not easily quantifiable and that were excluded from these analyses are the costs associated with emotional distress of people involved in WVCs, the expenses involved with conservation efforts for threatened or endangered species, the costs of the distress of injured animals, the costs associated with the rehabilitation of injured animals, and the cost of cultural values impacted by wounded animals (e.g., native Americans or other groups in society). Wildlife rehabilitators in Connecticut estimated that 36 percent of all reptiles and amphibians, 6 percent of all birds, and 12 percent of all mammals admitted to wildlife rehabilitation centers in Connecticut between 1996 through 2005 suffered from wounds inflicted by vehicles (Laurie Fortin, State of Connecticut, Department of Environmental Protection, personal communication). The total number of individuals (all species groups combined) that suffered from wounds inflicted by vehicles was 896 per year. At an average cost of \$150–200 per individual medical examination and treatment (visits to veterinarian, X-rays, medication, etc.), the yearly wildlife rehabilitation costs in Connecticut are estimated at \$134,400–179,200 (Laura Simon, Connecticut Wildlife Rehabilitators Association, personal communication).

SUMMARY

The cost of WVCs is summarized in table 6. Bear in mind that this analysis is based on a series of assumptions and estimates that may need to be modified as more and better data become available. A national estimate of vehicle collisions with moose or elk is unavailable. However, based on a total estimate of one million DVCs per year in the United States, the estimated total cost associated with WVCs is calculated to be \$8,388,000,000 (per year in the United States). Note that collisions with smaller animal species (smaller than deer) and domesticated species (e.g. livestock) were not included in this calculation.

Table 6. Summary of estimated costs of a WVC for a deer, elk, and moose.

| Description | Deer | Elk | Moose |
|---|----------------|-----------------|-----------------|
| Vehicle repair costs per collision | \$1,840 | \$3,000 | \$4,000 |
| Human injuries per collision | \$2,702 | \$5,403 | \$10,807 |
| Human fatalities per collision | \$1,671 | \$6,683 | \$13,366 |
| Towing, accident attendance and investigation | \$125 | \$375 | \$500 |
| Monetary value animal per collision | \$2,000 | \$3,000 | \$2,000 |
| Carcass removal and disposal per collision | \$50 | \$100 | \$100 |
| Total | \$8,388 | \$18,561 | \$30,773 |

CHAPTER 4. IMPACTS TO WILDLIFE

Roads and traffic can negatively affect wildlife in various ways, including habitat loss, reduced habitat quality, reduced habitat connectivity (and associated potential demographic and genetic consequences), and direct road mortality. (See references 83, 84, 85, and 86.) This chapter focuses on the effects of direct road mortality on wildlife only, specifically for threatened and endangered species.

As previously stated, in most cases, an animal that has been hit by a vehicle dies immediately or shortly after the collision. For example, in Michigan, Allen and McCullough estimated that a minimum of 91.5 percent of all white-tailed deer that were hit by a vehicle died at the scene or shortly thereafter.⁽⁸¹⁾ In Newfoundland, 88.5 percent of all moose collisions resulted in the death of the animal (4,800 moose fatalities out of 5,422 collisions). Many different wildlife species representing a wide variety of species groups have been observed as roadkill, sometimes in massive numbers. Seiler provided a review of estimates of the number of road-killed animals.⁽²³⁾ The combined number of road-killed amphibians, birds, ungulates, and other vertebrates runs in the multiple millions per year for most of the countries that were reviewed. In the United States the total number of road-killed vertebrates was estimated at 365 million per year.⁽⁸⁷⁾ The number of DVCs in the United States was estimated to exceed 500,000 per year, around 538,000 per year, and greater than 1,000,000 per year.^(3,4,45)

The number of WVCs and animal carcasses is often underestimated (as previously discussed in chapter 2); researchers have calculated the underestimation by 10.3 percent, 25 percent, 50 percent, 77.5 percent, and 87.9 percent. (See references 4, 68, 72, and 88.) These estimates for underreporting apply especially to deer, as this species is involved in the vast majority of all reported AVCs or large WVCs in North America; for example, 80 percent in Saskatchewan, and 81.4 percent in Maine.^(68,89) Underreporting may have various causes, including infrequent carcass checks, poor visibility of the carcass from the road, mutilation of the carcass by traffic to the point that the species can no longer be identified or that little to none of the carcass remains, decomposition, (illegal) removal by humans other than the data collectors, and scavengers.⁽⁹⁰⁾

While deer are the species of primary interest from a safety perspective, their survival probability is typically not a concern. Species most affected in their population survival probability seem to be species that have relatively low population density, large home ranges, travel long distances, are long lived, and have a relatively low reproduction rate. (See references 85, 91, 92, and 93.)

Roads and traffic can reduce population densities for some species such as different frogs and toads, the western European hedgehog (*Erinaceus europaeus*), and the desert tortoise (*Gopherus agassizii*).^(94, 95, 96) For some species, the survival probability of local or regional populations can be impacted too, especially if the species concerned also suffer from other human-related disturbances such as large-scale intensive agriculture and urban sprawl.^(97,98) The effect of road mortality on the population viability of a species can not always be separated from other effects associated with roads and traffic, but road mortality is believed to have affected the population survival probability for multiple species representing different species groups: amphibians (moor frog (*Rana arvalis*)), (leopard frog (*Rana pipiens*); spotted salamander (*Ambystoma maculatum*)), reptiles (timber rattlesnakes (*Crotalus horridus*)), (land and large bodies pond

turtles including the box turtle (*Terrapene ornata*), mammals (western European hedgehog), (Eurasian badger (*Meles meles*)), (otter (*Lutra lutra*)), (ocelot (*Leopardus pardalis*)), (Florida panther (*Felis concolor coryi*)), (Iberian lynx (*Lynx pardinus*)), (Florida Key deer (*Odocoileus virginianus clavium*)). (See references 91, 92, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, and 110.)

THREATENED AND ENDANGERED SPECIES

This section reviews federally listed threatened and endangered animal species in the United States for which direct road mortality is among the major threats to the survival of the species or certain populations of that species. The threatened and endangered species were not reviewed with regard to other effects associated with roads and traffic such as habitat loss, reduced habitat quality, and the barrier effect of transportation infrastructure. Note that the list in this chapter (table 7) has no regulatory status and that it does not replace potential consultation with the appropriate agencies about the impact of road improvement projects on local endangered species. In addition, because the required data were often difficult to access, and since only limited time was available for this effort, the list in this chapter is not necessarily complete.

METHODS

All threatened and endangered animal species (clams, snails, crustaceans, arachnids, insects, fishes, amphibians, reptiles, birds, and mammals) in each of the 50 states and Washington, DC, were combined into one list. If different populations of the same species were listed, they were treated separately.⁽¹¹¹⁾ Species (or populations) were identified for which direct road mortality is among the major threats to the survival probability of the species. Species that are aquatic were not reviewed with regard to vehicle collisions. Mortality as a result of collisions with trains and off-road vehicles was also excluded from the review. This review focused solely on the effect of direct mortality resulting from vehicle collisions (e.g., cars and trucks) on paved roads (e.g., asphalt or concrete).

The following sources were used to evaluate whether direct road mortality is a major threat to the survival probability of threatened and endangered species: (1) documents that provided a rationale for the listing of threatened and endangered species (*Federal Register* publications), (2) the 2006 International Union for Conservation of Nature and Natural Resources Red List of Threatened and Endangered Species, (3) other sources, including publications on individual species or species groups and expert opinions (appendix A).⁽¹¹²⁾ If an expert opinion was the sole source of information that direct road mortality is among the major threats to the survival of a certain species, additional quantitative information was sought out on the importance of road mortality before the species was added to table 7. In addition, speculations alone about the potential impact of direct road mortality were not sufficient for a species to be listed in this chapter.

The list presented in this chapter is not necessarily complete because the required information was difficult to access and the time available for this effort was limited. Furthermore, some species have been listed for decades and circumstances have changed or more and better knowledge about the threats to individual species has become available since the original listing documents were published. For these reasons one cannot only rely on the original listing

documents. Other sources have to be included in determining whether the survival probability of a species is substantially impacted by road mortality.

Even though the information available was carefully evaluated, the process of including and excluding species from the species listed in this chapter was at least partially subjective. Because of the diverse and inconsistent nature of the sources and data available, the inclusion or exclusion from the list could not be based on a simple definition. The inclusion or exclusion of the species listed relied, at least to a certain extent, on expert judgment that is open to debate. Furthermore, just as the status of species and circumstances have changed since the original listing documents were published (discussed above), the status and circumstances will continue to change and the list presented in this chapter will become less applicable over time.

RESULTS

For the 21 species listed in table 7, direct road mortality is considered a major threat to the survival of the species. The table includes three amphibian species, seven reptile species, three bird species, and eight mammal species. A brief discussion for each species follows table 7.

Table 7. Threatened and endangered species in the United States for which direct road mortality is among the major threats to the survival probability of the species.⁽¹¹¹⁾

| Species Group | Species Name | Sources Justifying the Inclusion of the Species Concerned in this Table | | |
|---------------|--|---|--|--|
| | | Federal Listing Documents | International Union for Conservation of Nature and Natural Resources | Other Source(s) |
| Amphibians | California tiger salamander (<i>Ambystoma californiense</i>), C. CA, S. Barb., Son. county | ⁽¹¹³⁾ | ⁽¹¹²⁾ | ^(114,115,116) Dave Johnston, California Department of Fish and Game, California, personal communication |
| Amphibians | Flatwoods salamander (<i>Ambystoma cingulatum</i>) | ⁽¹¹⁷⁾ | ⁽¹¹²⁾ | Bruce Means, Coastal Plains Institute and Land Conservancy, Tallahassee, FL, personal communication, John Palis, Palis Environmental Consulting, Jonesboro, IL, personal communication |
| Amphibians | Houston toad (<i>Bufo houstonensis</i>) | Threats not discussed | ⁽¹¹²⁾ | ⁽¹¹⁸⁾ |
| Reptiles | American crocodile (<i>Crocodylus acutus</i>) | ⁽¹¹⁹⁾ | Threats not discussed | ^(120,121) |
| Reptiles | Desert tortoise (<i>Gopherus agassizii</i>), except in Sonoran Desert | ⁽¹²²⁾ | Threats not discussed | (See references 96, 123, 124, and 125.) |
| Reptiles | Gopher tortoise (<i>Gopherus polyphemus</i>), W of Mobile/Tombigbee Rs. | ⁽¹²⁶⁾ | Threats not discussed | ^(125,127,128) |
| Reptiles | Alabama red-bellied turtle (<i>Pseudemys alabamensis</i>) | Collisions not listed as a threat | Threats not discussed | ^(125,129) D. Nelson, Dep. of Biol. Sc., Univ. S. AL, personal communication, Matthew J. Aresco, Nokuse Plantation, Bruce, Florida, personal communication |
| Reptiles | Bog turtle (Muhlenberg) northern population (<i>Clemmys muhlenbergii</i>) | ⁽¹³⁰⁾ | Threats not discussed | |
| Reptiles | Copperbelly water snake (<i>Nerodia erythrogaster neglecta</i>) | ⁽¹³¹⁾ | Not listed | ⁽¹³²⁾ |

Table 7. Threatened and endangered species in the United States for which direct road mortality is among the major threats to the survival probability of the species—continued.

| Species Group | Species Name | Sources Justifying the Inclusion of the Species Concerned in this Table | | |
|---------------|--|---|--|---|
| | | Federal Listing Documents | International Union for Conservation of Nature and Natural Resources | Other Source(s) |
| Reptiles | Eastern indigo snake, eastern indigo (<i>Drymarchon corais couperi</i>) | Collisions not listed as a threat | Not listed | ^(133,134,135) Bruce Means, Coastal Plains Institute and Land Conservancy, Tallahassee, FL, personal communication; John Palis, Palis Environmental Consulting, Jonesboro, IL, personal communication |
| Birds | Audubon's crested caracara (<i>Polyborus plancus audubonii</i>), FL pop. | ⁽¹³⁶⁾ | Threats not discussed | ⁽¹³⁷⁾ |
| Birds | Hawaiian goose (<i>Branta sandvicensis</i>) | Threats not discussed | ⁽¹¹²⁾ | ⁽¹³⁸⁾ K. Misajon, NPS, personal communication |
| Birds | Florida scrub jay (<i>Aphelocoma coerulescens</i>) | ⁽¹³⁹⁾ | ⁽¹¹²⁾ | ⁽¹⁴⁰⁾ |
| Mammals | Lower Keys marsh rabbit, (<i>Sylvilagus palustris hefneri</i>) | Collisions not listed as a threat | Threats not discussed | ^(141,142) |
| Mammals | Key deer (<i>Odocoileus virginianus clavium</i>) | Threats not discussed | Threats not discussed | ⁽¹⁴³⁾ |
| Mammals | Bighorn Sheep, Peninsular CA pop. (<i>Ovis canadensis</i>) | ⁽¹⁴⁴⁾ | Threats not discussed | |
| Mammals | San Joaquin kit fox (<i>Vulpes macrotis mutica</i>) | Threats not discussed | ⁽¹¹²⁾ | ⁽¹⁴⁵⁾ |
| Mammals | Canada lynx (<i>Lynx canadensis</i>), lower 48 states | ⁽¹⁴⁶⁾ | Collisions not listed as a threat | ⁽¹⁴⁷⁾ Alison Michael, U.S. Fish and Wildlife, personal communication; Phil Delphey, U.S. Fish and Wildlife Service, personal communication |
| Mammals | Ocelot (<i>Leopardus pardalis</i>) | Collisions not listed as a threat | Collisions not listed as a threat | ^(107,148) |
| Mammals | Florida panther (<i>Felis concolor coryi</i>) | Threats not discussed | Collisions not listed as a threat | ⁽¹⁴⁹⁾ |
| Mammals | Red wolf (<i>Canis rufus</i>), except where XN | Collisions not listed as a threat | ⁽¹¹²⁾ | |

Amphibians

The California tiger salamander (*Ambystoma californiense*) is affected by habitat loss due to urbanization and agriculture, unnatural hydrology, predation by nonnative species (bullfrogs, crayfish, various fish species), reduced availability of burrows as a result of rodent control programs, vehicle collisions, reduced food availability through the use of pesticides for mosquito control, hybridization with nonnative tiger salamanders, and storm water road runoff (Dave Johnston, California Department of Fish and Game, CA, personal communication). (See references 112, 113, 114, 115, and 116.)

The flatwoods salamander (*Ambystoma cingulatum*) was listed because of habitat loss and habitat alteration.^(117,150) However, direct mortality (road mortality during migration, capture by bait collectors) is also a potential or a major threat to this species (Bruce Means, Coastal Plains Institute and Land Conservancy, Tallahassee, FL, personal communication; John Palis, Palis Environmental Consulting, Jonesboro, IL, personal communication).^(112,117) At one location where a substantial population decline has been observed, road mortality was not considered substantial. In this case, habitat loss and habitat degradation (agriculture, silviculture, urbanization, and changes in hydrology, predation by nonnative fish species) are thought to be the primary cause of the decline.⁽¹⁵¹⁾ Silviculture is the cultivation and management of forest trees or woodlands for producing timber and other wood products.

The Houston toad (*Bufo houstonensis*) is affected by habitat loss and habitat alteration, mostly through urbanization, recreational development, and agriculture.^(112,118) However, direct road mortality through increased habitat fragmentation by road construction has also been identified as a major threat to the survival probability of the species.^(112,118) Other threats include predation by nonnative species (e.g., Brazil fire ants).⁽¹¹²⁾

Reptiles

The American crocodile (*Crocodylus acutus*) is affected by changes in hydrology and consequent changes in salinity levels.⁽¹²¹⁾ In addition, direct mortality of adult American crocodiles is considered higher than the population can sustain.⁽¹²¹⁾ Of the deaths recorded between 1971 and 2001, the majority were hit by cars.^(119,120,121) Warning signs and fences were installed along the major highways throughout crocodile habitat in south Florida.⁽¹¹⁹⁾ However, it appears that some or all of the planned underpasses may not have been built (U.S. Highway 1) and that some of the fencing that was installed (State Route 905) was not flush with the ground so that American crocodiles could enter but not exit the right of way. Some of these fence sections have now been removed (Frank Mazzotti, Department of Wildlife Ecology and Conservation, Fort Lauderdale Research and Education Center, Davie, FL, personal communication).

The desert tortoise (figure 22) is affected by habitat loss (agriculture, landfills) and habitat degradation (e.g., through off-road vehicle use, overgrazing, invasive plant species). (See references 96, 123, 152, and 153.) Substantial direct mortality occurs on highways as well as off highways (nonintentional and intentional crushing by off-road vehicle operators, trampling of their burrows by off-road vehicles and livestock, shooting). (See references 96, 122, 123, 124, 125, 152, and 153.) Other mortality causes are disease, drought, mining, wildfires, garbage and

litter, handling by humans, collection by humans, and predation by common ravens (*Corvus corax*). (See references 96, 123, 125, 152, 154, and 155.)



Figure 22. Photo. Desert tortoise (copyright: Marcel Huijser).

The gopher tortoise (*Gopherus polyphemus*) is affected by habitat loss (urbanization, agriculture, silviculture, mining) and habitat degradation (silviculture, fire suppression, nonnative plant species).^(126,127,128) Collection by humans and road mortality also affected the species substantially. (See references 125, 126, 127, and 128.) Furthermore, the species is affected by predation, including by nonnative fire ants.⁽¹²⁸⁾ Fences and culverts were installed along a section of Highway 63 in Green County, south of Leakesville, MS (Matthew J. Aresco, Nokuse Plantation, Bruce, FL, personal communication; Claiborne Barnwell and Chuck Walters, Mississippi Department of Transportation, personal communication). The aim of the mitigation measures is to reduce gopher tortoise road mortality and to allow for gopher tortoises to cross under the road (Claiborne Barnwell and Chuck Walters, Mississippi Department of Transportation, personal communication) (figure 23). Highway 63 has 24.1 km (15 mi) of road length with gopher tortoise fencing, and, because of the nature of the terrain, there is only one culvert that was specifically designed for the gopher tortoise (between Lucedale and Leakesville, MS) (Chuck Walters, Mississippi Department of Transportation, personal communication). At the site of the culvert, the fence stretches out about 914 m (3,000 ft) to either side of the culvert (Chuck Walters, Mississippi Department of Transportation, personal communication). Some of the fencing was installed as early as 1998, and along those road sections the number of reported road-killed gopher tortoises was reduced from one to two per year to zero (Chuck Walters, Mississippi Department of Transportation, personal communication).



Figure 23. Photo. Fences lead gopher tortoises towards a culvert along Highway 63 in Green County, south of Leakesville, MS (copyright: Chuck Walters, Environmental Division, Mississippi Department of Transportation).

The Alabama red-bellied turtle (*Pseudemys alabamensis*) is affected by egg predation, human disturbance, and road mortality (David Nelson, Department of Biological Sciences, University of South Alabama, personal communication; Matthew J. Aresco, Nokuse Plantation, Bruce, FL, personal communication).^(125,129,156) The small population size and low recruitment rates of the species make recovery a difficult process. A weekly road mortality survey along the Mobile Bay Causeway (6.5 mi from Spanish Fort to Mobile, AL) between 2001 and 2004 reported 324 Alabama red-bellied turtle carcasses (David Nelson, Department of Biological Sciences, University of South Alabama, personal communication) (figure 24 and figure 25).⁽¹²⁹⁾ In a typical year, 12–15 adult females, most of them with eggs, are found dead on the Mobile Bay Causeway (David Nelson, Department of Biological Sciences, University of South Alabama, personal communication). In addition, several dozen juveniles and a few males are killed by vehicles each year as well (David Nelson, Department of Biological Sciences, University of South Alabama, personal communication).



Figure 24. Photo. A section of the Mobile Bay Causeway that has relatively many road-killed Alabama red-bellied turtles (copyright: Marcel Huijser).



Figure 25. Photo. Road-killed Alabama red-bellied turtle (copyright: Marcel Huijser).

The northern population of the bog turtle (*Clemmys muhlenbergii*) is affected by habitat degradation and fragmentation from agriculture and development, habitat succession due to invasive exotic and native plants, and illegal trade and collecting.⁽¹³⁰⁾ In addition, roads

contribute “significantly” to mortality, especially where roads are adjacent to or within wetlands.⁽¹³⁰⁾

The copperbelly water snake (*Nerodia erythrogaster neglecta*) is affected by habitat loss and habitat fragmentation, primarily because of agriculture, drainage and damming of wetlands, coal mining, channelization, damming and diversion of streams and rivers, and residential and commercial development.⁽¹³¹⁾ In addition, predation by pets and vehicle-caused mortality are a concern.^(131,132) Traffic mortality may account for mortality of 14–21 percent of the population per year.⁽¹³²⁾ The species seems especially vulnerable as it frequently crosses overland to different wetland sites.⁽¹³²⁾

The eastern indigo snake (*Drymarchon corais couperi*) is affected by habitat loss due to development, collection and commercial trade, intentional killing, vehicular traffic, and residual pesticide exposure.^(135,157) In addition, gopher tortoise burrows that are gassed to kill rattlesnakes also unintentionally kill indigo snakes.⁽¹⁵⁷⁾ Bolt reported that road mortality was the highest cause of death in a study where 81 individuals were followed, some for more than three consecutive years.⁽¹³³⁾ At least 15 of the 38 known mortalities (39 percent) in the field were due to vehicles. In that study, twice as many males were killed on the road as females (M. Rebecca Bolt, The Dynamac Corporation, Kennedy Space Center, FL, personal communication). In another study, of the 31 indigo snakes documented, 5 were found dead on a road (16 percent of total number of individuals followed), accounting for 55 percent of all known mortalities.⁽¹³⁴⁾

Birds

The crested caracara in central Florida (*Polyborus plancus audubonii*) is affected by habitat alteration for agriculture and housing, illegal killing, and vehicle collisions.^(136,137) In a 3-year study, 52 percent of all fledgling mortality (14 out of 27 deaths) was caused by vehicle collisions.⁽¹³⁷⁾ The crested caracara spends substantial time close to roads as it searches for and feeds on road-killed animals (Dan Smith, Western Transportation Institute, Montana State University, personal communication).

The Hawaiian goose, or nene (*Branta sandvicensis*), is affected by habitat loss, predation by the nonnative small Indian mongoose (*Herpestes auropunctatus*), dogs, and perhaps rats and cats.⁽¹¹²⁾ Poaching and roadkills are also important causes of mortality (Kathleen Misajon, National Park Service, personal communication).^(112,138) Road mortality is the most common known cause of mortality in adults.⁽¹⁵⁸⁾ The species may also be affected by diseases and parasites, inbreeding depression, loss of adaptive skills in captive-bred birds, and dietary deficiencies.⁽¹¹²⁾

Haleakala National Park reported 35 road-killed Hawaiian geese between 1973 and 2006, and Hawai'i Volcanoes National Park reported 33 road-killed Hawaiian geese between 1996 and 2006 (Kathleen Misajon, National Park Service, personal communication). The population size of the Hawaiian goose fluctuated between 140 and 200 between 1996 and 2006 (Kathleen Misajon, National Park Service, personal communication). In Hawai'i Volcanoes National Park, five adult Hawaiian geese have been killed on the road in 2006 between January 1 and August 28, out of a total of 160 individuals (Kathleen Misajon, National Park Service, personal communication).

In Hawai'i Volcanoes National Park, the Hawaiian goose is attracted to roads because of feeding by park visitors, especially around parking areas (Kathleen Misajon, National Park Service, personal communication) (figure 26). This practice habituates the birds to roads and cars, and it encourages them to spend more time on and alongside roads, increasing their exposure to vehicles. Furthermore, some road sections in the park split roosting habitat from feeding habitat. When they have young, Hawaiian geese walk between roosting and feeding sites for 3–4 months and cross the road frequently, mostly at dawn or dusk, with relatively low visibility (Kathleen Misajon, National Park Service, personal communication). Pairs with goslings are basically pedestrian until the goslings fledge at 3–4 months of age.

Permanent warning signs have been installed in known Hawaiian goose kill areas (Kathleen Misajon, National Park Service, personal communication) (figure 27). In addition, temporary warning signs can be installed at new or unexpected locations. Nonetheless, all five individuals that were killed by vehicles between January 1 and August 28, 2006 were within signed crossing zones (Kathleen Misajon, National Park Service, personal communication). There are also indirect effects of roadkills to the Hawaiian goose population. For example, mates are left without partners, often for at least one breeding season, resulting in one less nesting attempt that year (Kathleen Misajon, National Park Service, personal communication). In addition, goslings without one or both parents have substantially reduced survival probability (Kathleen Misajon, National Park Service, personal communication).



Figure 26. Photo. “Do Not Feed Nene” sign (copyright: Hawai’i Volcanoes National Park, National Park Service).



Figure 27. Photo. Hawaiian goose (nene) warning sign (copyright: Haleakala National Park, National Park Service).

The Florida scrub jay (*Aphelocoma coerulescens*) is affected by habitat loss (housing developments, citrus-groves) and reduced habitat quality (disrupted fire regimes, human

disturbance), predation by nonnative species (feral cats) and roadkill. (See references 112, 139, 140, and 159.) Annual mortality rates of the Florida scrub jay have been recorded to be 65 percent higher in road territories compared to nonroad territories.⁽¹⁴⁰⁾ Furthermore, roadside territories are a population sink, and the high mortality rate appears to be caused by vehicle collisions rather than other factors associated with a roadside environment.⁽¹⁴⁰⁾

Mammals

The Lower Keys marsh rabbit (*Sylvilagus palustris hefneri*) is or has been affected by wetland drainage for residential, commercial and military purposes, habitat destruction associated with road building, hunting, predation by feral house cats, road mortality, mowing practices, and off-road vehicle use.^(117,160) In a combination of a field and modeling study, almost one-third of all mortalities were caused by vehicle collisions, and modeling showed that theoretical removal of road mortality would eliminate the chance of extinction for the Big Pine metapopulation.⁽¹⁴¹⁾ Dispersing subadult males seem especially vulnerable to traffic mortality.⁽¹¹⁷⁾

The Florida Key deer (*Odocoileus virginianus clavium*) is affected by vehicle collisions, habitat loss, and human disturbance.^(110,143) Vehicle collisions account for more than 50 percent of the total deer mortality, mostly on U.S. Highway 1.⁽¹⁴³⁾

The bighorn sheep, peninsular California population, (*Ovis canadensis*) is affected by a range of issues including disease, low recruitment, habitat loss, habitat degradation, habitat fragmentation, residential and commercial development and high predation rates.⁽¹⁴⁴⁾ This population, especially small groups that have low recruitment, is also threatened by road mortality.⁽¹⁴⁴⁾

The San Joaquin kit fox (*Vulpes macrotis mutica*) is threatened by habitat conversion (agriculture, urban development, industrial development), habitat fragmentation, loss of prey species (e.g., eradication of prairie dog towns), predation (coyotes, bobcats, nonnative red foxes, and domestic dogs), and vehicle mortality.^(112,145,161) In the San Joaquin Valley of California, habitat conversion for agriculture has slowed, but habitat loss, reduction of habitat quality, and habitat fragmentation are still a primary threat. Road mortality varies between studies: 20 out of 225 adult deaths (9 percent), 11 out of 142 juvenile deaths (8 percent), 1 out of 60 deaths (2 percent), 1 out of 22 deaths (5 percent), 2 out of 49 deaths (4 percent), 2 out of 17 deaths (12 percent), 15 out of 23 adult deaths (65 percent), and 6 out of 12 juvenile deaths (50 percent).⁽¹⁴⁵⁾ After predation, vehicle collisions are likely to be the second most common cause of mortality.⁽¹⁴⁵⁾

Canada lynx (*Lynx canadensis*) is likely impacted by urbanization and forestry practices (including fire suppression) and trapping.^(162,163) In addition, its population size fluctuates with the availability of its main prey species, the snowshoe hare (*Lepus americanus*).⁽¹⁶³⁾ In the United States, road mortality may limit the reestablishment of the Canada lynx in Wisconsin and Michigan.⁽¹⁴⁶⁾ A total of 218 adult lynx were released between 1999 and 2006, and there were 80 known mortalities as of June 30, 2006.⁽¹⁴⁷⁾ Starvation was a substantial cause of mortality in the first year of the releases only. About 31.3 percent of the known mortalities were human induced (including collisions with vehicles or shooting by humans).⁽¹⁴⁷⁾ Malnutrition and disease or illness accounted for 21.3 percent of the deaths, while 32.5 percent of the deaths were from unknown causes.⁽¹⁴⁷⁾ Closer and more recent analyses showed that road mortality accounted for a

minimum of 44 percent (11 out of 25) of human-caused mortalities (Alison Michael, U.S. Fish and Wildlife, personal communication). This percentage may be higher as this estimate only included confirmed vehicle-caused mortality and excluded suspected vehicle-caused mortality (Alison Michael, U.S. Fish and Wildlife, personal communication). In Maine, 11 road-killed Canada lynx have been reported since 1999; nine on two-lane logging roads that are also accessible to the public and two on paved public roads.⁽¹⁶⁴⁾ Recent data from Minnesota show that Canada lynx have died from shooting, trapping, collisions with trains, and road mortality (Phil Delphey, U.S. Fish and Wildlife Service, personal communication). Road mortality on paved highways amounted to 17 percent (5 out of 30) of all known mortalities since the species was listed in 2000 (Phil Delphey, U.S. Fish and Wildlife Service, personal communication).

The ocelot is affected by habitat loss (loss of dense thorn shrub habitat), mortality vehicle collisions, and genetic erosion.^(107,148,165) Vehicle collisions constituted 35 percent of all mortality.⁽¹⁴⁸⁾

The Florida panther is affected by habitat loss (agriculture, urbanization), habitat fragmentation, road mortality, and loss of genetic diversity.^(166,167,168) Road mortality is substantial, 25 out of 73 deaths were caused by vehicles.⁽¹⁴⁹⁾

The red wolf (*Canis rufus*) went extinct in the wild by 1980 and was reintroduced in 1987 in North Carolina.⁽¹¹²⁾ After reintroduction, the species was affected by hybridization with coyotes (*Canis latrans*).^(112,169,170) Direct mortality (vehicle collisions, shooting) can be substantial.⁽¹¹²⁾

Other Species

In addition to the species listed in table 7, the authors of this report recognize that other federally threatened and endangered species may be substantially affected by road mortality too. However, species that had insufficient data available, at least to the authors of this report at the time of publication, were excluded from table 7.

Summary

This chapter identified 21 federally listed species from four species groups (amphibians, reptiles, birds and mammals) for which direct road mortality is among the major threats to the survival of the species. However, road mortality is typically only one of the major threats to these species. Habitat loss (e.g., due to agriculture, urbanization, mining, and changes in hydrology), reduced habitat quality (e.g., due to agricultural and silviculture practices such as livestock grazing, logging, fire suppression, introduction of nonnative plant species, and water contamination with pollutants, and the use of pesticides, in general), habitat fragmentation (e.g., due to roads or other unsuitable habitat), competition and predation by nonnative species, other sources of natural and unnatural mortality (e.g., off-road vehicles, poaching, direct killing or collection by humans, disease), and low recruitment and loss of genetic diversity due to small populations also threaten the survival of the species listed in this chapter. This implies that a substantial reduction in road mortality is not necessarily sufficient for the recovery of the species listed in this chapter. For successful species recovery, including mitigation for effects related to roads and traffic, it is advisable to use an integrated approach.⁽¹⁷¹⁾

CHAPTER 5. MITIGATION METHODS THAT ATTEMPT TO INFLUENCE DRIVER BEHAVIOR

This broad category of WVC mitigation strategies includes those that attempt to help drivers avoid a WVC by changing their behavior. The specific mitigation measures reported on in this chapter, by broad category based on their intent, consist of the following categories:

- Public information and education.
- Improvement in driver attentiveness using warning signs by:
 - Standard signs.
 - Large, nonstandard signs.
 - Seasonal signs.
 - Animal detection systems.
- Improvement of driver attentiveness with in-vehicle warning systems by:
 - In-vehicle warning linked to roadside animal detection systems.
 - In-vehicle warning linked to on-board animal detectors.
- Increase in visibility to drivers by:
 - Roadway lighting.
 - Vegetation removal.
 - Wider striping.
 - Reflective collars for animals.
 - Reduced height of snow banks.
- Reduction in traffic volumes on roadways by:
 - Reduction in traffic volume on road network.
 - Temporary road closures.
- Reduction of average speeds on roadways by:
 - Reduction of the posted speed limit.
 - Traffic calming/reduction of design speed.
 - Posting of advisory speed limits.
- Wildlife crossing guards.

The mitigation measures presented in the report are what might be considered by planners as possible mitigation measures. FHWA is not recommending any of these measures by including them in this report. The majority of the mitigation measures presented have been used in practice

or at least tried as a case study, the exceptions being in-vehicle roadside animal detection linked to on-board computer warning and reduction in traffic volume on the road network.

PUBLIC INFORMATION AND EDUCATION

Increasing roadway safety via public information and driver education seeks to reduce death and serious injury on roadways by increasing motorists' awareness of the impacts, causes, and high-risk locations of WVCs, as well as to give drivers advice on the best actions to take to avoid crashes with animals. These WVC reduction efforts are implemented through general messages in the media, videos, brochures, posters, and bumper stickers. Often these activities work in concert with roadside messages at specific high-risk locations or in specific seasons of high wildlife migration or movement. Public information and driver education efforts are thought to work best when conducted in concert with other WVC reduction techniques.^(172,173)

The most common WVCs in the United States involve deer. DVC education and information efforts can be divided into two categories. In one category are efforts that provide information describing DVC significance, such as the local rates of DVCs or locations of roadway segments with high rates of DVCs. In the second category are efforts that provide information on DVC avoidance, namely, actions drivers can take to avoid wildlife if they appear on or near the roadway.⁽⁵³⁾

Many transportation professionals and researchers have discussed driver education and public information campaigns as a means to help reduce WVCs or have conducted research to incorporate their findings into motorist education efforts. (See references 29, 38, 70, 174, 175, and 176.) However, there are no known studies indicating the statistical effectiveness of driver education or public information/awareness efforts that have directly, by themselves, decreased the incidence rates of WVCs.⁽¹⁷⁶⁾

A national phone survey indicated driver respondents believe WVCs are a serious problem, and more than 97 percent believe driver education and media information to the general public would be helpful in reducing WVCs.⁽¹⁷⁵⁾ Respondents to a survey in Michigan (1,653 questionnaires) are receptive to receiving more information on what actions to take to reduce their probability of being involved in a WVC. They indicated newspapers as the preferred medium, although they also chose eight other avenues of receiving information.⁽¹⁷⁷⁾ In British Columbia a survey of 1,882 licensed drivers indicates respondents strongly (81 percent) believe wildlife warning signs reduce WVCs.⁽¹⁷⁸⁾

Public information and driver education, combined with other WVC reduction activities must work in concert to effectively reduce crashes and increase safety. Given a receptive audience for information, campaigns have great potential to tap into a public that seeks to more fully understand the dangers of WVCs, the actions drivers can take to avoid accidents, and the locations of high-risk roadways.

Many states have developed safety campaigns to increase public awareness. For example, the Maine Department of Transportation's Safety Office has a public information campaign to increase awareness of WVCs. They have developed a video, brochures, and crash maps for moose and deer at: <http://www.maine.gov/mdot/safetyoffice/maine-crash-data.php> (accessed

January 25, 2007). The Iowa Departments of Transportation, Public Safety, and Natural Resources in conjunction with insurance agencies and local law enforcement have developed the “Don’t Veer for Deer” campaign. Public information maps, brochures, Public Service Announcements, and a poster can be found at <http://www.dps.state.ia.us/commis/gtsb/deercrashes/index.shtml> (accessed January 25, 2007).

The “Colorado Wildlife on the Move” Campaign reached more than three million people through television, magazines, and other media and included 58,000 driver safety tip sheets and 500 posters distributed in welcome centers, national parks, and Enterprise Rent-A-Car offices in 85 cities and 175 locations.⁽¹⁷⁹⁾

As a result of a local outreach campaign in Montana, survey respondents who had heard or seen information on WVCs increased from 21 to 33 percent.⁽¹⁷³⁾

Case Studies and Contacts

Two relevant case studies relating to public information and education are the “Drivers for Wildlife” program in Jasper National Park and the program to reduce bird collisions at the NASA Kennedy Space Center.

The Parks Canada Drivers for Wildlife program in Jasper National Park combines public education, which includes bumper stickers (see figure 28) and roadway billboards (see figure 29, with two digital signs that record speed and advise drivers to slow down in the high-risk wildlife zone. The number of road-killed animals along park highways decreased by about 15 percent after the first 10 months of the public education and roadside sign program; however, the signs were given the most credit for the reduction of WVCs.⁽¹⁷²⁾



Figure 28. Photo. Example of bumper sticker for a driver awareness campaign to reduce WVCs in Jasper National Park, Canada (source: Parks Canada).

For information about Jasper National Park’s campaign, contact Brenda Shepherd, Park Ecologist, Jasper National Park, (780) 852-6232, brenda.shepherd@pc.gc.ca.

In July of 2005, the space shuttle Discovery hit a vulture during take-off. Initially NASA formed an “Avian Abatement Team” to address this safety issue. The program has been expanded to include prevention of roadkill (which attracts the birds) in concert with the Merritt Island National Wildlife Refuge, which is a 140,000-acre overlay of the Kennedy Space Center. The refuge provides a buffer zone for NASA.



Figure 29. Photo. Roadside billboard along highway in Jasper National Park, Canada (source: Parks Canada).

The Kennedy Space Center has developed a Web site with a video, materials, posters (see figure 30), stickers and updates on the latest roadkill statistics at: <http://environmental.ksc.nasa.gov/projects/roadkill.htm> (accessed January 25, 2007).

The Web site includes a link to the FHWA's Critter Crossings Web site at: <http://www.fhwa.dot.gov/environment/wildlifecrossings/index.htm> (accessed January 25, 2007).

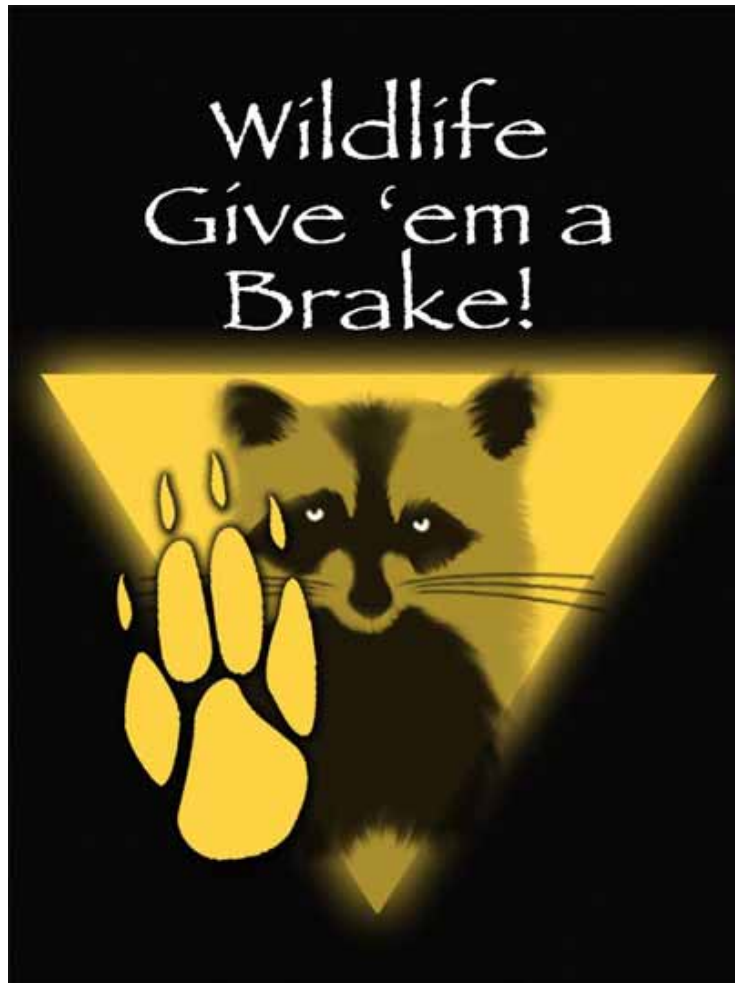


Figure 30. Photo. Poster created by NASA's John F. Kennedy Space Center as part of its RoadKill Prevention Program (source: NASA).

Direct Benefits

The Iowa Department of Transportation's Don't Veer for Deer campaign appears to be demonstrating benefits. Since implementation of this program the number of fatalities resulting from deer-car collisions dropped 60 percent in 2005, from 10 in 2003 to 4 in 2005, according to their Web site (http://www.dps.state.ia.us/commis/pib/Releases/2006/10-05-2006_Deer.htm).⁽¹⁸⁰⁾ The long-term effect requires further study.

The reduction in severity (i.e., number of fatalities) is a positive benefit, but no campaigns identified the direct level of correlation between public information and driver education efforts and the reduction of WVCs.

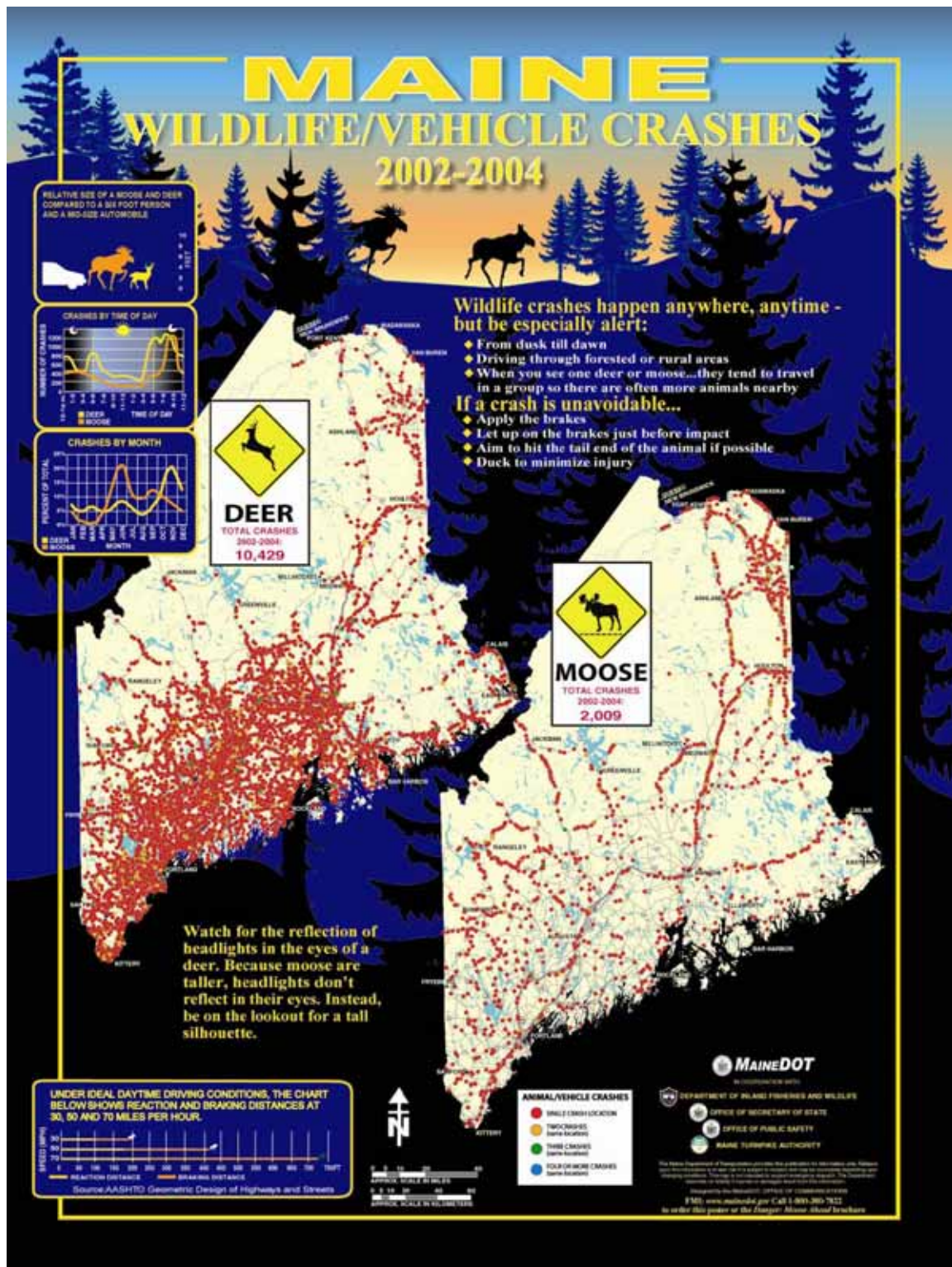


Figure 31. Photo. Poster produced by the Maine Department of Transportation (source: Maine Department of Transportation).

Indirect Benefits

Many driver education and public information campaigns summarize and display crash data maps related to WVCs. This spatial information can also be used for focusing limited resources to roadside mitigation methods for the most problematic areas within a state, county, or metropolitan area.

Undesirable Effects

No undesirable effects were identified in the literature review.

Costs

For statewide public information campaigns, costs were low compared to other mitigation methods. Maine has spent about \$6,500 for its moose and deer crash maps and moose safety brochures. This investment provided an adequate outreach supply to last for about three years (Duane Brunell, Maine Department of Transportation, personal communication). In Colorado, the “Wildlife on the Move” Campaign cost \$16,335. Most expenses were in two categories: (1) printing of publications (a little more than \$10,000) and (2) contract labor for outreach (a little more than \$4,500) (Monique DiGiorgio, Southern Rockies Ecosystem Project, personal communication). Costs for the Don’t Veer for Deer campaign in Iowa were negligible (Michael Pawlovich, Iowa Department of Transportation, personal comment).

Guidelines

Given that drivers are open to receiving more educational information to help reduce WVCs, it may be most cost effective to focus driver education and public information efforts toward 18- to 45-year-olds, as they are involved in the highest numbers of AVCs (see figure 32). In a study in Kent County, MI, registered drivers between the ages of 30 and 39 had the highest number of DVCs.⁽¹⁸¹⁾ If public campaigns or local education programs can be focused for specific age groups, 30- to 45-year-olds should be targeted. Note that figure 32 also suggests that drivers do not benefit from driving experience where AVCs are concerned. Campaigns directed at younger drivers, who have higher AVC crash rates, may also be studied.

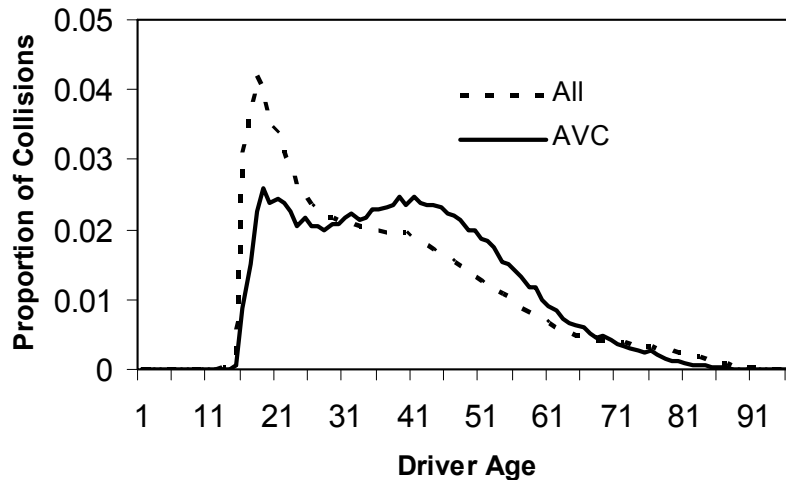


Figure 32. Graph. Driver age distribution for all crashes and AVCs (HSIS data).

ROADWAY WARNING SIGNS

Roadway wildlife warning signs are perhaps the most commonly applied WVC mitigation measure.^(85,182) The signs alert the drivers to the potential presence of wildlife on or near the road and urge them to be more alert, to reduce the speed of their vehicle, or a combination of both. These signs attempt to prevent a collision or to reduce the severity of a collision if one does occur by lowering vehicle speeds at impact (figure 33).

Since the effectiveness of warning signs depends on driver response, it is critical that warning signs are reliable (i.e., the driver is warned when there is a high chance of WVC). The warning signs discussed below (standard warning signs, large or enhanced warning signs, seasonal wildlife warning signs, and animal detection systems) should be placed in road sections that exceed a certain minimum risk of WVC. The current location selection process can typically be improved upon.^(53,183,184) Seasonal wildlife warning signs need to be in place during those periods of the year that animals cross the road most frequently. Animal detection systems (if used) need to be connected to reliable sensors used for the detection of large animals on or near the road.

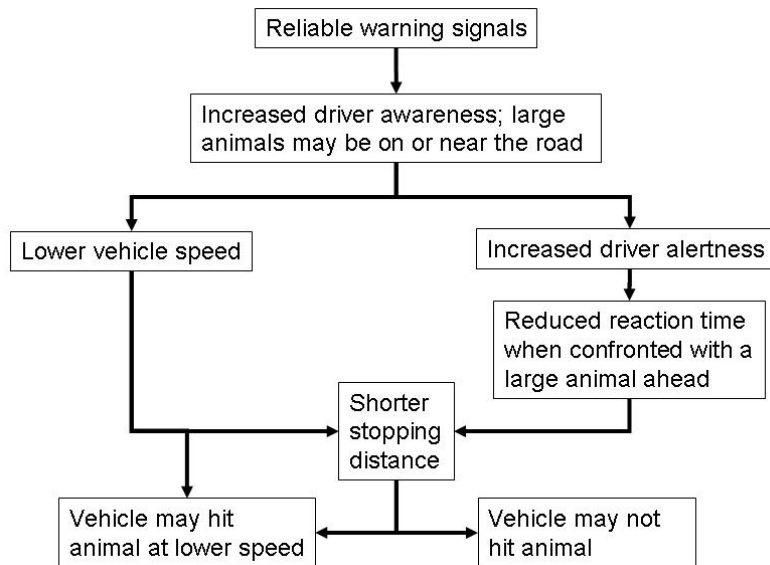


Figure 33. Flow chart. Warning signs and driver response.

Driver awareness and response are influenced by the type of warning sign.^(185,186,187) Large and graphic signs, flags attached to wildlife warning signs, permanently flashing lights on top of or around wildlife warning signs, and messages displayed on variable message signs are designed to attract the attention of the driver and invoke response to a greater extent than standard wildlife warning signs. Seasonal wildlife warning signs are designed to deliver a more time specific warning message to drivers; they are only displayed during certain times of the year when the risk is much higher, for example during the seasonal migration of certain species. Animal detection systems are even more time specific in their operation; the warning signals are only activated after a large animal has been detected on or near the road.

Driver response is split into two components: increased alertness and lower vehicle speed. Increased alertness can lead to a reduction in driver reaction time. Driver reaction time to an unusual and unexpected event can be reduced from 1.5 s to 0.7 s if drivers are warned.⁽¹⁸⁸⁾ Assuming a constant vehicle speed of 88 km/h (55 mi/h) before and after warning signals have been presented to a driver, increased driver alertness could reduce the stopping distance of the vehicle by 21 m (68 ft). This reduction in reaction time and stopping distance, however, has not been specifically tested with respect to the presence of large animals in rural areas, let alone for warning signals that may apply to road sections of many miles rather than a point or short road section. Lower vehicle speed allows for more reaction time, and should a collision still happen, it is likely to be less severe.⁽¹⁸⁹⁾ At relatively high speed even small reductions in vehicle speed matter because the relation between vehicle speed and the risk of a severe accident is exponential; small reductions in vehicle speed result in a disproportionate decrease in the risk of a severe accident.⁽¹⁸⁹⁾

STANDARD WILDLIFE WARNING SIGNS

The standard deer warning sign in the United States is a diamond-shaped panel with a black deer symbol on a yellow background, sometimes accompanied by text signs that indicate the length of the road section to which the sign applies (figure 34).



Figure 34. Photo. Standard deer warning sign along Montana Highway 83 (copyright: Marcel Huijser, WTI).

Meyer investigated the effectiveness of standard deer warning signs in Kansas by comparing the accident data before and after sign installation.⁽¹⁹⁰⁾ After taking all available accident data before sign installation and other road and landscape parameters into consideration, there was no evidence that the presence of the deer warning signs had resulted in fewer DVCs.⁽¹⁹⁰⁾ Rogers also concluded that the number of DVCs had not reduced as the result of the installation of deer warning signs.⁽³⁸⁾ Furthermore, the installation of standard camel crossing signs in Saudi Arabia did not result in reduced vehicle speed.⁽¹⁹¹⁾ Finally, in a driving simulator study, a standard deer warning sign resulted in an average vehicle speed of 123.2 km/h (76.6 mi/h), just over the posted speed limit of 120.7 km/h (75 mi/h).⁽¹⁹²⁾ This result shows that a standard deer warning sign was unable to reduce the average vehicle speed to the posted speed limit or lower.

Case Studies and Contacts

For information about the study on the effectiveness of deer warning signs in Kansas, contact: Eric Meyer, University of Kansas, Civil, Environmental & Architectural Engineering Department, 1530 West 15th Street, Room 2150, Lawrence, KS 66045-7609 (he is currently affiliated with Meyer Intelligent Transportation Services, (785) 843-2718, emeyer@insighthawks.com).

Direct Benefits

Based on the available data, standard deer warning signs are concluded to be ineffective in reducing WVCs, in general, and DVCs, in specific.

Most authors doubt the effectiveness of standard warning signs, but only two studies were found that had investigated the effectiveness, confirming the existing doubts. (See references 9, 38, 58, 182, 185, 190, and 193.)

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

As a general rule, unnecessary signs should be removed as they may distract drivers and require maintenance. However, standard warning signs may be required to reduce liability in case of WVCs.⁽¹⁹⁴⁾

Costs

One study estimated costs at \$94 (note not adjusted for inflation) per sign.⁽¹⁸⁵⁾ USA Traffic Signs reports the following costs: \$55 (61 by 61 cm (24 by 24 inches)), \$62 (76 by 76 cm (30 by 30 inches)), \$85 (91 by 91 cm (36 by 36 inches)).⁽¹⁹⁵⁾

Guidelines

The *Manual on Uniform Traffic Control Devices* (MUTCD) provides guidance on animal warning signs. The standard warning sign (figure 34) is known as W11-3. The MUTCD is very specific in the sign dimensions, colors, etc. However, the manual only provides general guidance on when to use these signs:

“Nonvehicular signs [this includes animal warning signs] may be used to alert road users in advance of locations where unexpected entries into the roadway or shared use of the roadway by pedestrians, animals, and other crossing activities might occur.”⁽¹⁹⁶⁾

See Knapp and Yi for a discussion on guidelines for the installation of standard deer warning signs.⁽¹⁸³⁾

LARGE, NONSTANDARD WILDLIFE WARNING SIGNS

Large or enhanced animal warning signs may take many forms. They can be larger than the standard wildlife warning signs, include graphic images of a vehicle hitting wildlife, and have permanently activated flashing amber warning lights, light emitting diodes (LEDs), or red flags attached to the signs (figure 35 and figure 36).



Figure 35. Photo. Large enhanced warning sign for bighorn sheep along State Highway 75 in Idaho (copyright: Marcel Huijser, WTI).

Lighted animated deer crossing signs reduced vehicle speed by 4.8 km/h (3.0 mi/h) compared to the same signs when they were turned off.⁽¹⁸⁵⁾ The presence of deer carcasses as a “supplement” to the signs resulted in a much greater reduction in vehicle speed: 12.6 km/h (7.9 mi/h) (lights turned off) and 10.0 km/h (6.2 mi/h) (lights turned on).⁽¹⁸⁵⁾ Despite the successful speed reduction of the lighted animated signs, they did not result in a reduction of DVCs.⁽¹⁸⁵⁾

Hammond and Wade conducted an experiment in a driving simulator and exposed drivers to standard deer warning signs and enhanced deer warning signs that had a flashing light on top of a standard deer warning sign.⁽¹⁸⁷⁾ The average vehicle speed with standard deer warning signs was 99.6 km/h (61.87 mi/h) (SD = 5.16). The enhanced sign with the lights turned off resulted in similar speeds of 99.5 km/h (61.80 mi/h) (SD = 4.80), but the enhanced sign with the lights turned on resulted in significantly lower vehicle speed of 95.9 km/h (59.55 mi/h) (SD = 4.66), a reduction of 3.7 km/h (2.32 mi/h).⁽¹⁸⁷⁾



Figure 36. Photo. Large enhanced elk warning sign along the Trans-Canada Highway in Banff National Park, Canada (copyright: Marcel Huijser, WTI).

Enhanced camel warning signs in Saudi Arabia resulted in a significant reduction of vehicle speed whereas standard camel warning signs did not.⁽¹⁹¹⁾ The standard warning signs were triangular where all sides were 110 cm (43 inches), with a red border and white interior with black camel silhouette, and did not have diamond reflective material. The enhanced signs were signs that were larger than the standard warning signs, had diamond reflective material, had a yellow camel on a black background, and/or were accompanied by the text message “camel-crossing” and a reduced advisory speed limit. The enhanced signs reduced vehicle speed by 3–7 km/h (2–4 mi/h).⁽¹⁹¹⁾

Hardy and others found that wildlife advisory messages posted on permanent and portable dynamic message signs (DMS) can reduce vehicle speeds.⁽¹⁷³⁾ The greatest effect occurred during “dark” conditions, when the number of AVCs is higher.

Stanley and others conducted experiments with a driving simulator and found that enhanced wildlife warning signs resulted in lower vehicle speeds and earlier braking when drivers were confronted with a deer in the simulated environment.⁽¹⁹²⁾

Case Studies and Contacts

For information about a driving simulator study with enhanced deer warning signs, contact Curtis Hammond and Michael G. Wade, University of Minnesota, Division of Kinesiology, 1900 University Ave SE, Minneapolis, MN 55455; (612) 625-2051, chammond@umn.edu; (612) 626-2094, mwade@umn.edu.

For more information about a field test with enhanced camel warning signs in Saudi Arabia, contact Ali Al-Ghamdi and Saad AlGadhi, Civil Engineering Department, College of

Engineering, King Saud University, P.O. Box 800, Riyadh 11421, Saudi Arabia, +966-1-4677019, (fax +966-1-4673366), asghamdi@ksu.edu.sa.

For information about wildlife advisory messages posted on permanent and portable DMS, contact Amanda Hardy, Western Transportation Institute, (406) 994-2322, ahardy@coe.montana.edu.

For information about a driving simulator study with enhanced deer warning signs, contact Laura Stanley, Virginia Polytechnic Institute & State University, Blacksburg, VA 24060, (540) 808-5140, lstanley@vti.vt.edu.

Direct Benefits

The only study identified that directly looked at sign impact on WVCs, rather than the impact on driver response, suggests that large or enhanced wildlife warning signs are not effective in reducing WVCs in general or DVCs specifically.⁽¹⁸⁵⁾ Nonetheless, the observed reduction in vehicle speed (3–7 km/h (2–4 mi/h)) suggests that the signs may be somewhat effective after all, perhaps reducing the severity of the crash in terms of property damage, human injuries and human fatalities. Only limited data are available on this subject.

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

Uniform warning signs across the United States are desirable so that drivers learn and understand what different signs represent (known as “driver expectancy”). While nonstandard signs may draw attention, a potential downside is that it takes drivers longer to interpret the sign, simply because it is nonstandard.

Costs

One cost estimate reported in the literature was \$2,000 (note: not adjusted for inflation) per sign.⁽¹⁸⁵⁾

Guidelines

It should be noted that many nonstandard animal warning signs deviate from the MUTCD. Although some states have adopted alternative signs into their state manual on traffic control, care should be taken when the MUTCD is not followed exactly. It may degrade driver expectancy and could open the State DOT to liability issues.

See Knapp and Yi for a discussion of guidelines for the installation of nonstandard deer warning signs.⁽¹⁸³⁾

SEASONAL WILDLIFE WARNING SIGNS

Seasonal wildlife warning signs are only present at certain times of the year when animals cross the road most frequently, such as during a seasonal migration (figure 37).



Figure 37. Photo. Seasonal deer migration sign in Utah (copyright: Marcel Huijser).

Sullivan and others erected temporary warning signs with (1) reflective flags and (2) permanently flashing amber lights in locations that were known to be used by mule deer (*Odocoileus hemionus*) during their seasonal migration.⁽⁴³⁾ The number of DVCs was reduced by 51 percent (range 41.5–58.6 percent for individual test areas) compared to control areas. The signs reduced the percentage of speeders from 19 percent to 8 percent during their first season of operation, but the effect was less pronounced in the second season, perhaps due to driver habituation.⁽⁴³⁾

Rogers investigated the effect of enhanced deer warning signs (black on yellow sign showing a deer and a car symbol, combined with a black on orange sign stating “HIGH CRASH AREA”) on the number of DVCs.⁽³⁸⁾ The signs were deployed between October and January (the peak of DVCs) for three consecutive years. Rogers found no effect of the seasonal signs on the number of DVCs.⁽³⁸⁾

Case Studies and Contacts

For information about a field study on the effectiveness of seasonal warning signs in Utah, Nevada and Idaho, contact Todd L. Sullivan, Jack H. Berry Institute, Department of Forest, Range and Wildlife Sciences, Utah State University, Logan, UT. (Current address: USDA/APHIS Wildlife Services, 5107 Austin Ellipse, Moody Air Force Base, GA 31699).

Direct Benefits

Seasonal deer warning signs may reduce DVCs; however, more studies on their effectiveness are required.

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

The signs reportedly are subject to vandalism and theft.⁽⁴³⁾

Costs

Sullivan and others reported a cost of \$268 per 1,609 m (\$435 per mi).⁽⁴³⁾

Guidelines

See Knapp and Yi for a discussion of guidelines for the installation of seasonal deer warning signs.⁽¹⁸³⁾

ANIMAL DETECTION SYSTEMS

Animal detection systems use sensors to detect large animals that approach the road. Once a large animal is detected, warning signals are activated to inform the drivers that a large animal may be on or near the road at that time (figure 38). The warning signals are extremely time specific. Huijser and others listed more than 30 locations in North America and Europe that have had an animal detection system installed, and they describe the experiences with installation, operation and maintenance, reliability, and effectiveness.⁽¹⁹⁷⁾ Since August 2007, a number of additional locations were equipped with an animal detection system, including along SR 260 near Payson, AZ (David Bryson, Electrobraid Fence Ltd., personal communication; Norris Dodd, Arizona Game and Fish Department, personal communication). An animal detection system combined with electric fencing was used at these locations.



Figure 38. Photo. Animal detection system along Highway 191 in Yellowstone National Park, MT (copyright: Marcel Huijser, WTI).

Two broad categories are commonly used in animal detection systems: area-cover systems and break-the-beam systems. Area-cover systems detect large animals within a certain range of a sensor. Area-cover systems can be passive or active. Passive systems detect animals by only receiving signals. The two most common systems are passive infrared and video detection. These systems require algorithms that distinguish between, e.g., moving vehicles with warm engines and moving pockets of hot air and movements of large animals. Active systems send a signal over an area and measure its reflection. The primary active area-cover system is microwave radar. Break-the-beam sensors detect large animals when their body blocks or reduces a beam of infrared, laser, or microwave radio signals sent by a transmitter to a receiver. Other less common detection systems include a system that depends on radio-collared animals and receivers placed in the right of way, and a system that uses seismic sensors to detect vibrations in the soil as large

animals approach.⁽¹⁹⁷⁾ Most of these systems have or had problems with the reliability of the sensors, although some of the manufacturers seem to have overcome these problems.⁽¹⁹⁷⁾

The effectiveness of animal detection systems has been investigated with regard to a potential reduction in vehicle speed and a potential reduction in AVCs. Once a driver is aware that a large animal may be on or near the road ahead, the driver may lower the speed of the vehicle. Previous studies have shown variable results: substantial decreases in vehicle speed (greater than or equal to 5 km/h (3.1 mi/h)), minor decreases in vehicle speed (less than 5 km/h (3.1 mi/h)), and no decrease or even an increase in vehicle speed. (See references 42, 187, 198, 199, 200, and 201.) This variability of the results appears to be related to various conditions, namely, 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 driver is a local resident, and perhaps also cultural differences that may cause drivers to respond differently to warning signals in different regions.⁽¹⁹⁷⁾

Kistler, Romer and Mosler-Berger, and Mosler-Berger and Romer have reported on the number of AVCs before and after seven infrared area-cover detection systems were installed in Switzerland (table 8). (See references 198, 202, 203, and 204.) These systems reduced the number of AVCs by 82 percent on average (1-sided Wilcoxon matched-pairs signed-ranks test, $P = 0.008$, $n = 7$).⁽¹⁹⁷⁾ All seven sites showed a reduction in collisions after an animal detection system was installed, and three of the seven sites did not have a single collision after system installation (as of 6–7 years after installation). The data relate to collisions with roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*), and collisions that occurred during the day when the systems were not active were excluded from the analyses.

While the data on the effectiveness of animal detection systems are encouraging, animal detection systems should still be regarded as an experimental mitigation measure rather than a measure that will reduce WVCs on short term with a high degree of certainty.⁽¹⁹⁷⁾

Table 8. Collisions with large animals before and after detection system installation in Switzerland.

| Location | Before Installation | | | After Installation | | | Reduction | |
|--------------------------|---------------------|------|----------|--------------------|------|----------|-----------|--------------|
| | Coll. (N) | Yrs. | Coll./yr | Coll. (N) | Yrs. | Coll./yr | Coll./yr | % |
| Warth | 14 | 7 | 2.00 | 3 | 10 | 0.30 | 1.70 | 85.00 |
| Soolsteg | 8 | 11 | 0.73 | 1 | 6 | 0.17 | 0.56 | 77.08 |
| Val Maliens | 7 | 3 | 2.33 | 6 | 5 | 1.20 | 1.13 | 48.57 |
| Marcau | 12 | 4 | 3.00 | 6 | 5 | 1.20 | 1.80 | 60.00 |
| Schafrein | 26 | 8 | 3.25 | 0 | 6 | 0.00 | 3.25 | 100.00 |
| Duftbächli | 18 | 8 | 2.25 | 0 | 6 | 0.00 | 2.25 | 100.00 |
| Grünenwald | 6 | 8 | 0.75 | 0 | 7 | 0.00 | 0.75 | 100.00 |
| Average Reduction | | | | | | | | 81.52 |

Case Studies and Contacts

For a general overview of technology, reliability and effectiveness, contact Marcel Huijser, Western Transportation Institute, P.O. Box 174250, Bozeman, MT 59717-4250, (406) 543-2377, mhuijser@coe.montana.edu.

For information about a field study on the effectiveness of animal detection systems, contact Christa Mosler-Berger, Wildtier Schweiz, Strickhofstrasse 39, 8057 Zürich, Switzerland, wild@wild.unizh.ch.

For more information about the animal detection system and wildlife fencing along State Route 260 in Arizona, contact Norris Dodd, Wildlife Research Biologist, Arizona Game and Fish Department, Research Branch, P.O. Box 2326, Pinetop, AZ 85935, (928) 368-5675, doddbenda@cybertails.com.

Manufacturer: Terry Wilson, Sensor Technologies and Systems, Inc., 8900 East Chaparral Road Scottsdale, AZ 85250, (480) 483-1997, (fax (480) 483-2011), terry_wilson@sensor-tech.com, <http://www.sensor-tech.com/> (accessed January 25, 2007).

Manufacturer: Calonder Energy AG's representative in USA: Willy Bärchtold, Swiss Army Vehicles, 1436 Van Asche Drive, Fayetteville, AR 72704, (479) 521-0056, cars@sav.ms.

Direct Benefits

The only available data on the effectiveness of animal detection systems show a reduction in collisions with large animals of 82 percent.⁽¹⁹⁷⁾ This percentage may change as more data become available.

Indirect Benefits

Animal detection systems do not restrict animal movements when deployed over long distances.

Undesirable Effects

Animal detection systems can reduce collisions with large animals, but the presence of poles and equipment in the right of way is a potential hazard to vehicles that run off the road.⁽¹⁹⁷⁾

Costs

Estimated costs of these systems are \$40,000–96,000 per km (\$65,000–154,000 per mi) (excluding installation costs) (unpublished data, Marcel Huijser, Western Transportation Institute, Montana State University).⁽¹⁹⁷⁾ The costs for the equipment will be higher if the road section concerned has curves or slopes, or if the line of sight in the right of way is blocked by objects.

Guidelines

It should be noted that many animal detection systems use signs that deviate from the MUTCD. Some states have adopted alternative signs into their state manual on traffic control. Care should be taken when the MUTCD is not followed exactly. It may degrade driver expectancy and could open the State DOT to liability issues.

See Huijser and others for considerations for planning and design.⁽¹⁹⁷⁾

IN-VEHICLE WARNINGS: ROADSIDE ANIMAL DETECTION SYSTEM LINKED TO ON-BOARD COMPUTER WARNING SYSTEM

The concept of an animal detection system that is linked to an on-board computer warning system is described in Huijser and others.⁽¹⁹⁷⁾ The technology would be designed to warn a driver through a warning signal inside the vehicle that an animal is on or near the roadway within a certain distance from the vehicle. This technology is not currently deployed. This information should be provided just before drivers get to the area covered by the animal detection system. Road signs and highway advisory radio messages are the most obvious ways to deliver this information to the driver. When approaching the animal detection system, a driver may be confronted with an activated warning signal indicating that a large animal has been detected and is present on or near the road at that time. In the future the information about the purpose and the location of the animal detection system may also be delivered to an on-board computer inside the vehicle. This procedure would require a two-way GPS-based communication system. The most essential part of the concept is that the warning signal from the animal detection system is delivered to the on-board computer as soon as the vehicle gets within a certain radius of the animal detection system and if a large animal has been detected.

Case Studies and Contacts

No case studies and contacts are available, as this technology has not yet been deployed.

Direct Benefits

This mitigation measure has not been specifically investigated. However, the effectiveness can be expected to be similar to that of animal detection systems, i.e., 82 percent reduction in collisions with large animals.⁽¹⁹⁷⁾ This percentage is likely to change as data become available.

Indirect Benefits

Animal detection systems do not restrict animal movements when deployed over long distances.

Undesirable Effects

Animal detection systems can reduce collisions with large animals, but the presence of poles and equipment in the right of way is a potential hazard to vehicles that run off the road.⁽¹⁹⁷⁾

Costs

Estimated costs for these systems are \$40,000–96,000 per km (\$65,000–154,000 per mi) (excluding installation costs), plus additional costs for the on-board computer and communication system (Marcel Huijser, unpublished data, Western Transportation Institute, Montana State University).⁽¹⁹⁷⁾ The costs for the equipment will be higher if the road section concerned has curves or slopes, or if the line of sight in the right of way is blocked by objects.

Guidelines

See Huijser and others for considerations for planning and design.⁽¹⁹⁷⁾

IN-VEHICLE WARNINGS: ON-BOARD ANIMAL DETECTORS

On-board animal detectors (typically infrared detectors) inform drivers when a large animal (or human being) is detected within a certain range from the sensors attached to the vehicle. (See references 205, 206, 207, and 208.) The range should be sufficient to allow for the driver to stop the vehicle before impacting the detected animal. The system could potentially detect large animals anywhere; it would not depend on the installation of any roadside equipment. However, it is uncertain whether these on-board detectors are still in production.

Case Studies and Contacts

For design concept, contact Masaki Hirota, Nissan Motor Co., Ltd., 1 Natsushima-cho, Yokosuka Kanagawa 237-8523, Japan, m-hirota@mail.nissan.co.jp.

Direct Benefits

Because this concept is still in the design phase, no direct benefits were identified in the literature review. However, the benefits would be expected to be similar to animal detection systems.

Indirect Benefits

The system would not only detect large animals but potentially also humans (e.g., pedestrians, bicyclists).

Undesirable Effects

Vehicle-based systems only inform drivers in vehicles equipped with such a detection system. Drivers in other vehicles will not benefit.

Costs

A reported cost for these detectors is \$2,250 per vehicle.⁽⁵³⁾

Guidelines

See Hirota and others for design concept.⁽²⁰⁷⁾

INCREASE VISIBILITY OF ANIMALS TO DRIVERS

A driver's ability to avoid a collision with an animal may be determined in a split second. Once drivers see a road hazard, it may take 0.7 to 1.5 s (depending on whether the hazard was anticipated or unexpected) to move their foot from the accelerator to the brake.⁽¹⁸⁸⁾ Depending on vehicle speed and when an animal crossing the road is first seen, a collision may occur before the driver even has the chance to brake. The sooner drivers see an animal in the road, the better their chances of responding quickly to avoid a collision. Roadway lighting and vegetation removal have been used in an attempt to increase visibility to provide as much time and space possible for drivers to see and respond to animals in or near the roadway.

INCREASE VISIBILITY OF ANIMALS TO DRIVERS: ROADWAY LIGHTING

Most WVCs occur between dusk and dawn when light, and thus visibility, is limited (see Section on Causes and Factors of WVCs: Temporal Distributions). (See references 9, 10, 38, 75, 78, 79, 209, 210, and 211.) The drab coloring of most wildlife species increases the probability that a driver may not see an animal in the dark. Even the most attentive driver would have difficulty seeing a dark-colored moose on a dark road at night in time to avoid a collision. Garrett and Conway characterized moose-vehicle collision occurrences in Anchorage, AK, finding these incidents were 2.6 times more likely to occur during periods of darkness; further, 61 percent of collisions that occurred during dark periods occurred where there were no streetlights illuminating the road.⁽⁷⁹⁾ Lavsund and Sandegren found the risk of moose-vehicle collisions in Sweden was six times higher during hours of darkness compared to daylight conditions.⁽⁷⁶⁾ It has been hypothesized but not well documented that lighting may help drivers see animals and avoid such collisions in nondaylight hours.

Numerous reviews of WVC mitigation measures mention use of roadway lighting in attempts to reduce WVCs. (See references 3, 9, 68, 74, 176, 212, 213, 214, 215, and 216.) Most of these reviews either do not provide support that highway lighting is effective or conclude that highway lighting is ineffective. Reed and Woodard found that highway lighting was not effective in reducing DVCs in Colorado.⁽²¹⁷⁾ L-P Tardiff and Associates, Inc. cited a study by Miller indicating that lighting was ineffective for mitigating WVCs (no further information was provided and the report was unavailable at the time that this review was drafted).^(68,218) Alternatively, one review states, "Lighting has been used on numerous occasions and has been shown to be effective in high crash locations because it gives drivers a longer reaction time" but does not cite any specific studies to support that claim.⁽²¹⁵⁾ Knapp classifies the use of roadway lighting as a method that is "not generally used and rarely studied for safety impacts" and cites that the American Association of State Highway Transportation Officials regard this measure as "experimental."⁽¹⁷⁶⁾

Despite discrepancies in the tested effectiveness of highway lighting, the practice of using highway lighting has been recommended in certain situations. Garrett and Conway recommend the installation of streetlights, encouraging drivers to upgrade older vehicles' headlights with halogen bulbs, and keeping the lenses of the lights free of dirt and debris to increase the chance of seeing a moose in time to avoid a collision.⁽⁷⁹⁾ Thomas also suggests that roadway lighting be considered for reducing moose-vehicle collisions in Alaska.⁽⁷⁸⁾

Given the paucity of information on the efficacy of lighting to reduce WVCs, there is a need to further explore the usefulness of this approach. If recommendations to install lighting are pursued, quantitative studies with experimental designs should be employed to further understand the effect that lighting and increased visibility may have on WVCs.

Reed and Woodard conducted a five-year study in Colorado that involved alternately turning roadside lights on and off for one-week periods to quantify the effect on DVCs, observed deer crossings of the highway at night, and vehicle speeds.⁽²¹⁷⁾ Lighting did not affect DVCs or driver speeds; however, drivers did significantly reduce speeds when a deer decoy was present (this practice was discontinued due to concerns about abrupt driver responses to the decoy, creating a potential safety concern for other motorists). Lighting did not disrupt deer crossing behaviors, although it appeared that a greater proportion of deer crossed in the lighted areas compared to prior to the study and when the lights were off.

A four-year study of the installation of roadway lighting, fencing, one-way gates and bridge modifications along 11.5 km (7.1 mi) of the Glenn Highway near Anchorage, AK, revealed a 70 percent decrease in moose-vehicle collisions overall.^(213,219,220) The entire area was lighted, while about 5.5 km (3.4 mi) of the road had fencing, one-way gates, and modified bridges. The lighted area with fences reduced moose-vehicle collisions by 95 percent, while the areas with lighting but without fencing reduced moose-vehicle collisions by 65 percent. However, it was not clear if the 65 percent reduction in moose collisions was the result of moose avoiding the lighted areas or the result of increased motorist visibility.^(213,219,220)

Case Studies and Contacts

For information about roadway lighting and fencing to reduce WVCs, contact Biota Research and Consulting, Inc., info@biotaresearch.com.

Direct Benefits

Reduction of moose-vehicle collisions by 65 percent was found in Alaska, but it is not clear if this was due to increased visibility or moose avoiding the lighted area.

Indirect Benefits

Griffith found that highway lighting reduced all “property damage only” (i.e., no human injury) crashes at night.⁽²²¹⁾ The typical method for comparisons for before/after installation is a reduction in the ratio of nighttime crash rates to daytime crash rates. Griffith found this ratio reduced by 32 percent for all property damage only crashes. However there was no reduction in injury or fatal crashes.

Undesirable Effects

An undesirable effect of roadway lighting is the impact on a driver’s vision after leaving the lighted area. While driving through the lighted area, a driver’s eyes will become accustomed to the light. Afterward, it may take some time before the driver’s eyes readjust to less light.

Some sensitive species (e.g., Canada lynx, mountain lions (*Felis concolor*), bears, and gray wolves (*Canis lupus*) may avoid light, which may result in an unintentional barrier effect for lighted areas.⁽²²²⁾ In addition, roadway lighting may temporarily blind certain species as their eyes are adapted to darkness, potentially increasing their vulnerability to traffic.⁽²¹²⁾

Costs

Mode and others noted that in 2001, \$1.3 million was dedicated to lighting three miles of the Glenn Highway in Alaska to improve motorist visibility of moose.⁽²²³⁾ Hedlund and others state that roadway lighting is expensive but did not provide any figures to illustrate the estimated expense.⁽²¹⁴⁾ L-P Tardiff and Associates, Inc. mention Miller's report, which states that highway lighting is expensive, but again, no figures accompanied that statement.^(68,218)

Guidelines

For guidelines on highway lighting, refer to the *Roadway Lighting Handbook* and Addendum.^(224,225)

INCREASE VISIBILITY OF ANIMALS TO DRIVERS: VEGETATION REMOVAL

Visibility may be improved by reducing roadside vegetation that may obscure wildlife approaching the road. In a study of DVC mortalities in east central South Dakota, Gleason and Jenks found that deer were killed more often than expected in areas adjacent to shelterbelts with canopy vegetation.⁽²²⁶⁾ Puglisi and others found that DVC occurrences were less common where wooded areas were more than 23 m (25 yds) away from a highway in Pennsylvania.⁽³²⁾

Clearing vegetation from roadsides resulted in a 20-percent reduction in moose-vehicle collisions in Sweden.⁽⁷⁶⁾ In a study examining the effect of scent marking, intercept feeding and forest clearing, analyses demonstrated that forest clearing resulted in a 49-percent reduction in collisions.⁽²²⁷⁾ While it is recognized that the results may not translate to a highway setting, the clearing of vegetation across a 20- to 30-m (70- to -100-ft) swath on each side of a Norwegian railway reduced moose-train collisions by 56 percent (+/-16 percent).⁽²²⁸⁾

Thomas states that vegetation clearing is one of the most commonly applied measures to reduce moose-vehicle collisions; recommendations from that report include that vegetation clearing should be applied in an effort to reduce moose-vehicle collisions in Alaska.⁽⁷⁸⁾ Distance between the roadway and forest cover has been shown to be negatively correlated to DVCs in Illinois; recommendations from that study included removing vegetation to provide an open width of the road corridor of at least 40 m (131 ft) in areas where DVCs are particularly high.⁽³⁰⁾ Based on results from predictive models, Seiler notes that moose-vehicle collisions in Sweden were more common on roads that cross through clear cuts and young forests and suggests collisions with moose may be reduced by 15 percent in areas where the distance between forest cover and the road exceeds 100 m (300 ft).⁽²⁵⁾

In addition to affecting visibility, roadside vegetation management may be directed to reducing the attractiveness of roadside forage to animals. While vegetation management to increase visibility and reduce the draw of animals to the right of way may be complementary goals in

some cases, Putman and others summarize the potentially conflicting outcomes of reducing vegetation along roadways:

“The management of roadside vegetation—and specifically, the clearance of woodland or scrub from a margin at the road edge—may have benefits both in increasing driver awareness of deer at the roadside, and increasing visibility of oncoming traffic to the deer themselves. In addition, removal of such vegetation and the cover that it provides may also reduce the probability of deer approaching so close to the road edge in the first place. The method and timing of removal of such vegetation may however be critical. While the removal of vegetation within transportation corridors may help improve driver and animal visibility, simple cutting of encroaching shrub and tree growth may at the same time increase the subsequent attractiveness of these cut-over areas as foraging sites by deer. Such measures might thus actually result in an increase in the number of deer utilizing the roadside—ultimately increasing the risk of accident.”⁽⁵⁸⁾

For further discussion of vegetation issues, see also the section titled “Influence Species Composition or Minimize Nutritional Value of Vegetation in Right of Way” in chapter 6.

Case Studies and Contacts

No contacts for this mitigation measure were identified in the literature review.

Direct Benefits

Jaren et al. and others conducted an eight-year study of the effect of vegetation removal on moose-train collisions in Norway and found that clearing vegetation across a 20- to 30-m (70- to 100-ft) swath on each side of the railway reduced moose-train collisions by 56 percent (+/-16 percent).⁽²²⁸⁾ Lavsund and Sandegren showed that clearing of vegetation along transportation corridors resulted in a 20-percent reduction in moose-vehicle collisions in Sweden.⁽⁷⁶⁾

Indirect Benefits

Reducing the number of large trees near roads may result in fewer collisions with these stationary obstructions.⁽²¹⁴⁾

Undesirable Effects

Removal of brushy species of vegetation or canopy may result in fresh growth of attractive forage that draws grazing animals to the right of way, potentially counteracting the potential safety gains of better visibility with increased probability of drivers encountering wildlife.⁽⁷⁴⁾

Costs

Vegetation removal requires long-term maintenance commitment and may involve expenses to acquire right of way in order to manage vegetation as desired. Jaren and others calculated that if collisions are reduced by at least 50 percent as a result of removing vegetation, then the costs of vegetation removal treatment would be economically beneficial if applied in areas where more than 0.3 per km (0.48 per mi) moose-train collisions occur.⁽²²⁸⁾ Andreassen and others estimate forest clearing for 18 km (11.2 mi) costs \$500 per km (\$800 per mi) or \$9,000 per year, showing

that the number of moose saved using this technique could result in a profit of \$1,080.⁽²²⁷⁾ Andreassen and others state that forest clearing may be more economical compared to scent marking and supplemental feeding, stating that the initial cutting is the main expense.⁽²²⁷⁾

Guidelines

Thomas provides a summary of a variety of vegetation clearing methods used in Alaska including hydroaxing, hand clearing, steam clearing, and spray inhibitors.⁽⁷⁸⁾

The timing and effect of vegetation clearing depends on the vegetation and climate at the roadway site and needs to be carefully evaluated.

INCREASE VISIBILITY OF ANIMALS TO DRIVERS: WIDER STRIPING

Drivers may see a break in the painted highway striping (particularly if it is wide) when an animal crosses it, even if the animal itself is difficult to distinguish due to color, background, or lighting conditions, and thus be warned of its presence on the highway. In addition, wide striping may make the driver perceive a narrower roadway, potentially resulting in lower vehicle speed (see later section on traffic calming and reducing design speed).

Wide striping was used along Rt. 4 in Phillips, ME, and along Rt. 6/15 in Shirley, ME.⁽²²⁹⁾ The Rt. 6/15 road section in Shirley also had temporary optical markers (TOMs) installed. TOMs are small yellow reflective tags which are typically used as a substitute for striping during roadway construction activities. When a large animal, e.g., a moose, enters the roadway, the absence of light reflecting off the TOMs obstructed by the animal may result in a visual break for drivers, and thus a warning.⁽²²⁹⁾ No evaluation or results of these installations were found.

Case Studies and Contacts

Contacts for the case studies mentioned above could not be identified.

Direct Benefits

No direct benefits were identified in the literature review.

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

No undesirable effects were identified in the literature review.

Costs

No costs were identified in the literature review.

Guidelines

No guidelines were identified in the literature review.

INCREASE VISIBILITY OF ANIMALS TO DRIVERS: REFLECTIVE COLLARS FOR ANIMALS

One of the mitigation measures under consideration at a location in Canada is to put collars with reflective tape on a number of animals to increase their visibility to drivers. Free ranging wood bison (*Bos bison*) were reintroduced in northeast British Columbia. Their number has grown to about 100 individuals. The bison spend about 90 percent of their time on or near a 150-km (31-mi)-long section of the Alaska Highway near the Yukon border because of the attractive vegetation in the right of way and because the disturbance associated with the right of way may provide a shelter from predators. They are typically found in large groups, and a number of serious bison-vehicle collisions have taken place.

Case Studies and Contacts

For information about the proposal to put collars with reflective tape on bison, contact Conrad Thiessen, Wildlife Biologist, Peace Region, Ministry of Environment, 400-10003 110 Ave., Fort St. John, British Columbia, V1J 6M7 Canada, phone: (250) 787-3287, fax: (250) 787-3490, Conrad.Thiessen@gov.bc.ca

Direct Benefits

No direct benefits were identified in the literature review.

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

It requires considerable and continuous effort to have a certain minimum number of bison (or any other species, including deer) equipped with collars with reflective tape. In addition, capturing and handling activities are likely to cause stress and risk of injury and death for the animals involved.

Costs

No costs were identified in the literature review.

Guidelines

No guidelines were identified in the literature review.

INCREASE VISIBILITY OF ANIMALS TO DRIVERS: REDUCE HEIGHT OF SNOWBANKS

Garrett and Conway suggested reducing the height of snow berms in order to increase drivers' visibility of moose on the side of the road.⁽⁷⁹⁾ They acknowledge this practice would be impractical and expensive to employ on all streets, and thus this might be better applied in particular areas with high rates of moose-vehicle collisions.

Case Studies and Contacts

No contacts were identified in the literature review.

Direct Benefits

No direct benefits were identified in the literature review.

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

No undesirable effects were identified in the literature review.

Costs

No costs were identified in the literature review.

Guidelines

No guidelines were identified in the literature review.

REDUCE TRAFFIC VOLUME ON ROAD NETWORK

The increase in the number of WVCs (chapter 2) is associated with factors such as new highway construction, increased traffic volumes and speeds, wildlife population distribution, and wildlife abundance.^(58,230) As mentioned in chapter 2 in the section titled "Is the Problem Growing," the average crash rate (number of crashes per vehicle mile traveled) has held fairly constant for WVCs; but the total number of VMT and thus the total WVCs have increased. The relationship between the number of WVCs and traffic volume on a single roadway, however, is confounded by changes or differences in wildlife population size and relatively great data variability.⁽⁷⁴⁾

No original studies were located that tested the effectiveness of permanently lowering traffic volume on highways or permanently lowering road density of paved roads as a mitigation measure for reducing WVCs. Literature reviews by Danielson and Hubbard, D'Angelo and others, Putman and others, and Knapp did not address this potential mitigation measure on either the local or landscape scale. (See references 58, 61, 176, and 231.)

Some modeling efforts found a relationship between traffic volume and WVCs and suggest reduced traffic volumes as a potential solution to WVCs.^(17,19,20) The modeling effort only identified a relationship between roads with a certain traffic volume and the presence of WVCs; it did not prove a causal relationship. Jaarsma and Willems for example, suggest implementing traffic calming on the more minor rural roads in order to shift the traffic onto a few major highways.⁽²⁰⁾ A similar number of studies found that higher volumes on roadways reduced the number of WVCs (see section in chapter 2 on traffic density and speed). As presented in a later section on “Undesired Effects,” lower densities may actually increase crash rates.

Citing road mortality as one of the reasons, Friends of the Earth is campaigning for a 10-percent reduction in overall road traffic levels in the UK by 2010, as compared to 1990 levels.⁽²³²⁾ However, it is unclear how to feasibly achieve this reduction.

Case Studies and Contacts

Reducing traffic volume has not been attempted directly as a mitigation measure for reducing WVCs. However, Catharinus Jaarsma has done extensive modeling on possible impacts (see description in previous paragraphs): Catharinus Jaarsma, Land Use Planning Chair, Wageningen University, the Netherlands.

Direct Benefits

Some modeling studies suggest reduced traffic volumes will result in decreased WVCs, although other studies found the opposite result. The relationship between road mortality, traffic volume and animal density, and mobility warrants further study.⁽²²⁾

Indirect Benefits

Numerous indirect benefits can be suggested such as reduced energy demand, reduced pollution, etc. However, one should keep in mind the more holistic picture. For example, traffic calming measures may shift traffic to more major highways, but this would actually require drivers to travel further to get where they are going, ultimately increasing fuel use and emissions.

Undesirable Effects

Lower traffic volumes do not necessarily equate with fewer roadkills.⁽²⁰⁾ As noted above, this method may actually increase the number of WVCs. Additionally, limiting traffic on a roadway may have adverse economic impacts.

Costs

No costs were identified in the literature review.

Guidelines

No guidelines were identified in the literature review.

TEMPORARY ROAD CLOSURES

During periods of high animal movement, roads could be temporarily closed. Several temporary closures have been implemented for the reduction of WVCs. Some low-volume paved roads are closed seasonally during the night. In Delaware Water Gap National Recreation Area, the River Road is closed annually during the night (6 p.m. to 6 a.m.) in March and April when there is a forecast calling for rain with temperatures greater than 10 °C (50 °F). This allows multiple amphibian species to cross the road during their seasonal migration.^(233,234) In the Shawnee National Forest, the LaRue Road at the base of the bluffs adjacent to LaRue Swamp is closed day and night from March 15 to May 15 and September 1 to October 30 to allow amphibians and reptiles, including several snake species, to conduct their seasonal migration.⁽²³⁵⁾ In East Brunswick, NJ, the Beekman Road is closed several nights in the spring to allow spotted salamanders to cross the road during their seasonal migration.⁽²³⁶⁾

Case Studies and Contacts

For information on road closure in the LaRue-Pine Hills in the Shawnee National Forest, contact: Mississippi Bluffs Ranger District, 521 North Main Street, Jonesboro, IL 62952, (618) 833-8576.

Direct Benefits

Although the magnitude of impacts on WVCs has not been documented in the literature, it is clear that while a road is closed to traffic, there will be no WVCs.

Indirect Benefits

Like the previous section, numerous indirect benefits can be suggested such as reduced energy demand, reduced pollution, etc. (assuming that drivers do not just take an alternative route).

Undesirable Effects

Closing roads may have adverse economic impacts and accessibility issues. Road closures may require people to reroute, actually requiring drivers to travel further to their destination, ultimately increasing fuel use and emissions.

Costs

No costs were identified in the literature review.

Guidelines

No guidelines were identified in the literature review.

REDUCE VEHICLE SPEED

For areas with high WVC frequency, reducing vehicle speed is occasionally suggested as a mitigation strategy. Before discussing the methods and implications of this strategy, it is

important to understand the different types of speeds associated with the design and operation of a highway:

- The **design speed** is “a selected speed used to determine the various geometric design features of the roadway.”⁽¹⁾ Certain minimum design standards are used for different design speeds. A higher design speed typically means higher minimums for curve radius, lane widths, shoulder widths, clear zone widths, and other design parameters. Higher design speeds also mean lower maximums for the number of access points (e.g., intersections, driveways, or interchanges) per mile.
- After a road is built, a spot speed study is done. **Operating speed** is determined as “the speed at which drivers are observed operating their vehicles during free-flow conditions. The 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature.”⁽¹⁾ Speed studies are typically done before speed limit signs are installed, or speed limit signs are covered during the study. The theory assumes that drivers are the best judge of a safe driving speed of a roadway and 85 percent of the people will travel at reasonable speeds.
- The enforceable **posted speed limit** is the maximum legal speed at which a vehicle is allowed to travel. These are typically set near the operating speed (85th percentile speed).
- When a portion of the roadway has characteristics where the design speed is less than that of the rest of the road, an **advisory speed** can be posted. For example an advisory speed sign in the Netherlands is located at a gap in exclusionary wildlife fencing (figure 39). Advisory speeds are lower than the posted speed limit and are not enforceable other than by using basic “reasonable and prudent” laws.



Figure 39. Photo. Advisory speed sign in The Netherlands located at a gap in exclusionary wildlife fencing (copyright: Marcel Huijser).

Under typical circumstances, the design speed, operating speed, and posted speed should be almost equal for a given roadway. With this in mind, there are effectively three ways to reduce vehicle speed: (1) reduce the posted speed, (2) reduce the design speed through traffic calming or redesign, and (3) post an advisory speed.

REDUCE VEHICLE SPEED BY REDUCING THE POSTED SPEED LIMIT

This mitigation entails reducing the posted speed. The ability to do this depends on who owns the roadway (state, county, city), as well as the legislation and guidelines governing those agencies. Once approval for the reduced speed is obtained, this mitigation is implemented by replacing the existing speed limit signs.

One location where posted vehicle speeds were reduced to mitigate WVCs is in Jasper National Park in Alberta, Canada, on the Yellowhead Highway. This roadway is a rural two-lane highway in a national park, with 3.7-m (12-ft) lane widths, and 3-m (10-ft) shoulders.⁽²³⁷⁾ Passing sight distance exists for most of the length. Passing sight distance is defined as “determined on the basis of the length needed to complete normal passing maneuvers in which the passing driver can determine that there are no potentially conflicting vehicles ahead before beginning the maneuver.”⁽¹⁾

Prior to the mitigation, the speed limit for the roadway was 90 km/h (56 mi/h). Traffic in 1998 was 1.2 million vehicles per year with a high percentage of trucks, buses, and recreational vehicles. The area includes grizzly bear, white-tailed deer, mule deer, bighorn sheep, and elk.

In 1991, the speed limit was reduced from 90 km/h (56 mi/h) to 70 km/h (43 mi/h) on three sections of the road; 2.5, 4, and 9 km (1.5, 2.5, and 5.6 mi) in length. Bertwistle reported that on average, 5,475 speeding tickets are issued each year (although he was not specific as to if these were in the 70 km/h (43 mi/h) zones or on the highway as a whole). Even with the speed limits and enforcement, a speed study in 1995 at two of the speed reduction locations showed that less than 20 percent of the vehicles obeyed the 70 km/h (43 mi/h) speed limit. Bertwistle reported that bighorn sheep collisions actually increased in the reduced speed zones and decreased in the control areas (the 90 km/h (56 mi/h) areas). Elk collisions were monitored at one reduced speed location and both the control and the reduced speed zones had increases in elk vehicle collisions. Bertwistle stated that there was a relationship between reducing the posted speed and the frequency of elk-vehicle collisions; however, the data presented in the paper appear to be inconclusive.

A report by Biota Research and Consulting, Inc. summarizes WVCs in the Jackson, WY area.⁽²¹³⁾ On a particular 1.4-km (0.9-mile) stretch of highway, the authors suggest highway lighting as a solution, because even with the posted speed limit reduced to 56 km/h (35 mi/h), drivers continue to strike and kill deer. The report does not state whether or not there was a decrease in WVCs from the posted speed limit reduction.

Often reduced speed zones are tied to other mitigation methods. A variable speed limit is associated with an animal detection system in Switzerland. (This system is described in the section on Animal Detection Systems earlier in this chapter.) Advisory speeds have also been used in conjunction with gaps in exclusionary fencing in The Netherlands, as previously mentioned (figure 39).

Case Studies and Contacts

For further information on the reduced speed limits in Jasper National Park, contact Jim Bertwistle, Warden, Jasper National Park, Alberta, Canada, (403) 852-6155.

Guidelines

If reduced speed zones are implemented, the following design considerations are recommended:

- Consider additional signing in advance of the reduced speed zones to inform motorists of the intent and hazard present. In Jasper National Park the signs stated “Slow Down for Wildlife.”
- Reduced speed zones will have limited effectiveness without consistent visible enforcement, especially if the posted speed is significantly below the operating speed or design speed.

Direct Benefits

The effect of reducing vehicle speed on WVCs is unclear. However, for all crashes, reducing vehicle speeds will generally reduce the frequency of severe crashes (i.e., human injury or fatality).⁽²³⁸⁾

Indirect Benefits

Indirect benefits cited in the literature include

- Fines collected from regular enforcement.
- Increased fuel economy: West and others showed that for a mix of vehicle types, fuel efficiency peaked at about 88 km/h (55 mi/h).⁽²³⁹⁾
- Reduced emissions: the exact relationship is unclear but they are closely related to fuel efficiency.
- Reduced injury severity of crashes.

Undesirable Effects

Extreme caution should be taken in reducing the posted speed limit excessively below the operating speed. Such a reduction can set up a situation where motorists are encouraged to break the law and leads to speed dispersion (the spread of vehicle speeds). Instead of a tight distribution of speeds for vehicles on the road, there tends to be two speed groups: one group of vehicles will travel at the posted speed limit and another will travel at the operating speed. It has been shown that speed dispersion increases crash rates even if average speeds decrease. Solomon and Cerrelli found that vehicles traveling close to the average speed had the lowest crash involvement rates.^(240,241) Crash involvement rate not only increased for faster vehicles, but also for slower vehicles. Garber and Gadiraju found a similar U-shaped relationship, where the further the posted speed was from the design speed, the higher the crash rate for the roadway.⁽²⁴²⁾ Speed dispersion is particularly an issue on two-lane rural roads (where WVCs occur most often), because it increases the number of vehicles passing in unsafe situations.

Costs

Costs include the following:

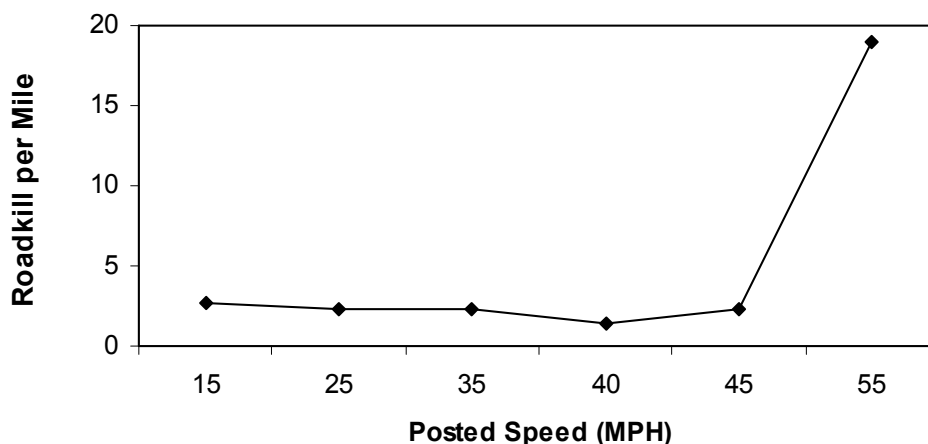
- The initial cost of replacing speed limit signs.
- The cost of regular enforcement.
- Additional costs in increased travel time need to be considered.
- Potential increase in head-on and other collisions due to speed dispersion.

REDUCE VEHICLE SPEED BY TRAFFIC CALMING/REDUCING DESIGN SPEED

Reducing the design speed of a road may be more effective in reducing vehicle speed than reducing the posted speed limit. A lower design speed typically relates to sharper horizontal and vertical curves, narrow lane widths, narrow or no shoulders, and narrow clear zones (i.e.,

obstructions such as trees closer to the roadway). In addition to the basic highway geometrics, there are numerous traffic calming methods used to slow vehicles down. These are typically used in residential neighborhoods or on a highway approaching a town, and rarely on major highways where most WVCs occur. Traffic calming treatments include speed bumps/humps, traffic circles, curb extensions, sidewalk extensions, raised medians, and rumble strips.

Gunther and others showed that in Yellowstone National Park, roads with higher posted speed limits had higher WVC occurrences.⁽²⁴³⁾ His primary evidence is shown in figure 40, where an 88 km/h (55 mi/h) roadway has significantly higher roadkill per mile than roadways with lower posted speed limits. Notice, however, that WVC frequencies do not increase until 88 km/h (55 mi/h) speed limit. The 88 km/h (55 mi/h) road (U.S. 191) used by Gunther in this analysis is not an interior roadway and experiences much higher traffic over the year than the other roads considered. Gunther did show that internal roadways that were reconstructed with higher design speeds did see an increase in roadkill.



1 mi/h = 1.61 km/h

Figure 40. Graph. Roadkill by posted speed limit in Yellowstone.⁽²⁴³⁾

Below are three examples of traffic calming applications for wildlife:

One example is shown in figure 41 where speed bumps are used to reduce vehicle speed for Cassowaries (*Casuarius casuarius*), a large bird species in Queensland, Australia. The top sign originally displayed a warning for a speed bump, but was vandalized with a black marker to look like a dead bird.



Figure 41. Photo. Speed bumps used to reduce WVCs in Australia (copyright: Marcel Huijser). (Please disregard graffiti on signs.)

A second example is the installation of four “slow points” on a road in Tasmania that experienced a dramatic increase in collisions with eastern quolls (*Dasyurus viverrinus*) and Tasmanian devils (*Sarcophilus laniarius*) after the road section in a national park was widened and sealed and modal speed increased by 20 km/h (12.4 mi/h).⁽²⁴⁴⁾ In addition, after the initial widening the population size of the two species declined substantially and the eastern quoll population became extinct. The slow points consisted of concrete barriers with a “Give Way” sign that constricted traffic to a single lane in the center of the road in or close to locations that had a concentration of roadkill.⁽²⁴⁴⁾ The tight curves and the merging of traffic forced vehicles to slow down. After the installation of the slow points, the median vehicle speed in the center of the road section dropped by about 20 km/h (12.3 mi/h) (17–35 percent reduction), while vehicle speed at the outer two slow points close to the park boundary and wildlife zone boundary was only reduced by 1–7 percent. In addition, road mortality became more sporadic; the eastern quoll population became reestablished and was at 50 percent of its size before the road was widened and sealed two years after the installation of the slow points.⁽²⁴⁴⁾ Furthermore, there was some indication that Tasmanian devil population was recovering as well.

A third example is the installation of (1) rumble strip patches along a road in south Florida in combination with (2) a black-on-yellow warning sign that reads “PANTHER CROSSING NEXT X MI” that has (3) a permanently activated flashing amber light installed on top of the warning sign. These mitigation measures are designed to increase driver alertness and to reduce vehicle speed to reduce collisions with the Florida panther.

Case Studies and Contacts

Although this mitigation has not been implemented directly, Kerry Gunther has done extensive modeling on potential impacts of design speed reductions: Kerry Gunther, Bear Management Office, Yellowstone National Park, kerry_gunther@nps.gov.

For more information on the slow points installed in Tasmania, contact Menna Jones, Department of Zoology, University of Tasmania, GPO Box 252-5, Hobart, Tas. 7001, Australia, E-mail: Menna.Jones@utas.edu.au.

Direct Benefits

Direct benefits of this measure in reducing WVCs are inconclusive.

Indirect Benefits

Lower speeds may reduce the number of fatal crashes and improve the overall safety of the roadway.

Undesirable Effects

Certain traffic calming measures have maintenance issues with snow removal. Also, the economic impacts of longer travel times should be considered.

Costs

No costs were identified in the literature review.

Guidelines

For further information on typical traffic calming measures and design guidelines, refer to the FHWA/ITE report on “Traffic Calming: State of the Practice” available at: <http://www.ite.org/traffic/tcstate.htm> (accessed January 25, 2007).

REDUCE VEHICLE SPEED BY POSTING ADVISORY SPEED SIGNS

Advisory speeds are typically only used in conjunction with other mitigation methods (primarily roadway warning signs). The results of those implementations are not revisited here, as they are discussed in other sections.

WILDLIFE CROSSING GUARDS

In some cases, individuals will direct traffic in areas where animals cross the roadway. This situation often occurs in national parks where mini-traffic jams (referred to as “animal jams”) occur as vehicles stop on the highway to view wildlife. In some cases, this traffic control is conducted by park staff. In other situations, it may be the work of volunteers. For example, a story in *USA Today* on September 24, 2006, by Mick Cochran told of the volunteer group calling itself the Bugle Corps in Rocky Mountain National Park that manages traffic along the park’s roads during the Rocky Mountain elk (*Cervus elaphus nelsoni*) rutting (breeding) season.⁽²⁴⁵⁾

Case Studies and Contacts

Most local technical assistance program (LTAP) centers offer flagger training and certification. Contact information for LTAP centers is located at: <http://www.ltapt2.org/> (accessed January 25, 2007).

Direct Benefits

No direct benefits were identified in the literature review.

Indirect Benefits

When vehicles stop to view wildlife, it creates an unsafe situation with vehicles weaving around the stopped vehicles and pedestrians walking along roadways. This mitigation measure may reduce vehicle-vehicle and vehicle-pedestrian collisions.

Undesirable Effects

Staff or volunteers that manage traffic are exposed to potential injury from inattentive motorists.

Costs

Costs include training costs and the cost of the time spent by the individuals managing traffic. Costs of safety vests and stop/yield paddles (mandatory) are minimal.

Guidelines

Volunteers or staff should be trained in traffic control.

Note that the application of this mitigation measure is typically in national parks or other protected areas where wildlife may be habituated to people, traffic, and roads. In addition, the measure is typically only deployed when traffic volume is relatively high and when staff or volunteers are available.

CHAPTER 6. MITIGATION METHODS THAT SEEK TO INFLUENCE ANIMAL BEHAVIOR

These WVC reduction strategies are designed to change where, how, and when wildlife cross roads by modifying the animals' behavior without the use of major structures on or along the roadway. The specific mitigation measures reported on in this chapter are as follows:

- Deer reflectors and mirrors.
- Audio signals in right of way or attached to vehicles.
- Olfactory repellents.
- Deer flagging models.
- Hazing.
- Deicing alternatives.
- Intercept feeding.
- Influence species composition or minimize nutritional value of vegetation in the right of way.
- Remove carcasses along transportation corridors.
- Increase median width.

DEER REFLECTORS AND MIRRORS

Deer mirrors and reflectors are roadside installments intended to act as visual wildlife repellents. Mirrors directly reflect vehicle headlights off the roadway and into the surrounding right of way.⁽⁶¹⁾ Reflectors beam colored reflected light from headlights into roadside habitat (Swareflex, D. Swarovski & Co., Wattens, Austria, <http://www.swareflex.com/> (accessed January 26, 2007)) or onto the roadway itself (Strieter-Lite, Strieter Corp., Rock Island, IL, <http://www.strieter-lite.com/>).⁽²⁴⁶⁾

Most studies testing the effectiveness of mirrors and/or reflectors on reducing WVCs found that they had (1) no effect, (2) mixed results, or (3) inconclusive results. (See references 38, 59, 247, 248, 249, 250, 251, and 252.) Differences in experimental design and in the variety of models tested confound the comparison of results.⁽²³¹⁾ However, Schafer and Penland did find a significant reduction (88 percent) in WVCs using Swareflex reflectors in Washington State.⁽²¹¹⁾ Pafko and Kovach found in Minnesota that reflectors reduced rural incidences by 50–97 percent, but suburban metropolitan WVC incidences increased.⁽²⁵⁰⁾

The Strieter-Lite company suggests there is scientific proof that their reflectors do work (78–90 percent reduction in DVCs) and that reflective luminance (brightness) is not a major factor, because wild animals have acute night vision.^(253,254) Sivic and Sielecki conducted a spectrometric evaluation of Swareflex and Strieter-Lite wildlife warning reflectors and noted operational implications of low light reflection intensities.⁽²⁵⁵⁾ Reflectors require suitable placement, alignment maintenance, and regular cleaning; however, in a roadside application it is impossible to keep reflectors clean at all times.^(72,254,256) Possible reasons why reflectors and mirrors do not result in fewer roadkill include improper installation, lack of maintenance (no replacement of missing reflectors or realigning them after they became out of alignment), and dirty mirrors/reflectors (especially in winter).

Utah DOT discontinued use of reflectors due to an increase in deer kills and difficulty in keeping reflectors clean; high installation and maintenance/cleaning costs were also factors.⁽²⁵⁶⁾ Thirty-nine percent of Swareflex reflectors used in Wyoming showed deterioration after 3 years.⁽²⁴⁸⁾ In British Columbia, reflectors were prone to theft and vandalism.⁽⁷²⁾ Where mirrors and reflectors work in reducing WVCs, it may be a result of driver behavior, particular site characteristics, or rural versus suburban landscapes.^(250,251,257)

Mirrors and reflectors are addressed in several literature reviews and annotated bibliographies. (See references 58, 61, 176, 231, 248, 258, and 259.) Knapp and others summarized 10 studies, five of which concluded that roadside reflectors did not appear to impact DVCs, two of which concluded that they did, and three reached inconclusive or mixed results.⁽⁵³⁾

Studies testing the influence of reflectors on animal behavior found little or no evidence of avoidance.^(59,246,257) A study of Strieter-Lite wildlife warning reflectors in four colors (red, white, blue-green, and amber) found them to be ineffective at altering white-tailed deer behavior so that DVCs might be prevented.⁽²⁴⁶⁾ Interestingly, data indicated that deer increased negative behavioral responses toward vehicles in the presence of reflectors.⁽²⁴⁶⁾ Ramp and Croft, however, found Swareflex reflectors produced a weak fleeing response in kangaroos.⁽²⁶⁰⁾ Ujvari and others found that deer initially responded to reflectors with alarm and flight but then became habituated to the light reflection.⁽²⁶¹⁾ D'Angelo and others recommend that future development of deer-deterrent devices for WVC mitigation be based on empirical knowledge of deer senses and behavior.⁽²⁴⁶⁾

Case Studies and Contacts

For information on a couple of the reflectors that are available, contact Swareflex Reflectors, D. Swarovski & Co., Wattens, Austria, www.swareflex.com, and Strieter-Lite, Strieter Corp., Rock Island, IL, <http://www.strieter-lite.com/> (accessed January 26, 2007).

For information on effectiveness of reflectors on animal behavior, contact Gino D'Angelo, Daniel B. Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA 30602, (706) 227-6867, gid4895@owl.forestry.uga.edu.

Direct Benefits

Roadside reflectors and mirrors are categorized as “tried” (as defined by AASHTO Safety Strategy Groups) and “used with conflicting safety analysis results” in a critical evaluation of DVC crash countermeasures.⁽¹⁷⁶⁾

Indirect Benefits

This mitigation approach allows for animal movements at grade and allows animals to change where they cross over time.

Undesirable Effects

Deer have been documented to move toward vehicles in the presence of reflectors.⁽²⁴⁶⁾

Costs

A manufacturer advertises total cost of installation with reflectors, posts, equipment, and labor to be \$4,000–6,000 per km (\$7,000–10,000 per mi). The average life of reflectors is 12.5 years, so costs amount to \$169–199 per km (\$272–320 per mi) per year. Maintenance cost per mile per year is \$500 (\$300 per km per year) (Strieter-Lite, Strieter Corp., Rock Island, IL, <http://www.strieter-lite.com/>).⁽²⁶²⁾ In British Columbia, reflectors cost approximately \$10,000 per km (\$16,000 per mi) to install along both sides of a highway, and maintenance costs range in the order of \$500–1,000 per km (\$800–1,600 per mi) annually.⁽⁷²⁾

Guidelines

The manufacturers have installation guidelines. Regular maintenance, e.g., cleaning of the reflectors, may be needed.

AUDIO SIGNALS IN RIGHT OF WAY OR ATTACHED TO VEHICLE (DEER WHISTLES)

Audio animal warning devices are intended to alert wildlife of oncoming traffic. Sav-A-Life Deer Alert (Sav-A-Life Industries, New York, New York, <http://www.sav-a-life.com/> (accessed January 26, 2007)) and Game Tracker’s Game Saver, marketed as vehicle-mounted ultrasonic animal warning devices, elicited no response in 150 groups of free-roaming mule deer in with/without trials.⁽²⁶³⁾ Behavioral observations of captive kangaroos in response to the Shu Roo, a vehicle-mounted ultrasonic kangaroo deterrent, did not differ in the on or off position.⁽²⁶⁴⁾

Many literature reviews and annotated bibliographies deem audio repellants ineffective in terms of modifying animal behavior for the goal of WVC reduction. (See references 58, 61, 74, 176, 216, 231, 265, and 266.)

A roadside wildlife warning system utilizing high-frequency sounds has been developed (International Road Dynamics, Inc., (IRD) Saskatoon, Saskatchewan, Canada, <http://www.irdinc.com/> (accessed January 26, 2007)).⁽²⁶⁷⁾ Results from a study were not conclusive, and the system is no longer in service (Rob Bushman, IRD Inc., personal

communication). While it is recognized that the results may not apply to highways, a wildlife warning system was installed along a railroad in Poland.⁽²⁶⁸⁾ The system is activated when trains approach.⁽²⁶⁸⁾ The effectiveness of this system has not been evaluated.

Another roadside wildlife warning system was developed by Firma Günter Josef Folda in Austria.⁽²⁶⁹⁾ Headlights from approaching cars activate equipment that is integrated with the poles and reflectors that delineate the roadway (Edward Mulka, Jafa Technologies, Inc., personal communication). Once activated, the equipment emits a high-pitched alarm sound along with a supplemental blue light strobe light (Edward Mulka, Jafa Technologies, Inc., personal communication).^(269,270) Unconfirmed data from Austria (between the cities of Nassereith and Imst in the Gurgltal on the Miemingerstraße road) indicate that the equipment may reduce WVCs by 85–93 percent.⁽²⁷⁰⁾ The equipment is encased in a weather-resistant box and is powered by solar cells, batteries, or both (Edward Mulka, Jafa Technologies, Inc., personal communication).⁽²⁷⁰⁾ The equipment weighs less than a pound and can be mounted on trees or small poles. The equipment can be directed such that the sound and strobe emitter face away from the road in the direction of wildlife that may be in the process of approaching the road (Edward Mulka, Jafa Technologies, Inc., personal communication).⁽²⁷⁰⁾

A study of fallow deer (*Dama dama*) behavioral responses to acoustic road markings showed that while behavioral responses differed initially, deer became completely indifferent to the acoustic stimuli within 10 days.⁽²⁷¹⁾

In a comparison of whistle acoustic frequencies and intensities and deer hearing abilities, Scheifele and others determined closed-end whistles produced frequencies of ~3.3 kHz with little variation with changes in air pressure, while open-end whistles emitted frequencies of ~12 kHz with significant variation depending on air pressure.⁽²⁷²⁾ Deer hearing sensitivity is estimated to be between 2 kHz and 6 kHz.^(272,273) Taking into consideration the masking effect of road and car noise, however, deer are not likely to be able to hear the whistles.^(263,272) Recordings made during dynamic drives found that the Shu Roo signal was not detectable above the noise of four vehicles traveling at different speeds, yielding no difference whether the device was turned on or off.⁽²⁶⁴⁾ Further, if whistles were audible in combination with vehicle and road noise, there is no evidence that they affect animal behavior and habituation to these sounds is possible. (See references 263, 264, 271, 272, and 274.)

Case Studies and Contacts

Contacts for some audio signal manufacturers are:

- Sav-A-Life Industries, New York, NY, <http://www.sav-a-life.com>.
- Rob Bushman, International Road Dynamics, Inc., <http://www.irdinc.com/search>.
- WIWASOL-II. Firma Günter Josef Folda, Perkonigweg 3, 9311 Kraig, Austria, Phone: +43 (0) 664 2301980, Fax: +43 (0) 720 555870, Email: office@wildwarner.at <http://www.wildwarner.at/pages/31alhomepag.html>. Distributor USA: Edward A. Mulka, Jafa Technologies, Inc., 213 Hooton Road, Mt. Laurel, NJ 08054, Tel/Fax: (856) 802-9095, Cell: (856) 278-1597, E-mail: emulka@jafatech.com, <http://www.jafatech.com/>.

Direct Benefits

Deer whistles are categorized as “tried” (as defined by AASHTO Safety Strategy Groups) and “used with conflicting safety analysis results” in a critical evaluation of DVC crash countermeasures.⁽¹⁷⁶⁾

The effectiveness of the IRD system is inconclusive. Maintenance staff anecdotally felt the system was effective, but the data were inconclusive, possibly since not enough data were collected. Currently the IRD system is not in use.(Rob Bushman, IRD Inc., personal communication).

The effectiveness of the WIWASOL-II system may be 85–93 percent, but these results are currently unconfirmed.⁽²⁷⁰⁾

Indirect Benefits

This approach accommodates unrestricted animal movements at grade.

Undesirable Effects

Audio signals may frighten animals away in areas where there may be interest in establishing or improving habitat connectivity across a highway.

Costs

The Sav-A-Life Deer Alert individual vehicle-mounted devices cost \$23.50 each.

For a test installation of a roadside-based audio signal system along a 6-km (3.7-mi)-long road section, the costs were about €19,000.⁽²⁷⁰⁾

Guidelines

If auditory warnings are used, their frequency must be within the auditory range of the species, and they must not be drowned out by the surrounding road and vehicle noise.

OLFACTORY REPELLENTS

Olfactory repellents involve odorous chemical or organic compound applications along roadways to act as deterrents for wildlife.

A literature review of capsaicinoids, synthesized animal odors, other animal products, garlic, particulates, soaps, thiram, bittering agents, natural predator excretions, and putrescent egg determined the latter two hold the most potential for keeping ungulates away from roadways but have not been field tested.^(176,275) An experimental study and literature review found olfactory repellents did not prove effective as area repellents for large-scale application on travel corridors, making them unsuitable for use in reducing WVCs.⁽²⁷⁶⁾ Other literature reviews that addressed effectiveness in terms of reducing WVCs have determined that olfactory repellents have not been adequately tested, show only limited effectiveness, or are impractical because of the need to

repeat applications, especially after precipitation events. (See references 22, 58, 61, 176, 216, 277, and 278.) Future development of olfactory repellent measures requires further study of wildlife behavioral responses on a range of species and of the potential for animal habituation.^(176,260,279)

Experimental scent marking using Duftzaun (HAGOPUR GmbH, Landsberg am Lech, Germany), a mixture of bear, gray wolf, Eurasian lynx (*Lynx lynx*), and human components, showed an 85 percent reduction in moose-train collisions in Norway, but results were questionable given that short treatment distances (500 m (1,640 ft)) yielded small and variable samples sizes for the number of collisions.⁽²²⁷⁾

Captive trials of Wolfin[®] (Pro Cell Biotenik, Hornefors, Sweden), a synthetic scent repellent, showed no repellency of caribou or black-tailed deer.^(280,281) The repellent Plant Plus (Roe Koh and Associates Pty. Ltd., Mornington, Victoria, New Zealand), a synthetic canine predator odor, had aversive effects on one species of marsupial but attracted another, indicating a need for more research.⁽²⁶⁰⁾ Captive trials of Deer Away[®] Big Game Repellent (Intagra, Inc. Lakeville, Minnesota), a putrescent whole egg repellent, initially altered caribou feeding behavior, but feeding times and amount eaten returned to pretreatment levels.⁽²⁸⁰⁾

Manufacturers of a proprietary “chemical fence” (repellent chemicals encapsulated in slow release organic foam and applied to roadside posts or trees) reported some repellency and a reduction in frequency of roe deer-vehicle collisions in one treated section.^(9,282) However, a more detailed assessment found DVCs rose in untreated sections.^(58,283) A roadside wildlife warning system utilizing scent repellents has been developed (International Road Dynamics, (IRD) Inc., Saskatoon, Saskatchewan, Canada, <http://www.irdinc.com/>), but results from a study were not conclusive and the system is no longer in service (Rob Bushman, IRD Inc., personal communication).⁽²⁶⁷⁾

Case Studies and Contacts

For information about effectiveness of repellents on animal behavior, contact Lisa Shipley, Department of Natural Resource Sciences, Washington State University, (509) 543-8955 or Marion Carey, Project Monitor, Environmental Affairs Office, Washington Department of Transportation, (360) 705-7404.

Direct Benefits

In terms of reducing WVCs, evidence for effectiveness remains sparse and temporary at best.⁽²²⁾ Repellents are categorized as “experimental” (as defined by AASHTO Safety Strategy Groups) and “not generally used and rarely studied for safety impacts” in a critical evaluation of DVC crash countermeasures.⁽¹⁷⁶⁾

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

Kinley and Newhouse caution that unintended negative effects may arise from olfactory repellent application and recommend a cost-benefit analysis of associated safety, economic, and ecological factors.⁽²⁷⁵⁾ Potential negative effects may include attracting predators to the roadside and causing a panic reaction (instead of avoidance) in ungulates resulting in erratic movements toward the roadway.

Costs

Costs should take into consideration maintenance requirements, time intervals for reapplications, the area to be treated, and ecological impacts.^(22,176)

According to the literature, one liter of Plant Plus concentrate costs \$30 (currency was not specified, but presumably Australian dollars).⁽²⁸⁴⁾

Guidelines

If olfactory repellents are used, it is important to ensure that the repellent works to deter animal movement and that animals do not become habituated to them.

DEER FLAGGING MODELS

Deer flagging models are based on the behavioral characteristic of white-tailed deer that raise their tails to expose the white underside when fleeing. Tail flagging, however, has not been shown to act as a warning signal to other members of the species.⁽²⁸⁵⁾

A single deer flagging model study was found.⁽²⁸⁶⁾ The researchers used painted wooden silhouette models of deer with painted or actual deer tails in a control/treatment experiment and found the models to be ineffective for deterring deer from the roadway.⁽²⁸⁶⁾ A number of confounding factors make it difficult to determine whether or not this mitigation alternative is viable.⁽¹⁷⁶⁾ Future studies that consider pertinent variables (e.g., fluctuations in deer movements) could validate or refute this study and address potential safety or DVC impacts of deer flagging models.⁽¹⁷⁶⁾

Case Studies and Contacts

For review information about deer flagging models, contact Keith Knapp, Texas Transportation Institute, Work Zone and DMS Program, Room 410D, 3135 TAMU, College Station, TX 77843-3135, (979) 845-5686, k-knapp@tamu.edu.

For further information about deer tail flagging, contact Tim Caro, University of California-Davis, Wildlife, Fish, and Conservation Biology Department, 1395 Academic Surge Building, 95616, (530) 752-0596, tmcaro@ucdavis.edu.

Direct Benefits

Deer flagging models are categorized as “experimental” (as defined by AASHTO Safety Strategy Groups) and “not generally used and rarely studied for safety impacts” in a critical evaluation of DVC crash countermeasures.⁽¹⁷⁶⁾

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

No undesirable effects were identified in the literature review.

Costs

No costs were identified in the literature review.

Guidelines

No guidelines were identified in the literature review.

HAZING

Hazing or aversive conditioning is the practice of dispersing wildlife by frightening them, which has been done using such things as lights, lasers, water sprays, pyrotechnics, cannons, guns, helicopters and predatory-resembling chases. (See references 287, 288, 289, and 290.)

Romin and Bissonette found 3 of 43 natural resource agency respondents used hazing as a method to reduce deer road mortality, one of which reported success.⁽³⁾ Hazing was not effective in moose-vehicle collision mitigation efforts in Alaska.⁽⁷⁸⁾ In British Columbia, Roosevelt elk (*Cervus canadensis roosevelti*) were relocated when hazing failed as a WVC mitigation measure.⁽⁷²⁾

Green and blue lasers were found to be ineffective as frightening devices to disperse deer at night.⁽²⁹⁰⁾ During treatment and control (observation with no laser) behavioral experiments, deer saw and followed the laser light and appeared to be more curious than frightened.⁽²⁹⁰⁾ Red lasers were not tested because deer cannot see in the red portion of the spectrum.⁽²⁹⁰⁾ Lasers have been proven to be effective on birds but not on deer, probably a result of species-specific threat perception (i.e., animals may not associate the disturbance with danger).^(287,290) Lights and water sprays have only limited effectiveness.⁽²⁸⁷⁾

Hazing with sounds (e.g., pyrotechnics, cannons, guns, and helicopters) may offer a temporary solution for dispersing animals, but noise is a consideration in areas of human populations.^(287,288) In a study of Key deer capture techniques, hazing with helicopters or shooting out of vehicles in residential areas was not attempted.⁽²⁸⁸⁾

Aversive conditioning treatments resembling predatory chases by humans and dogs were effective in increasing flight responses in 24 moderately habituated radio-collared elk; habituated animals have been associated with WVCs in Banff National Park.⁽²⁸⁹⁾ Natural wolf activity, however, appeared to reduce the efficacy of the aversive conditioning techniques (i.e., elk remained closer to town sites).⁽²⁸⁹⁾ Aversive conditioning has shown some success in keeping grizzly bears off roadsides.⁽²⁹¹⁾

No scientific studies have been done to test the effectiveness of hazing on reducing WVCs, and hazing is not covered in other pertinent reviews on WVC mitigation measures.^(61,176,231) DeNicola and others address hazing in managing deer in suburban environments but not within the context of WVC reduction.⁽²⁸⁷⁾ Hazing can be difficult to implement in established conflict situations, because animal behavioral habits are difficult to change and habituation is possible.⁽²⁸⁷⁾

Case Studies and Contacts

For information about aversive conditioning in Banff National Park, contact Elsabe Louise Kloppers, University of Alberta, Canada, elsabekloppers@yahoo.ca.

Direct Benefits

Direct benefits are unknown. No scientific studies have been done to test the effectiveness of hazing on reducing WVCs.⁽⁶¹⁾

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

No undesirable effects were identified in the literature review.

Costs

Aversive conditioning using humans was 15 percent less expensive than conditioning with dogs (Can\$4,300).⁽²⁸⁹⁾

Guidelines

No guidelines were identified in the literature review.

DEICING ALTERNATIVES

The principal deicers used by highway agencies are chloride-based salts such as sodium chloride (NaCl), calcium chloride (CaCl₂), and magnesium chloride (MgCl₂), and acetate-based deicers such as potassium acetate, sodium acetate, and calcium magnesium acetate (Xianming Shi and Laura Fay, Western Transportation Institute, Montana State University, personal communication).

The use of chloride salts in winter maintenance can attract wildlife to the right of way and may increase WVCs, especially in areas without natural salt licks. (See references 61, 74, 176, and 292.) A study of 11 radio-collared moose in New Hampshire determined that all of their home ranges converged on the area containing roadside salt (NaCl) licks formed by runoff of road salt.⁽²⁹³⁾ Implications associated with these roadside salt licks include increased moose-vehicle collisions and increased brain worm infections in moose and white-tailed deer.⁽²⁹³⁾ Reducing the amount of salt or using alternative deicers (without salt), especially in areas of high WVCs, may reduce the attractiveness of the right of way.⁽²⁹⁴⁾

Lithium chloride, a gastrointestinal toxicant, was found to effectively discourage captive caribou from eating treated food and may prove useful in reducing WVCs by discouraging ungulates from licking road salt.⁽²⁸⁰⁾ CaMg-acetate has been recommended as an alternative to deice roads in Finland instead of NaCl.⁽⁷⁴⁾ Attempts at discouraging animals from road salt using the deicer calcium chloride were unsuccessful in Jasper National Park, Canada.⁽²⁹⁵⁾

A study of the pattern of moose-vehicle collisions in relation to the presence of roadside saltwater pools showed that 43 percent of moose-vehicle collisions occurred within 100 m (328 ft) of a saltwater pool, higher than what would randomly be expected.⁽²⁹⁶⁾ About the same number of collisions happened more than 300 m (984 ft) from a roadside saltwater pool.⁽¹⁷⁶⁾ Knapp questions the assumption of the study (i.e., all locations have an equal chance for a collision).⁽¹⁷⁶⁾

Road salt and deicing alternatives are addressed in literature reviews; however, whether the reduction or replacement of the road salt would reduce WVCs involving ungulates remains unknown.^(61,176,292)

Case Studies and Contacts

For further information on efforts using deicing alternatives, contact Jim Bertwistle, Warden, Jasper National Park, Alberta, Canada, (403) 852-6155.

Direct Benefits

Whether the reduction or elimination of the road salt would reduce WVCs remains unknown.⁽¹⁷⁶⁾ Deicing salt alternatives are categorized as “experimental” (as defined by AASHTO Safety Strategy Groups) and “used but not studied for safety impacts” in a critical evaluation of DVC crash countermeasures.⁽¹⁷⁶⁾

Indirect Benefits

The intake of road salt has been found to be toxic to several bird species, porcupines, rabbits, deer, and moose that ingest it.^(292,297) Reduction or elimination of road salt may reduce or eliminate this toxicity.

Brain worm in moose and white-tailed deer is associated with road salt; elimination of road salt may reduce this occurrence.⁽²⁹³⁾

Undesirable Effects

While the reduction or elimination of road salt may benefit certain species, alternatives to chloride salts may also be toxic to wildlife (Xianming Shi, Western Transportation Institute, Montana State University, personal communication), but this has not yet been specifically studied.

Costs

No costs were identified in the literature review.

Guidelines

No guidelines were identified in the literature review.

INTERCEPT FEEDING

Intercept feeding provides strategically placed supplemental food sources in an attempt to divert animals away from roadways.⁽¹⁷⁶⁾

A two-year control/treatment experiment tested the effectiveness of intercept feeding as a means to reduce DVCs by diverting mule deer from roadsides in Utah.⁽²⁹⁸⁾ The researchers concluded that intercept feeding may have reduced DVCs by as much as 50 percent.⁽²⁹⁸⁾ However, no information was provided on the number of DVCs before intercept feeding stations were operational.⁽¹⁷⁶⁾

After testing the effectiveness of scent marking, forest clearing, and supplemental feeding, researchers in Norway determined such mitigations might help reduce (but not eliminate) moose-train collisions if applied over long distances.⁽²²⁷⁾ Attempts at discouraging animals from road salt using intercept mineral baiting were unsuccessful in Jasper National Park, Canada.⁽²⁹⁵⁾

Intercept feeding may work in some cases, such as for short-term reductions in areas of high deer concentrations or in combination with other mitigation measures. (See references 61, 176, 216, and 298.) Intercept feeding is labor intensive and may create a dependency on supplemental food and actually increase population size.^(216,298) Intercept feeding is addressed in several pertinent literature reviews. (See references 61, 176, 216, and 231.)

Case Studies and Contacts

For further information on intercept feeding efforts, contact Jim Bertwistle, Warden, Jasper National Park, Alberta, Canada, (403) 852-6155.

Direct Benefits

Intercept feeding is categorized as “experimental” (as defined by AASHTO Safety Strategy Groups) and “not generally used and rarely studied for safety impacts” in a critical evaluation of DVC crash countermeasures.⁽¹⁷⁶⁾ Additional study that can refute or validate the effectiveness of intercept feeding in reducing DVCs would be appropriate.⁽¹⁷⁶⁾

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

Intercept feeding may create a dependency on supplemental food or increase population size.⁽²⁹⁸⁾

Costs

Intercept feeding is labor intensive.^(216,298)

Guidelines

No guidelines were identified in the literature review.

INFLUENCE SPECIES COMPOSITION OR MINIMIZE NUTRITIONAL VALUE OF VEGETATION IN RIGHT OF WAY

Roadside vegetation can attract wildlife to roads and increase their vulnerability to WVCs.^(299,300) The practice of planting trees near roadways for landscaping reasons can attract ungulates to the right of way and increase the risk of WVCs.⁽⁹⁾ Several sources recommend managing vegetation in the right of way so that it does not serve as an attractant to wildlife (i.e., by planting unpalatable species, reducing forage quality, or applying noxious chemicals), while others focus on improving roadside habitat for wildlife. (See references 9, 74, 301, 302, 303, 304, 305, and 306.) Techniques employing forage repellents, unpalatable species, and roadside brush removal have been used with limited effectiveness or are not cost efficient when broadly applied.⁽³⁰⁴⁾

An experimental study of vegetation removal along a railway line (20–30 m (66–98 ft) on each side) in Norway caused a 56 percent (+/- 16 percent) reduction in moose-train collisions.⁽²²⁸⁾ The researchers concluded that there would be an economic benefit to perform vegetation removal treatments in areas with more than 0.3 collisions per km (0.48 per mi) but that local evaluations are necessary to confirm that vegetation cover is the main contributor to collisions in specific sections.⁽²²⁸⁾ It is possible, however, that the experimental design may have overstated the collision reduction potential of vegetation removal.^(176,228)

A detailed literature review on roadside vegetation management, plant response to tissue removal, and ungulate foraging behavior yielded recommendations for more carefully designed cutting regimes as a countermeasure for reducing moose-vehicle collisions.⁽³⁰⁴⁾ Willows cut in mid-July were found to be high in digestible energy and protein compared to plants cut at other times of the year and uncut controls, suggesting that summer brush cutting regimes may inadvertently be attracting moose with nutritious regrowth.^(304,307) Cutting in early June results in browse with significantly less nutritional value for the first two years after cutting compared to plants cut later in the growing season and uncut controls.^(304,307) Rea recommends cutting roadside brush in early spring soon after leaves develop to keep nutritional value and palatability to a minimum but recognizes operational challenges and limitations (i.e., ground too wet for tractor use, different ungulate species-specific responses to same management regime, etc.) and cautions that this countermeasure may not be suitable for all management areas.⁽³⁰⁴⁾

No studies were found that specifically analyze the WVC safety impacts of roadside management policies or plantings; however, a 1999 report by the Arizona Department of Transportation (ADOT) describes a future five-year monitoring plan to address the effectiveness of a number of mitigation measures (including those related to vegetation/habitat changes) on reducing WVCs.^(176,308) The need to properly study the safety impact of vegetation management along roadways remains.⁽¹⁷⁶⁾

Note: see also the section titled “Increase Visibility of Animals to Drivers: Vegetation Removal” in chapter 5.

Case Studies and Contacts

For information about roadside vegetation management, contact Roy Rea, Natural Resources and Environmental Studies, University of Northern British Columbia, Canada, reav@unbc.ca.

Direct Benefits

Roadside vegetation management is categorized as “tried” (as defined by AASHTO Safety Strategy Groups) and “used but rarely studied for safety impacts” in a critical evaluation of DVC crash countermeasures.⁽¹⁷⁶⁾

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

Minimizing the nutritional vegetation may restrict the use of native vegetation along the roadside. In addition, reducing habitat quality may increase the road effect zone.⁽⁸³⁾

Costs

No costs were identified in the literature review.

Guidelines

Some guidance for implementing this mitigation measure is presented by Rea.⁽³⁰⁴⁾

REMOVE CARCASSES ALONG TRANSPORTATION CORRIDOR

Highway safety is an impetus for timely removal of road-killed animals, and carcass composting may yield economic, ecological, and aesthetic benefits.^(176,309) The carcasses of road-killed animals that are not removed may serve as food sources for other wildlife, attracting them to roads and increasing their vulnerability to WVCs.⁽¹⁷⁶⁾ Evaluation of the impact of roadside carcass removal on reducing WVCs has not been studied and has rarely been considered.⁽¹⁷⁶⁾ While carcasses may be an attraction for scavengers, ungulates are not likely to be attracted or deterred by the presence of carcasses in the right of way. Therefore, carcass removal may not have a substantial effect on the number of DVCs and the total number of WVCs. Nonetheless,

omnivores and carnivores, including some rare, threatened, or endangered species, may experience less road mortality as a result of the removal of food sources along the roadway.

Case Studies and Contacts

For information about carcass removal efforts in New York State, contact Elisabeth Kolb, Maintenance Environmental Coordinator, New York State Department of Transportation, (845) 575-6158.

Direct Benefits

Carcass removal, as an element in “roadway maintenance, design and planning policies,” is categorized as “tried” (as defined by AASHTO Safety Strategy Groups) and “used but rarely studied for safety impacts” in a critical evaluation of DVC crash countermeasures.⁽¹⁷⁶⁾

Indirect Benefits

Carcass removal may reduce the frequency of secondary roadkill of scavengers that feed on carcasses.

Undesirable Effects

No undesirable effects were identified in the literature review.

Costs

In Canada, the clean-up and carcass removal and disposal costs for animal carcasses were estimated at Can\$100 (deer), Can\$350 (elk) and Can\$350 (moose).⁽⁷²⁾ In Pennsylvania, the average cost for deer carcass removal and disposal in a certified facility was \$30.50 per deer for contractors and \$52.46 per deer for the Pennsylvania Department of Transportation in 2003–2004 (Jon Fleming, Pennsylvania Department of Transportation, personal communication).

Guidelines

Carcass removal allows for easy data collection of roadkill, which helps with planning and monitoring mitigations for WVCs. A composting plant would mitigate the waste management issue.

INCREASE MEDIAN WIDTH

Crossing several lanes of traffic moving in opposite directions is a difficult task for an animal to perform. Wider medians can provide a “refuge” for the animals, giving them a break in their roadway crossing. Medians allow animals to deal with only one direction of traffic at a time, enabling them to stop partway across the roadway and identify and wait for an adequate gap in traffic before crossing the second half of the roadway. A literature review by Clevenger and Kociolek found that it was unclear whether or not a vegetated median increased the ability of wildlife to cross the road safely.⁽³¹⁰⁾

Case Studies and Contacts

No case studies were identified in this literature review.

Direct Benefits

No direct benefits were identified in the literature review.

Indirect Benefits

A wider median may provide a more aesthetically pleasing view to the driver. It may also allow for high beams to be kept on for longer periods at night to aid visibility.

Undesirable Effects

No undesirable effects were identified in the literature review.

Costs

No costs were identified in the literature review.

Guidelines

No guidelines were identified in the literature review.

CHAPTER 7. MITIGATION METHODS THAT SEEK TO REDUCE WILDLIFE POPULATION SIZE

A comprehensive review by Knapp, Putman and others suggests that a reduction of the population size across a relatively wide area can be effective in reducing DVCs. (See references 52, 53, 54, 58, 61, 62, and 311.) Nonetheless, actual data on the effectiveness of population reduction programs on WVCs are few. For example, a field test showed that a deer population reduction program in Minnesota reduced winter deer densities by 46 percent and DVCs by 30 percent.⁽⁵²⁾

Deer population sizes, especially those of white-tailed deer, have grown substantially over the last century in the United States.⁽⁵⁵⁾ This population growth is especially apparent since the 1960s.^(55,57) This increase in population size was triggered by better protection, a matrix of habitat providing cover (forests) and food (agriculture, silviculture), the loss or decline of their natural predators, and more recently, reduced hunting pressure by humans through an increase in refugia (private land, (sub) urban areas), and a decrease in hunters. (See references 55, 57, 312, 313, 314, and 315.) Currently, white-tailed deer numbers are believed to be higher than they have ever been in the past several hundred years, causing or contributing to a series of problems, including DVCs. (See references 55, 57, 314, and 316.) This situation has triggered efforts to eliminate, reduce, or control the size of the deer population, especially white-tailed deer.

The fertility of white-tailed deer depends on their population density; their reproduction is higher at relatively low densities than at higher densities. The fertility of white-tailed deer is weakly density dependent for adult does.⁽³¹⁷⁾ However, the fertility of first-year and yearling females is strongly density dependent, with very low fertility when population densities exceed 30 deer/km².⁽³¹⁷⁾ These observations suggest that as population density is reduced, increased effort is needed to keep the deer density at the lower level. This phenomenon needs to be addressed in potential population size reduction programs.

The relationship between deer population density and the number of DVCs seems intuitive but is often complex and variable.^(59,60) Nonetheless, a comprehensive review by Knapp, Putman and others suggests that a reduction of the population size across a relatively wide area can be effective in reducing DVCs. (See references 52, 53, 54, 58, 61, 62, and 311.)

This chapter discusses the following measures to reduce wildlife population size along roads

- Wildlife culling.
- Wildlife relocation.
- Anti-fertility treatment.
- Habitat alteration away from the road.

WILDLIFE CULLING

Wildlife culling involves a substantial reduction of the population size through eliminating a large number of individual animals over a short period of time. This measure is typically applied to or proposed for deer. The culling is sometimes done by recreational hunters through increased quota; sometimes it is done by professionals, especially if there are refugia for the deer (private land, (sub)urban areas). (See references 52, 312, 318, and 319.)

A field test showed that a deer population reduction program in Minnesota reduced winter deer densities by 46 percent and DVCs by 30 percent.⁽⁵²⁾ Sharpshooting by professionals over bait was deemed to be the most effective and adaptable culling method in an urban setting, as opposed to controlled hunts in large parks and refuges or opportunistic sharpshooting by professionals.⁽⁵²⁾

The killing of does (females) is more effective for reducing the population size than the killing of bucks (males), not only because the reproductive potential of the herd is more effectively reduced, but also because does tend to stay in their existing home range while bucks have a greater tendency to disperse.⁽⁵⁵⁾ The does are less likely to migrate and establish new populations elsewhere.

A modeling project by Porter and others showed that if female dispersal (i.e., animals that leave the area) was 8 percent, culling would have to reduce annual survival to 58 percent to maintain a population just under ecological carrying capacity (the maximum sustainable population size).⁽³²⁰⁾ A further reduction of the annual survival to 42 percent would keep the population at 0.5 of the carrying capacity.⁽³²⁰⁾

Culling efforts are more likely to result in a substantial reduction in deer population size if the herd size is relatively small to begin with and if it is a closed population that does not allow influx of animals from nearby places. The effort has to be repeated periodically as the deer population will grow back to the same levels if the habitat conditions remain similar (i.e., it is not a one-time-only measure). In addition, the effort involved for population size reduction programs increases disproportionately with higher population size reduction goals, and substantial reductions (for example ≥ 50 percent) may be hard to obtain, perhaps capping the potential reduction in DVCs at 50 percent. Finally, wildlife culling can meet with strong public opposition.

Case Studies and Contacts

For information about a field test of four population management methods to reduce a deer population in Bloomington, MN, contact Michelle Doerr, 2887 Ulm Avenue, Stewart, MN 55385, ewiggers@islc.net.

For more information about a field test of the effects of baiting and supplemental antlerless seasons on deer harvest, contact Timothy Van Deelen, Department of Wildlife Ecology, University of Wisconsin, Madison, WI 53706-1598, trvandeelen@wisc.edu.

Direct Benefits

The relationship between deer population size and DVCs can be highly variable (see earlier discussion). Nonetheless, based on Doerr, Knapp and others, a certain percentage in population size reduction may result in a similar percentage in DVC reduction.^(52,53) However, reductions in population size of 50 percent or more may be hard to obtain, perhaps capping the potential reduction in DVCs at 50 percent or less.⁽⁵²⁾

Indirect Benefits

Indirect benefits of reducing wildlife population size include reduced negative impacts from “overpopulation” on agricultural crops, silviculture, and natural vegetation.⁽⁵⁵⁾

Undesirable Effects

Wildlife culling may not be favored or accepted by the public, especially in areas that have a high degree of ecological integrity (“hands-off” approach).^(57,321,322) A public relations campaign should be considered along with a culling effort.

Culling may not be possible or effective on private lands, in remote locations, or in urban and suburban areas.^(55,312) If refugia are present, more intensive effort will have to be undertaken at locations that are accessible to hunters or wildlife managers.⁽³¹²⁾

The effort will have to be repeated periodically as the deer population will grow back to the same levels if the habitat conditions remain similar; it is not a one-time-only measure.

Recreational hunters tend to focus on mature bucks rather than young animals or does, which is the least effective way to reduce the population size.⁽⁵⁵⁾ A change in regulations may be required to allow for greater quota, specifically for younger animals and does.^(312,323)

The number of hunters is declining, perhaps demanding a shift from recreational hunting to professional culling.^(313,318)

Baiting in order to facilitate wildlife culling increases efficacy but is illegal in some areas, and it can lead to undesirable side effects such as increased risk of the spread of diseases, reduction in the consumption of natural foods and consequent changes in the ecosystem, population increase and consequent starvation, crowding, fighting and injuries of deer, deer domestication and habituation to unnatural foods and humans, decrease in hunter satisfaction, and increase in concerns of the nonhunting public.^(323,324)

Costs

The costs for a controlled hunt were estimated at \$117 per deer killed. The cost of using professional sharpshooters was \$108–121–194 per deer for conservation officers, park rangers, and police officers, respectively.⁽⁵²⁾ Others estimated these costs at \$91–310 per deer.⁽²⁸⁷⁾

Guidelines

No guidelines were identified in the literature review.

WILDLIFE RELOCATION

Wildlife relocation involves the capture, transport, and release of animals (mostly moving deer to another location). It is typically considered if population reduction is required but culling is not an option.

At the Sea Pines residential area on Hilton Head Island, SC, a deer relocation experiment was conducted.⁽³²⁵⁾ The relocated deer experienced relatively high mortality from capture-related causes, and 50 percent of the relocated deer dispersed from their release site.⁽³²⁵⁾

Case Studies and Contacts

For more information on a field test of the live-capture and small-scale relocation of urban deer on Hilton Head Island, SC, contact Jennifer Cromwell, United States Department of Agriculture, Wildlife Services, Moseley, VA, 23120, (804) 734-7739, jennifer.s.cromwell@aphis.usda.gov.

Direct Benefits

The relationship between deer population size and DVCs can be highly variable (see earlier discussion). Nonetheless, based on Doerr, Knapp and others, a certain percentage reduction in population size may result in a similar percentage reduction in DVCs.^(52,53) However, reductions in population size of 50 percent or more may be hard to obtain, perhaps capping a potential reduction in DVCs at 50 percent or less.⁽⁵²⁾ The effectiveness can be seriously diminished if it is an open population that allows the individuals from neighboring populations to fill the gaps or that allows the relocated individuals to return.⁽³²⁵⁾

Indirect Benefits

Benefits include reduced negative impacts from “overpopulation” on agricultural crops, silviculture, and natural vegetation.⁽⁵⁵⁾

Undesirable Effects

With an open population or relocation over relatively short distances, individuals from neighboring populations may fill the gaps or a substantial portion of the relocated individuals may return to the original location, seriously limiting the effectiveness of this measure.⁽³²⁵⁾ In one study, 50 percent of the relocated deer did not remain in their release area.⁽³²⁵⁾

The effort will have to be repeated periodically as the deer population will grow back to the same levels (growth, immigration, including of individuals that were relocated) if the habitat conditions remain similar; it is not a one-time-only measure.

Relocated individuals tend to experience a lower survival rate and increased human-induced mortality, including from the capturing effort.^(325,326) Relocation of deer can result in the spread of infectious diseases.⁽³²⁷⁾ Wildlife relocation is, in general, not recommended.⁽³²⁸⁾

Relocated individuals may compete with individuals that are already present at the release site, or they may contribute to the growth and overpopulation at the release site and the negative effects associated with overpopulation.⁽⁵⁵⁾

The effort may not be favored or accepted by the public, especially in areas that have a high degree of ecological integrity (“hands-off” approach).⁽⁵⁷⁾

Costs

The costs for relocation were estimated at \$387 per relocated deer.⁽³²⁶⁾ Others estimated these costs at \$431 or \$400–2,931 per deer.⁽²⁸⁷⁾

Guidelines

No guidelines were identified in the literature review.

ANTI-FERTILITY TREATMENT

Anti-fertility treatment can reduce reproduction of deer. (See references 329, 330, 331, 332, and 333.) This measure is typically considered or applied where killing (through hunting) is illegal (private lands, legislation) or impractical ((sub) urban areas, public pressure), where recolonization possibilities from elsewhere are limited (closed population), and where a relatively small deer population exists (e.g., 2000 or fewer breeding females). (See references 330, 334, 335, 336, and 337.) Some drugs have shown to be effective for up to 1 or 2 years, but repeated application is often needed. The reversibility of anti-fertility treatment can be considered an advantage (if reproduction is necessary later) as well as a disadvantage (continuing treatment required).^(330,338)

Modeling efforts have shown that sterilization in combination with hunting can control the population size of deer.^(334,335) For the deer on Cumberland Island National Seashore, GA, (herd size 1,500 animals), the model predicted that the herd size could be controlled at 750 animals if 200 sterilizations are done per year for the first 3 years, followed by 42 sterilizations per year for the following years.⁽³³⁴⁾ Should the existing levels of hunting and predation continue, these numbers can be reduced to 81 (initial 3 years), but they would be higher for the following years (58 per year). Modeling by Seagle and Close showed that with contraception rates of less than 50 percent of female deer, the population growth curve was less steep, but herd size was not reduced.⁽³³⁵⁾ A minimal contraception rate of 50 percent was required to reduce the herd size. With contraception rates greater than 50 percent, substantial changes in population size were only observed after 5–10 years. Variability of the results was high, suggesting that it is difficult to detect population changes in the field.⁽³³⁵⁾ Another modeling effort showed that a deer population could be reduced by 30–60 percent in 4–10 years if 25–50 percent of the fertile females were sterilized annually.⁽³³⁹⁾ Models developed by Porter and others showed that with 8 percent female dispersal, contraception would need to be effective in 32 percent of the females if the population were at about carrying capacity, and 68 percent if the population were at one-half of carrying capacity.⁽³²⁰⁾

Results of a field test on a suburban white-tailed deer population in Irondequoit, NY, using immunocontraception suggest that the measure may be most practical when a population density

between 30 and 70 percent of ecological carrying capacity is acceptable. However, it is only considered useful in relatively small and closed populations (≤ 200 females).⁽³³⁶⁾ Walter and others captured and treated suburban female white-tailed deer in Connecticut with a contraceptive.⁽³⁴⁰⁾ Baiting and capturing of the deer was more effective in spring than in fall. The study indicated that treatment of about 70 percent of the population was possible.⁽³⁴⁰⁾ A capture and sterilization program for a white-tailed deer population in Cayuga Heights, NY showed that capture efforts had to be relatively high because the traps were not sex or age specific.⁽³⁴¹⁾ Furthermore, the efficacy of the sterilization program was dramatically reduced because it was not a closed population.⁽³⁴¹⁾

Case Studies and Contacts

For information on a field test using immunocontraception in a suburban white-tailed deer in Irondequoit, NY, contact Brent Rudolph, Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI 48824, (517) 432-4943, rudolp13@msu.edu.

For information on a field test using a contraceptive in a suburban white-tailed deer in Connecticut, contact David Walter, Oklahoma Cooperative Fish and Wildlife Research Unit, Oklahoma State University, 404 Life Sciences West, Stillwater, OK, 74078, wdwalte@okstate.edu.

For information on a field test using sterilization in a white-tailed deer population in Cayuga Heights, NY, contact Johnny Merrill, Cornell University, Department of Natural Resources, Fernow Hall, Ithaca, NY 14853, jam82@cornell.edu.

Direct Benefits

The relationship between deer population size and DVCs can be highly variable (see earlier discussion). Nonetheless, based on Doerr, Knapp and others, a certain percentage in reduction of population size may result in a similar percentage reduction in DVCs.^(52,53) However, reductions in population size of 50 percent or more may be hard to obtain, perhaps capping the potential reduction in DVCs at 50 percent or less.⁽³³⁶⁾ The effectiveness is seriously diminished if it is an open population that allows the individuals from neighboring populations to fill the gaps.⁽³⁴¹⁾

Indirect Benefits

Benefits include reduced negative impacts from “overpopulation” on agricultural crops, silviculture, and natural vegetation.⁽⁵⁵⁾

Undesirable Effects

Fertility control and immunocontraceptives by some drugs disrupt normal reproductive behavior and can cause physical problems with the reproductive system, abscesses and inflammations, weight gain, changes in general behavior, and changes in the sex ratio in the herd.^(342,343) However, health problems and effects on social behavior may not always occur, or they may be minimal.⁽³³⁸⁾

The efforts will have to be repeated constantly in a population, and depending on the drug used, the same animals may have to be treated multiple times during their lives.(See references 330, 334, 338, and 344.)

The effort is less effective, or not effective, when recolonization from elsewhere can occur (open population).⁽³³⁵⁾

The method may only be feasible for relatively small populations (200 or fewer females).⁽³³⁶⁾

Costs

Walter and others calculated that \$33,833 (\$1,128 per treated deer) was required to treat 30 deer for 2 years (labor was 64 percent of the total budget).⁽³⁴⁰⁾

Guidelines

No guidelines were identified in the literature review.

HABITAT ALTERATION AWAY FROM THE ROAD

Deer population density depends on the quality of their habitat. An abundance of food and cover, in combination with an absence of predators and hunting, allows for relatively high population densities. (See references 55, 57, 312, 313, 314, and 315.) In general, good feeding habitat for deer may include young forests (e.g., in harvested areas that have been replanted or that have naturally regenerated), agricultural lands (hay or alfalfa meadows, especially if they are fertilized and irrigated, and crop lands), lawns and gardens (including golf courses), and riparian habitat.

Good cover is provided by forests or shrubland. When there is a matrix of good cover with good feeding habitat, deer population densities are typically relatively high. The size of the herd can be reduced through culling, relocation, or anti-fertility treatment, but if the habitat remains similar, deer densities will quickly return to their original levels, partly as the result of density-dependent fertility. Therefore habitat alterations that will limit the population density in certain areas can be considered. These measures may include reducing the amount of edge habitat by having larger patches of cover and feeding habitat or reducing the quality and quantity of the available food.⁽³⁴⁵⁾

Reducing the quality of the available food may be achieved by certain mowing or cutting practices, allowing for natural succession to more mature forests (where applicable) with different grass-herb and shrub vegetation on the forest floor, and reducing or stopping irrigation and the use of fertilizers.⁽³⁴⁶⁾ Reducing the quantity of the available food can be achieved by allowing the natural succession to more mature forests (where applicable) with less grass-herb and shrub vegetation on the forest floor, or making prime feeding habitat unavailable to the deer, e.g., through the use of wildlife fencing.^(346,347)

Reducing the quality of the available food may only limit populations in relatively poor years, and stimulating attractive browse to lure animals away from croplands may only work on a small scale and affect primarily females and has to take into account the relative attractiveness of the foods available in the area^(345,348,349)

Some of the measures discussed above may take a long time to take effect, while other measures may require a change in land use practices. However, these types of measures would reduce the frequency and level of population culling, relocation, and anti-fertility treatment needed to reduce deer population density to an “accepted” level.

Case Studies and Contacts

For information regarding movements of female white-tailed deer in relation to timber harvests in the central Appalachians, contact Tyler Campbell, Warnell School of Forest Resources, University of Georgia, Athens, GA 30602, (706) 542-4280, tcampbell@smokey.forestry.uga.edu.

For information on the effects of food or cover removal on spacing patterns and habitat use in roe deer (*Capreolus capreolus*), contact Sandro Lovari, Section of Behavioral Ecology, Ethnology and Wildlife Management, Department of Environmental Sciences, University of Siena, Via Mattioli 4, 53100, Siena, Italy, lovari@unisi.it.

For information on changes in roe deer population density in response to forest habitat succession, contact Robin Gill, Forest Commission Res. Div., Alice Holt Lodge, Farnham, Surrey GU10 4LH, United Kingdom, robin.gill@forestry.gsi.gov.uk.

Direct Benefits

The relationship between deer population size and DVCs can be highly variable (see earlier discussion). Nonetheless, based on Doerr, and Knapp and others, a certain percentage in population size reduction may result in a similar percentage in DVC reduction.^(52,53) However, reductions in population size of 50 percent or more may be hard to obtain, perhaps capping the potential reduction in DVCs at 50 percent or less.⁽³³⁶⁾ The effectiveness of habitat alteration is less dependent on having a relatively small and closed population compared to population culling, relocation, and/or anti-fertility treatment.

Indirect Benefits

This WVC mitigation approach minimizes damage to agricultural crops and gardens and lawns.

Undesirable Effects

If the habitat is negatively affected on a large scale within a short time period, population control may be required to avoid potential starvation or dispersal in response to the reduction in habitat quality and availability.

Costs

Costs are expected to be highly variable depending on site-specific circumstances. No costs were identified in the literature review.

Guidelines

No guidelines were identified in the literature review.

CHAPTER 8. MITIGATION METHODS THAT SEEK TO PHYSICALLY SEPARATE ANIMALS FROM THE ROADWAY

This broad category of WVC mitigation strategies includes those that attempt to physically separate animals from the roadway. The specific mitigation measures reported on in this chapter, by broad category based on their intent, consist of the following:

- Wildlife fencing.
- Boulders in the right of way.
- Long tunnels and bridges over landscape.
- Wildlife underpasses and overpasses.

WILDLIFE FENCING

Fencing is one of the most commonly applied measures to separate wildlife from motorists.⁽³⁾ Wildlife fences in North America typically consist of 2.0–2.4-m (6.5–8-ft)-high wire mesh fence material (figure 42). Several types of fence material are used, but page wire or cyclone fence material is most common. The Utah Department of Transportation has painted wire mesh dark brown, which effectively camouflages the wire mesh. Wooden or metal fence posts are typically used, and the latter are particularly important when fencing over rock substrates.



Figure 42. Photo. Wildlife fence along Interstate 90 near Bozeman, MT (copyright: Marcel Huijser, WTI).

Woods reported 94–97 percent reduction in ungulate-vehicle collisions along a fenced section of the Trans-Canada Highway.⁽³⁵⁰⁾ Along the same road, Clevenger and others showed that fences were effective in reducing vehicle collisions with ungulates by 80 percent.⁽³⁵¹⁾ Clevenger and others also identified that WVCs were closer to fence ends than expected by chance; however, access points (gaps in the fence) were not hotspots for WVCs along the Trans-Canada Highway in Banff National Park, Alberta.⁽³⁵¹⁾ Dodd and others found that wildlife fencing in combination with underpasses reduced elk-vehicle collisions by 86.8 percent.⁽³⁵²⁾ Reed and others reported an average reduction of 78.5 percent for deer vehicle accidents in Colorado, and Ward reported a reduction of greater than 90 percent for mule deer in Wyoming.^(353,354) In Sweden, fencing reduced moose-vehicle collisions by 80 percent.⁽⁷⁶⁾ Boarman and Sazaki found that new or properly maintained fences significantly reduced mortality for several wildlife species, including the desert tortoise.⁽³⁵⁵⁾ They found 93 percent fewer tortoise carcasses and 88 percent fewer vertebrate carcasses along a fenced section compared to an unfenced section of highway. In British Columbia, exclusion fencing (2.4 m (8 ft) high on both sides) was 97–99 percent effective at reducing accidents with large wildlife.⁽³⁵⁶⁾ In Pennsylvania, Feldhamer and others determined that 2.7-m (8.9-ft)-high fence was more effective than the 2.2-m (7.2-ft)-high fence but that deer permeated both types of fences, and overall DVCs were not reduced.⁽²⁹⁴⁾ They suggested that fencing may be effective if properly maintained to fix holes that people cut into it and to repair gaps that develop under the fence. They also suggest that the size of the openings in the woven wire mesh be decreased.

The effectiveness of electric fencing (ElectroBraid™) in keeping deer off runways at airports was studied by Seamans and VerCauteren, and their results could be applicable to preventing deer from accessing short segments of highway.⁽³⁵⁷⁾ The authors found that fencing as low as 1.3 m (4.3 ft) was sufficient to exclude deer unless deer were pressured across it. Fences were highly effective (90 percent) when turned on and maintained.

In a theoretical study investigating how full fencing (no wildlife crossings) with the intent of keeping wildlife off of roadways and reducing wildlife mortality might affect the long-term viability of animal populations, Jaeger and Fahrig modeled population responses to a range of scenarios.⁽³⁵⁸⁾ Their models showed that when no fencing was in place, traffic mortality had a stronger effect on population viability than the effect of animals avoiding the road. The authors concluded that fencing could improve viability in populations with high road mortality. They discouraged the use of fencing (without crossing structures) when the population size was stable.

Case Studies and Contacts

For more information about wildlife fencing in combination with wildlife overpasses and wildlife underpasses on the Trans-Canada Highway in Banff National Park, Canada, contact Anthony Clevenger, Western Transportation Institute, Montana State University, P.O. Box 174250, Bozeman, MT 59717-4250, (403) 609-2127, Tony.Clevenger@pc.gc.ca.

For more information about wildlife fencing and underpasses along State Route 260 in Arizona, contact Norris Dodd, Wildlife Research Biologist, Arizona Game and Fish Department, Research Branch, P.O. Box 2326, Pinetop, AZ 85935, (928) 368-5675, doddbenda@cybertails.com.

For information about wildlife fencing along U.S. Highway 93, Flathead Indian Reservation, Montana, contact Pat Basting, Montana Department of Transportation, (406) 523-5872, pbasting@mt.gov.

For an evaluation of ElectroBraid™ fencing, contact Thomas Seamans; Wildlife Service, USDA, National Wildlife Resource Center, Ohio Field Station, Sandusky, OH 44870, thomas.w.seamans@usda.gov.

Direct Benefits

Depending on the species concerned, the type of fencing, and whether safe crossing opportunities are provided, wildlife fencing may reduce the number of WVCs 80–99 percent. It is important to note, however, that these reductions were obtained where wildlife fencing was used in combination with wildlife overpasses and/or wildlife underpasses. If safe crossing opportunities are not provided for, or if they are too few, too small or too far apart, animals are more likely to break through the wildlife fence, reducing the effectiveness of the wildlife fencing.

Indirect Benefits

Wildlife fences help keep pedestrians away from the travel lanes with fast-moving traffic.

Undesirable Effects

Wildlife fences, when installed correctly, form a nearly impermeable barrier to large mammals. While this can nearly eliminate collisions with large mammals or at least reduce the number of collisions substantially, wildlife fences result in several unintended side effects, for example:

- Animal movements across the road are blocked or nearly completely blocked, which increases the barrier effect of the road, disrupting daily, seasonal, and dispersal movements and potentially reducing the population survival probability of the species concerned. The species affected may include species that are not a safety threat or that may not have a population in the immediate vicinity of the transportation corridor. Therefore, absolute barriers, such as wildlife fencing, should always be accompanied with safe crossing opportunities.
- Animals are more likely to break through the wildlife fencing if safe crossing opportunities are not provided or if they are too few, too small, or too far apart. Even if safe crossing opportunities have been provided for, animals may still end up in between the fences, caught in the transportation corridor, and these animals may pose a safety risk and expose the species concerned to road mortality after all. Animals may end up in between the fences around fence ends, digging under the fence (coyotes slipped beneath the fence along the Trans-Canada Highway in Banff National Park), through gaps in the fence, or they may be able to climb the fence. Therefore, absolute barriers, such as wildlife fencing, should always be accompanied with escape opportunities for animals that end up in between the fences.
- Animals can and do cross the road where fences end. In some cases it can result in a concentration of AVCs at fence ends (Norris Dodd, Arizona Game and Fish Department, personal communication).⁽³⁵¹⁾ Therefore, consideration should be given to measures that mitigate a potential concentration of WVCs at fence ends.
- Wildlife fencing can have a negative impact on landscape aesthetics; many people perceive tall wildlife fences as ugly.
- Wildlife fencing may pose a direct or indirect mortality risk for certain species. Large mammals may get tangled up in the fence, or fences may injure them, potentially resulting in a slow death. In addition, wildlife fences may also be exploited by predators when pursuing prey. After the addition of two lanes on the Trans-Canada Highway and installation of fencing that cut off escape terrain for bighorn sheep, coyotes learned to stampede sheep into the fence. More than 30 sheep were killed this way until a mitigation measure was put in place (discussed later). In addition, wolves, bears, and other predators have also occasionally been seen running prey species into the wildlife fences.⁽³⁵⁹⁾ Finally, birds may collide with fences and die.^(360,361)
- Access roads to the main road require a disruption of the wildlife fencing, resulting in an opening that has to be mitigated in order to avoid animals getting caught inside the fences along the transportation corridor.

- Access for people (hiking, biking, fishing) may be blocked by wildlife fencing.

Wildlife underpasses and overpasses are tunnels and vegetated bridges designed for wildlife to allow them to cross the road. In addition, wildlife jump-outs are usually integrated with wildlife fencing. These features allow animals that do manage to cross the fence to escape from the fenced road and right of way. Other potential solutions for the unintended side effects described above are described in the next section “Addressing Undesirable Effects of Wildlife Fencing.”

Costs

Wildlife fencing (2.4 m (8 ft) high) in Banff National Park, Alberta cost Can\$30 per meter (Can\$9 per ft) (one side of highway) during the phase 3A Trans-Canada Highway expansion in 1997 (Terry McGuire, Parks Canada, personal communication). For the entire 18-km section of highway, fencing both sides cost roughly Can\$1,000,000. ElectroBraid™ fencing used in the study by Seamans and VerCauteren consisted of five-rope strands at 25 cm (9.7 inches) and cost \$9 per meter (\$2.7 per ft).⁽³⁵⁷⁾ 1.2-m (4-ft)-high 5-Braid™ ElectroBraid™ Deer Exclusion Fence is advertised at \$4,300 per km (\$7,000 per mi), while 1.5-m (5-ft)-high, 5-Braid™ ElectroBraid™ Moose Exclusion Fence is advertised at \$4,750 per km (\$7,500 per mi).⁽³⁶²⁾

Sielecki compared the benefits to costs of fencing over different time spans (20–30 years) and given different levels of potential damage prevented. He determined that benefits of the wildlife fencing outweighed potential costs in 12 of 16 cases.⁽³⁵⁶⁾ Fencing in his study ranged from Can\$40,000–80,000 per km.

The cost of wildlife fencing along U.S. Highway 93 on the Flathead Reservation in Montana varied depending on the road section concerned: \$26, \$38, or \$41 per m (\$7.9, \$11.6, or \$12.5 per ft) (Pat Basting, Montana Department of Transportation, personal communication). A finer mesh fence was dug into the soil and attached to the wildlife fence for some fence sections at a cost of \$12 per m (\$6.7 per ft) (Pat Basting, Montana Department of Transportation, personal communication).

Fencing could be impractical in dense vegetation areas, where there is little or no public roadside right of way.

Guidelines

For large mammals and particularly ungulate species, the standard height of wildlife fencing is currently 2.4 m (8 ft). When targeting specific fauna of smaller size, lower fence heights and more customized designs are generally used.^(355,363,364) To keep some climbing species (cougars, bears) from scaling, wildlife fences can be made higher, the mesh size can be made smaller, and outriggers or overhangs can be incorporated into the design.^(365,366) Some testing of these fences has taken place in captive settings, but they have not been objectively tested in the field. Fencing should also be tied to the ground or buried into the ground, depending on the target species and soil characteristics. If properly installed, fence material (wire and posts) should last 20 years or more without integral replacement (Terry McGuire, Parks Canada, personal communication).⁽³⁶⁷⁾ However, regular inspection for gaps and other problems is required.⁽³⁶⁸⁾

Regular fence maintenance is critical in order to keep the fence functioning properly. Earth slumping on hill slopes, inadequate installation techniques resulting in gaps between ground and fence bottom, and breaches of the fence by the public (e.g., hunters, snowmobile operators) allow animals to gain entry to the right of way. Fence maintenance is a major concern because priorities and budgets change over time. Fence maintenance is usually neglected shortly after construction; meanwhile fence damage and gaps are a recurrent problem.

ADDRESSING UNDESIRABLE EFFECTS OF WILDLIFE FENCING

Absolute barriers such as wildlife fences increase the barrier effects of a road, disrupting daily, seasonal, and dispersal movements and potentially reducing the population survival probability of the species concerned. The species affected may include species that are not a safety threat or that may not even have a population in the immediate vicinity of the transportation corridor. Therefore absolute barriers, such as wildlife fencing, should always be accompanied by safe crossing or escape opportunities for wildlife. The specific mitigation measures reported on in this section, by broad category based on their intent, consist of the following:

- Create gaps in fencing.
- Install wildlife underpasses and overpasses.
- Provide escape opportunities for wildlife stuck in the right of way using:
 - Jump-outs or escape ramps.
 - One-way gates.
- Mitigate WVCs at fence ends using:
 - Boulders between fence and roadway.
 - Animal detection systems.
- Improve landscape aesthetics of wildlife fencing.
- Reduce wildlife mortality risk of fencing.
- Mitigate gaps in fencing at access roads using:
 - Gates.
 - Cattle or wildlife guards.

Despite the fact that the primary intention of the various measures described in this section is to mitigate undesirable side effects of absolute barriers, some of the measures can also help further reduce WVCs while others may lead to an increase in WVCs. This is noted in the “direct benefits” and “undesirable effects” sections of the individual measures.

SAFE CROSSING OPPORTUNITIES: GAPS IN FENCE

Gaps in fences on opposite sides of the road allow animals to cross the road. In most cases such gaps are accompanied with wildlife warning signs, crosswalks for wildlife, wildlife warning signs in combination with mandatory or advisory speed limit reductions, or animal detection systems. Along SR 260 near Payson, AZ, a gap in an electric fence has been combined with an animal detection system (David Bryson, Electrobraid Fence Ltd., personal communication; Norris Dodd, Arizona Game and Fish Department, personal communication).

A system of wildlife fences and gaps was installed to reduce vehicle collisions with mule deer (*Odocoileus hemionus*) along a two-lane and divided four-lane highway in northeastern Utah.⁽⁴¹⁾ The gap had warning signs for motorists, and a crosswalk was painted on the road surface as an additional sign for motorists. Road mortality was reduced by 42.3 percent (four-lane highway) and 36.8 percent (two-lane highway) compared to the expected road mortality. However, statistical significance of this reduction could not be demonstrated.

Similar to wildlife fences, median barriers can be an absolute or partial barrier to certain species.⁽³¹⁰⁾ In some cases gaps have been created in the median barrier to allow animals to cross the road. However, the effectiveness of these gaps has largely been untested.⁽³¹⁰⁾

Case Studies and Contacts

For information on gaps in wildlife fencing with warning signs and crosswalk, contact John Bissonette, Utah Cooperative Fish Wildlife Research Unit, Utah State University, Logan, UT, 84322-5290, (435) 797-2511, john.bissonette@usu.edu.

An example of a gap in a wildlife fence accompanied by wildlife warning signs and an advisory speed limit reduction in The Netherlands is shown in figure 43.

An example of a gap in a wildlife fence combined with an animal detection system and accompanying wildlife warning signs and an advisory speed limit reduction in The Netherlands is shown in figure 44.



Figure 43. Photo. Gap in a wildlife fence accompanied by wildlife warning signs and advisory speed limit reduction, The Netherlands (copyright: Marcel Huijser).



Figure 44. Photo. Gap in a wildlife fence combined with an animal detection system, wildlife warning signs, and advisory speed limit reduction, The Netherlands (copyright: Marcel Huijser).

Direct Benefits

Wildlife fences may reduce road mortality by 80–99 percent but may increase the barrier effect of the road. Gaps in the wildlife fence allow animals to cross the road, but since they cross at grade, mortality occurs, reducing the effectiveness of the wildlife fence. Data are not available on the roadkill that occurs at a gap with or without warning signs, but a gap in a wildlife fence that is combined with wildlife warning signs and a crosswalk reduced the effectiveness of the wildlife fence from 80–99 percent to 42.3 percent (four-lane highway) and 36.8 percent (two-lane highway).⁽⁴¹⁾ Animal detection systems have been used at gaps in wildlife fences, but there are no data on the effectiveness of this measure in combination with a gap in a fence. As a standalone mitigation measure, however, animal detection systems may reduce collisions with ungulates by 82 percent on average.⁽¹⁹⁷⁾

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

At gaps in fences, animals cross the road at grade, exposing the drivers and wildlife to potential collisions. This may reduce the effectiveness of the wildlife fence, but this depends on what type of warning signals are presented to drivers at the gap in the fence. No data have been located about the risk of gaps that have static warning signs, but the available data for animal detection systems suggest that a gap with an animal detection system may reduce the effectiveness of the wildlife fencing from 87 percent (on average) to 82 percent. In addition, once through a gap, animals may wander along the road or in the right of way, becoming trapped in between the wildlife fences, exposing the drivers and wildlife to other potential collisions. Measures that allow animals to escape from the road and right of way should be implemented (see further information later in this section).

Costs

The costs of crosswalks across a two-lane road and a four-lane road (excluding wildlife fencing and escape from right of way measures) were reported at \$15,000 and \$28,000, respectively.⁽⁴¹⁾

The estimated cost of animal detection systems at a gap in the fence is \$50,000 (including installation and fence).⁽¹⁹⁷⁾

Guidelines

See Lehnert and Bissonette for guidelines.⁽⁴¹⁾

SAFE CROSSING OPPORTUNITIES: WILDLIFE UNDERPASSES AND OVERPASSES

Wildlife underpasses and overpasses are used extensively by a wide array of species to get from one side of the road to the other side (figure 45 through figure 47). (See references 294, 368, 369, and 370.) The performance of these structures in reducing WVCs and creating crossing opportunities is linked to associated wildlife fencing that keeps animals off the road and funnels

them toward the wildlife overpasses and underpasses.⁽³⁶⁸⁾ In some cases wildlife fencing is only installed over relatively short distances funneling wildlife towards a crossing structure.⁽³⁷¹⁾ The use of wildlife fencing was found to increase the use of underpasses by elk (*Cervus elaphus*) and increase the permeability of a road substantially.⁽³⁵²⁾ In other cases wildlife underpasses and overpasses have no or very limited wildlife fencing, making them the primary measure to reduce WVCs on short road sections.

The location, type, and dimensions of wildlife crossing structures must be carefully planned with regard to the species and surrounding landscape. For example, grizzly bears, deer and elk tend to use wildlife overpasses to a greater extent than wildlife underpasses, while black bears and mountain lions use underpasses more frequently than overpasses.⁽³⁶⁸⁾ In addition, different species use different habitats, influencing their movements and where they want to cross the road. Other factors that should be considered are the vegetation in the direct vicinity of the crossing structure (cover), co-use by humans, and the time it takes for animals to learn the location of the structures and to learn that they are safe to use.

In North America, wildlife overpasses are far less common than in Europe. Therefore there are few experiences with tunnels and wildlife overpasses, as only six of the latter are found in North America and only two in Banff have been studied with regard to their effectiveness in terms of reducing road mortality and allowing for safe crossing opportunities.

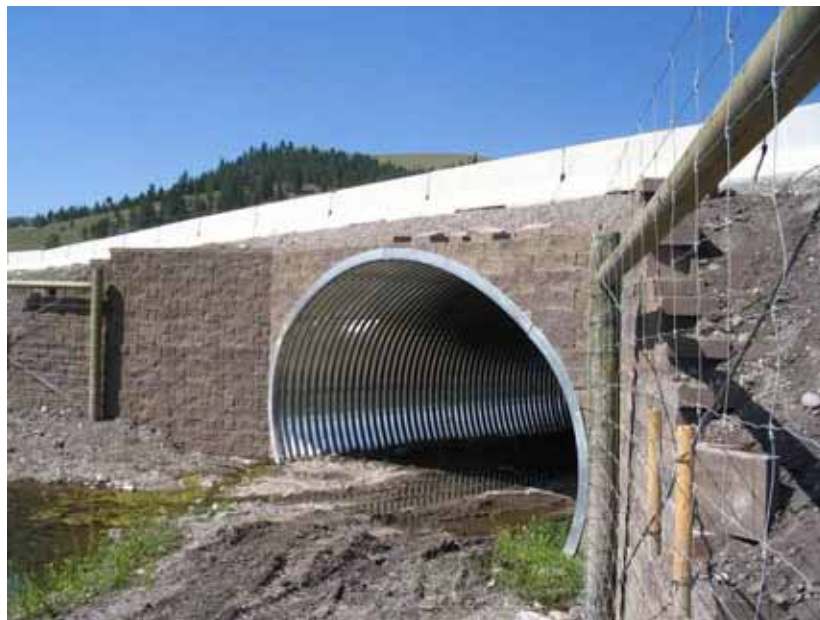


Figure 45. Photo. Wildlife underpass along U.S. Highway 93 on the Flathead Indian Reservation, MT (copyright: Marcel Huijser, WTI).

The use of wildlife underpasses and overpasses depends on many parameters, including their location in the landscape, their dimensions, the habitat surrounding the structures, human co-use,

and the time since installation (learning curve for the animals).⁽³⁶⁸⁾ Furthermore, different species have different preferences.



Figure 46. Photo. Wildlife overpass in Banff National Park, Alberta, Canada (copyright: Marcel Huijser).



Figure 47. Photo. Underpass in southern Florida that allows for ecosystem processes (hydrology) as well as wildlife use, including the Florida panther (copyright: Marcel Huijser).

Case Studies and Contacts

For information on crossing structures in Banff National Park, contact Tony Clevenger, Western Transportation Institute, (403) 609-2127, tony.clevenger@pc.gc.ca.

For information on Florida crossing structures, contact Melissa Foster, University of Florida, Gainesville, FL.

For more information on wildlife underpasses and one wildlife overpass along U.S. Highway 93 on the Flathead Indian Reservation in Montana and on one wildlife overpass across Montana Highway 83 near Salmon Lake (in planning, under construction and completed), contact Pat Basting, Montana Department of Transportation, (406) 523-5872, pbasting@mt.gov.

For more information about wildlife fencing and underpasses along State Route 260 in Arizona, contact Norris Dodd, Wildlife Research Biologist, Arizona Game and Fish Department, Research Branch, P.O. Box 2326, Pinetop, AZ 85935, (928) 368-5675, doddbenda@cybertails.com.

Direct Benefits

Wildlife overpasses and underpasses increase the effectiveness of wildlife fencing or other barriers alongside the road in reducing WVCs. If no safe crossing structures are provided, animals are more likely to break through the wildlife fencing (or other barrier) and thereby reduce the effectiveness of the wildlife fencing.

Indirect Benefits

Wildlife overpasses and underpasses provide crossing opportunities for wildlife, which are needed to mitigate habitat fragmentation effects of roads and maintain viable populations over the long term.

Undesirable Effects

If overpasses are not designed properly, wildlife that are reluctant to use the structure may try to breach the fence and cross the highway.

Costs

Costs vary widely depending on dimensions of underpass structures. Some estimated costs for different underpass structures are box culverts (3.0 m (9.8 ft) high by 2.5 m (8.2 ft) wide) = \$Can2,800 per m (\$854 per ft) length, elliptical culverts (4 m (13 ft) high by 7 m (23 ft) wide) = \$Can5,400 per m (\$Can1,646 per ft) length, open span bridge underpass (13 m (43 ft) wide by 5 m (16 ft) high) = \$Can55,000 per m length (Terry McGuire, Parks Canada, unpublished data).

In The Netherlands, large underpasses (7–10 m (23–33 ft) wide) are estimated to cost €30,000–50,000 per m.⁽³⁷²⁾

Tunneling and overpass structures can cost approximately \$Can33,650 per m (\$Can10,259 per ft) for a 50-m (164-ft)-wide overpass to \$Can119,300 for a 27-m (88-ft)-wide and 200-m

(656-ft)-long tunnel (Terry McGuire, Parks Canada, unpublished data). Actual overpasses were estimated at Can\$1,750,000 (Anthony P. Clevenger, Western Transportation Institute, Montana State University, personal communication).

A proposed overpass across Montana Highway 83 near Salmon Lake (two-lane road) is estimated to cost \$1,500,000–2,400,000.

The costs for seven wildlife overpasses in The Netherlands ranged between €1,400,000 and €5,600,000.⁽³⁷²⁾

Guidelines

Recommended minimum dimensions for underpasses and overpasses have been suggested for some ungulate species, but the needs of wide-ranging species are vague at best.⁽¹⁶⁶⁾ The most comprehensive guidelines for designing wildlife crossing structures, including most below-grade crossing structures, can be found in Iuell.⁽³⁷³⁾ This European handbook draws from the wealth of European experience building a variety of wildlife crossings. Guidelines for different wildlife taxa in Europe and North America can be found in Iuell, Foster and Humphrey, Clevenger and Waltho, Clevenger and Waltho, and Kruidering and others. (See references 166, 372, 373, 374, and 375.) The last publication includes cost estimates for a range of types of crossing structures. Guidelines for wildlife crossings are being developed from NCHRP 25 to 27 and will be available in 2008.

If large species are involved that are sensitive to human disturbance, or if multiple habitats have to be provided for on an overpass, wildlife overpass structures are generally recommended to be at least 50–70 m (164–230 ft) wide. Further rationale for this width is provided by Pfister and others, who showed that the increase in use of wildlife overpasses increases linearly until a width of about 50 m (164 ft) at which point the increase in wildlife use starts to taper off.⁽³⁷⁶⁾

ESCAPE OPPORTUNITIES FROM RIGHT OF WAY

Animals may end up in between fences or other barriers placed along the transportation corridor, posing a safety risk and exposing the species concerned to road mortality. Therefore, absolute barriers, such as wildlife fencing, should always be accompanied with escape opportunities for animals that have ended up in between the fences. (See references 82, 294, 370, and 377.)

ESCAPE OPPORTUNITIES FROM RIGHT OF WAY: JUMP-OUTS OR ESCAPE RAMPS

Jump-outs or “escape ramps” are sloping mounds of soil placed against a backing material approximately 1.5 m (5 ft) in height and constructed on the right-of-way side of the fence (figure 48). The highway fence (2.4 m (8 ft)) is lowered at the ramp site and forms an integral part of the jump-out that allows deer or other species to jump to the safe side of the fence. The vertical drop off on the back side of escape ramps is designed to preclude deer from gaining access to the right of way from the nonhighway side of the fence. Deer and elk are the most common users of jump-outs along the Trans-Canada Highway in Banff National Park, but moose and bighorn sheep have also used these structures (Bruce Leeson, personal communication).



Figure 48. Photo. Jump-out or escape ramp along U.S. Highway 93 on the Flathead Indian Reservation, MT (copyright: Marcel Huijser, WTI).

Bissonette and Hammer studied the effectiveness of earthen escape ramps (jump-outs) and one-way gates along a fenced section of U.S. 91 and U.S. 40 in northern Utah.⁽⁸²⁾ The 2.4-m (8-ft) fence was not 100 percent effective, due to human vandalism and gaps under the fence, so additional measures were necessary to help get deer off the highway. The authors noted peaks in DVCs in spring and fall, and noted that DVCs declined after installation of jump-outs. Jump-outs were eight to eleven times more effective than one-way gates. The authors calculated that if the ramps offset even 2 percent of deer mortality, they would be considered cost effective within 1 to 2 years. They recommended jump-outs instead of one-way gates and determined that (with fencing) these are effective mitigation measures at removing deer from highway rights of way and minimizing accidents with motorists. Clevenger and others documented use of jump-outs by deer, elk, and coyote on the Trans-Canada Highway.⁽³⁷⁸⁾

Case Studies and Contacts

For information on jump-outs along U.S. Highway 93, Flathead Indian Reservation, Montana, contact Pat Basting, Montana Department of Transportation, (406) 523-5872, pbasting@mt.gov.

For more information on field tests with escape ramps in Utah, contact John Bissonette and Mary Hammer, USGS Utah cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife, College of Natural Resources, Utah State University, Logan, UT 84322-5290, (435) 797-2511, john.bissonette@usu.edu; and hammer@wra-ca.com.

For information on field observations from jump-out use along the Trans-Canada Highway, Canada, contact Tony Clevenger, Western Transportation Institute, Montana State University, P.O. Box 174250, Bozeman, MT 59717-4250, (403) 609-2127, Tony.Clevenger@pc.gc.ca.

Direct Benefits

Using jump-outs or escape ramps along two fenced road sections reduced collisions by 28.6 percent on average.⁽⁸²⁾

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

If the jump-outs are not high enough, animals may jump up and end up in the right of way in between the fences. On the other hand, if jump-outs are too high, animals will not use them to escape from the transportation corridor. Furthermore, jump-outs need to be well away from the travel lanes and recovery zone to avoid cars running into them.

Costs

Reported costs for one jump-out include \$11,000 and \$6,250 (Pat Basting, Montana Department of Transportation, personal communication).⁽⁸²⁾

Guidelines

The wall of a jump-out must be just high enough to discourage wildlife from trying to jump up into the right of way, but not so high that they discourage wildlife from jumping off. This is a delicate balance, and the optimal height of the jump-out is likely to be influenced by the species that is expected to breach the fence most often and the nature of the terrain surrounding the jump-outs (e.g., up slope or down slope). To prevent injury to the animals that jump out, the landing spot at the bottom of the jump-out should consist of loose soil or other soft material (Bruce Leeson, personal communication). Where bears are present, the walls must be smooth to prevent them from climbing into the right of way (Bruce Leeson, personal communication). Furthermore, it is thought to be best for jump-outs to be positioned in a set-back in the fence, in an area protected with tree cover, where animals may calm down and have time to decide whether to jump off the jump-out (Bruce Leeson, personal communication). A short fence on the jump-out itself, perpendicular to the road and the right-of-way fence, may also help guide animals to the jump-outs. For additional guidelines see Bissonette and Hammer.⁽⁸²⁾

ESCAPE OPPORTUNITIES FROM RIGHT OF WAY: ONE-WAY GATES

One-way gates allow animals to enter from the road side and go through the fence, providing a possible opportunity for escape from the transportation corridor. Gates (figure 49 and figure 50) have been built for different species, including elk, deer, and the Eurasian badger.^(82,370,372) Reed and others found one-way gates relatively effective for deer, whereas Lehnert found that only 17 percent of the deer that approached the gates ended up using them.^(377,379) In general one-way

gates are no longer recommended as wildlife can learn how to use them to get into the right of way, sometimes aided by hikers, fisherman, equestrians, and bikers who propped and tied the gates open (Bruce Leeson, personal communication).⁽³⁶⁸⁾ In Banff National Park, Canada, an elk herd not only learned how to go through the gate the “wrong way,” but they also destroyed the gate within a week after they learned how to enter the gate from the wrong side (Bruce Leeson, personal communication). In the same area, coyotes learned to crawl through the tines to feed on mice that became more abundant in the right of way now that it was no longer grazed by ungulates (Bruce Leeson, personal communication). At another location, at least one elk has been observed taking a gate “out” as the gate was too small for its body size (Monique DiGiorgio, Southern Rockies Ecosystem Project, personal communication), and at least one moose has been observed getting stuck with its antlers and damaging its velvet (Rick Sinnott, Alaska Fish and Game, personal communication). Finally, jump-outs appear more effective than one-way gates in allowing ungulates to escape from the right of way.⁽⁸²⁾

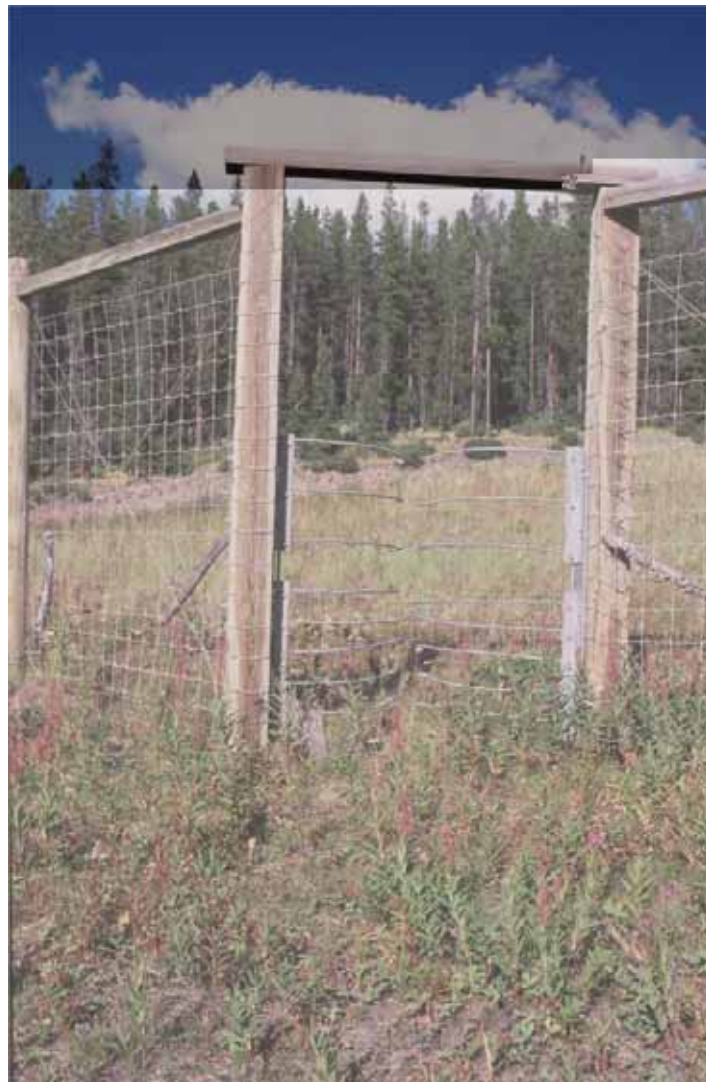


Figure 49. Photo. One-way elk gate in British Columbia, Canada (copyright: Marcel Huijser).



Figure 50. Photo. One-way Eurasian badger gate, The Netherlands (copyright: Marcel Huijser).

Case Studies and Contacts

For more information on one-way gates for deer in Utah, contact John A. Bissonette, Utah Cooperative Fish Wildlife Research Unit, Utah State University, Logan, UT, 84322-5290, (435) 797-2511, john.bissonette@usu.edu.⁽⁸²⁾

Direct Benefits

No direct benefits were identified in the literature review.

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

There are undocumented reports that animals tried to back up in elk gates, got stuck, wounded themselves, and died.

Costs

Estimated costs were reported at \$8,000 per one-way gate.⁽⁸²⁾

Guidelines

See Bissonette and Hammer for guidelines.⁽⁸²⁾

MITIGATION FOR FENCE ENDS: BOULDERS BETWEEN FENCE AND ROADWAY

To discourage ungulate species from entering the fenced sections of the Trans-Canada Highway in Alberta, Canada, rock impediments or boulder fields were placed at the ends of the fence between the roadway and the fence, as shown in figure 51.⁽³⁷⁸⁾ Boulders roughly the size of bowling balls were laid out uniformly to create a boulder field. The boulders are thought to discourage animals, especially ungulates, from walking on them.

The boulder field at Dead Man's Flats wildlife underpass along the Trans-Canada Highway east of Canmore, Alberta, is 100 m (328 ft) long with the width varying from about 8–20 m (26–66 ft), depending on how close the fence is positioned to the roadway, with the boulders extending right from the edge of pavement up to the fence (Bruce Leeson, personal communication) (figure 51). In addition, a 19-m (62-ft)-wide strip of boulders was placed in the median. The boulders are subangular, quarried rock, ranging in size from 20 to 60 cm (7.8–23.6 inches) (about 75 percent are larger than 30 cm (11.8 inches)). The boulder apron, at a depth of about 40–50 cm (15.7–19.7 inches), is installed on geofabric on subexcavated smoothed ground. The boulders project about 20–30 cm (7.8–11.8 inches) above the local ground surface (Bruce Leeson, personal comment).

Case Studies and Contacts

For information on the use of boulders between the fence and roadway at fence ends along the Trans-Canada Highway in Banff National Park, contact: Bruce Leeson, Bruce F. Leeson Environmental Consulting Co., 10011 5th St. S.E., Calgary, Alberta, Canada T2J 1L4, (403) 271-7235 (desk), (403) 869-8180 (cell), bfleeson@shaw.ca; and Tony Clevenger, Western Transportation Institute, Montana State University, P.O. Box 174250, Bozeman, MT 59717-4250, (403) 609-2127, Tony.Clevenger@pc.gc.ca.

Direct Benefits

Clevenger and others found that the combination of the boulder field and wildlife fencing were effective in reducing WVCs. Six DVCs occurred prior to fencing (and boulder field installation), while only two occurred after fencing.⁽³⁷⁸⁾ The boulders were believed to be an effective deterrent in keeping ungulates from wandering in between the fences.⁽³⁷⁸⁾



Figure 51. Photo. The boulder field at the fence end at Dead Man's Flats along the Trans-Canada Highway east of Canmore, Alberta, Canada (copyright: Bruce Leeson).

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

In areas of regular snowfall, the boulder fields become covered with snow, which allows ungulates to travel across them. There may be some motorist safety issues for some states by having an obstruction (and hazard) within the clear zone. In Alberta these safety issues were addressed by placing a guard rail at the road edge.

Costs

The material and labor for the installation of boulders at the fence end at Dead Man's Flats wildlife underpass along the Trans-Canada Highway east of Canmore, Alberta, was estimated to cost Can\$65,000 (installed in 2005, cost estimate for 2007) (Bruce Leeson, personal communication).

Guidelines

The boulder field begins at the fence end, sits on the margin of the paved edge of the highway, and is approximately 15 m (49 ft) wide. The length of the field starting at the fence ends is approximately 20–25 m (66–82 ft).

MITIGATION FOR FENCE ENDS: ANIMAL DETECTION SYSTEMS

Animals may cross the road where fences end, which can in some cases result in a concentration of AVCs. In Arizona, an experiment is currently being conducted with animal detection systems at fence ends to mitigate a concentration of deer and elk vehicle collisions (Norris Dodd, Arizona Game and Fish Department, personal communication).

Case Studies and Contacts

For information on animal detection systems at fence ends, contact Norris Dodd, Wildlife Research Biologist, Arizona Game and Fish Department, Research Branch, P.O. Box 2326, Pinetop, AZ 85935, (928) 368-5675, doddbenda@cybertails.com.

Direct Benefits

The benefits of using animal vehicle detection systems at fence ends are unknown, but as a standalone mitigation measure, animal detection systems can reduce collisions with large ungulates by 82 percent.⁽¹⁹⁷⁾ The application of animal detection systems at fence ends can be expected to result in a similar reduction in WVCs, but data on effectiveness are relatively scarce and may vary.

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

No undesirable effects were identified in the literature review.

Costs

No cost were identified in the literature review.

Guidelines

See Huijser and others for general design considerations.⁽¹⁹⁷⁾

LANDSCAPE AESTHETICS OF WILDLIFE FENCING

Wildlife fencing can have a negative impact on landscape aesthetics; many people perceive tall wildlife fences as ugly. A potential solution is to replace wildlife fencing with large boulders (see earlier) to discourage ungulates from entering the right of way. However, there are no data on how effective large boulders are at reducing WVCs. Other approaches have been tried or are in the process of being tried to make the fence less visible by installing fences behind trees and painting the fence brown or green so that it blends in better with the background (Terry McGuire, Parks Canada, personal communication).

Case Studies and Contacts

For details on installation of fences behind trees along Trans-Canada Highway, contact Terry McGuire, Parks Canada, terry.mcguire@pc.gc.ca.

For information on future experiments with green instead of metal-colored fencing along the Trans-Canada Highway, contact Terry McGuire, Parks Canada, terry.mcguire@pc.gc.ca.

Direct Benefits

Colored fencing has no known additional impact on WVCs beyond the standard colored wildlife fencing.

Indirect Benefits

Less visible fences have reduced impact on landscape aesthetics.

Undesirable Effects

As fencing becomes less visible, the risk of wildlife colliding with it may increase (see “Reduce Mortality Risk of Wildlife Fencing” below).

Costs

Fencing costs remain similar to standard wildlife fencing (see earlier) (Terry McGuire, Parks Canada, personal communication).

Guidelines

Similar to standard wildlife fencing (see earlier).

REDUCE MORTALITY RISK OF WILDLIFE FENCING

Wildlife fencing may pose a direct or indirect mortality risk for certain species through entangling or wounding animals, or because predators run prey species into the wildlife fence. Parks Canada installed a green “curtain” on the wildlife fence along a section of the Trans-Canada Highway, which enabled the sheep to see the fence and veer away from it (Terry McGuire, Parks Canada, personal communication). Chestnut paling has been used in deer exclusion fences to make them more visible to birds, especially capercaillie (*Tetrao urogallus*).⁽³⁶¹⁾

Case Studies and Contacts

For details on the green curtain on the wildlife fence used to increase visibility for bighorn sheep along the Trans-Canada Highway in Banff National Park, contact Terry McGuire, Parks Canada, terry.mcguire@pc.gc.ca.

For information on chestnut paling used in a deer exclusion fence to increase visibility for birds, especially capercaillie, contact: John Dobson, The Croft, Balmoral, Ballater, Scotland, AB35 5TX, forestry@balmoralestate.co.uk.

Direct Benefits

There is no additional benefit from this alteration that further reduces WVCs as compared to the basic WVC mitigation measure.

Indirect Benefits

Wildlife mortality as a result of the presence of the fence is decreased.

Undesirable Effects

Increased visibility of the fence may negatively impact landscape aesthetics.

Costs

No costs were identified in the literature review.

Guidelines

No guidelines were identified in the literature review.

GAPS CAUSED BY ACCESS ROADS

Access roads to the main road require a disruption of the wildlife fencing, resulting in an opening that has to be mitigated in order to avoid animals getting caught inside the fences along the transportation corridor. The following sections describe potential solutions to this problem.

GAPS CAUSED BY ACCESS ROADS: GATES

Gates can be opened when leaving or accessing the main road. This approach is an inconvenience to drivers, as they have to stop and get in and out of their vehicle. Gates are normally only installed at access roads that have very low traffic volume.

Case Studies and Contacts

For information on gates along U.S. Highway 93, Flathead Indian Reservation, MT, contact: Pat Basting, Montana Department of Transportation, (406) 523-5872, pbasting@mt.gov.

Direct Benefits

The use of gates results in no further reduction in collisions compared to an undisrupted wildlife fence (presuming the gates are closed by users).

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

Gates are an inconvenience to drivers, and they may potentially increase WVCs if they are left open.

Costs

Costs for single- and double-panel gates along U.S. Highway 93 on the Flathead Indian Reservation, MT, were \$300–360 and \$350–550, respectively (Pat Basting, Montana Department of Transportation, personal communication).

Guidelines

No guidelines were identified in the literature review.

GAPS CAUSED BY ACCESS ROADS: CATTLE OR WILDLIFE GUARDS

Cattle or wildlife guards are designed to discourage wildlife, especially ungulates, from walking through a gap in the fence (figure 52). However, standard cattle guards may be easily passable by Florida Key deer and mule deer and dangerous to pedestrians and cyclists, and special designs may be needed (for example, those developed for the Florida Key deer).^(380,381) In some cases, such as along a side road of the Trans-Canada Highway in Banff National Park, Canada, a wildlife guard has also been put under electric current to discourage bears from walking across it. An electrified mat across an access road has also been used to discourage ungulates from using a gap in a fence for an access road to approach a larger road with higher traffic volume and vehicle speeds (David Bryson, Electrobraided Fence Ltd, personal communication).



Figure 52. Photo. Wildlife guard along U.S. Highway 93 on the Flathead Indian Reservation, MT (copyright: Marcel Huijser, WTI).

Case Studies and Contacts

For details on an electrified wildlife guard in Banff National Park, Canada, contact Terry McGuire, Parks Canada, terry.mcguire@pc.gc.ca.

For information on wildlife guards along U.S. Highway 93 on the Flathead Indian Reservation, MT, contact Pat Basting, Montana Department of Transportation, (406) 523-5872, pbasting@mt.gov.

Direct Benefits

Cattle or wildlife guards offer no additional benefits in reducing WVCs compared to uninterrupted wildlife fencing. Depending on the type of cattle or wildlife guard, the guard may be ineffective at discouraging certain species, or it may be only partly effective (e.g., 75–99 percent for Florida Key deer), depending on the type of wildlife guard.⁽³⁸¹⁾ Intrusions result in wildlife ending up on the road or in between the fences along the right of way, posing a threat to traffic safety and putting the animal's life in danger.

Indirect Benefits

Wildlife guards are easy on drivers as they do not require them to stop or get out of their vehicle. In addition, in contrast to a gate, a wildlife guard cannot accidentally be left open.

Undesirable Effects

Depending on the design, cattle or wildlife guards may be dangerous to pedestrians and cyclists and unpleasant to drivers.

As mentioned above, depending on the design and target species, some cattle or wildlife guards may be fully or partially passable to certain wildlife species.

Costs

The reported cost of a specially designed wildlife guard was \$30,000 (Pat Basting, Montana Department of Transportation, personal communication).

Guidelines

See Peterson and others for guidelines.⁽³⁸¹⁾

ACCESS FOR PEOPLE SUCH AS HIKERS, SKIERS, CYCLERS, AND FISHERS

Wildlife fencing presents people with a barrier. In some cases, access has been provided that allows people to cross the wildlife fence, for example to hike, cycle, or fish on the other side of the fence. Angled openings (figure 53) and swing gates, with or without steps to accommodate for deep snow (figure 54), have been implemented to allow access for people. In The Netherlands, gates for people have been installed that have angled doors that allow gravity to automatically close the gate (Marcel P. Huijser, Western Transportation Institute, Montana State University, personal communication).



Figure 53. Photo. Angled opening in fence allowing access for people along U.S. Highway 93, MT (copyright: Marcel Huijser, WTI).



Figure 54. Photo. Swing gate in fence (spring loaded) allowing access for people, along the Trans-Canada Highway in Banff National Park, Alberta, Canada (copyright: Adam Ford, TCH research project/WTI-MSU).

Case Studies and Contacts

For details on an opening in a fence along U.S. Highway 93 (south), contact Pat Basting, Montana Department of Transportation, (406) 523-5872, pbasting@mt.gov.

Direct Benefits

No direct benefits were identified in the literature review.

Indirect Benefits

No indirect benefits were identified in the literature review.

Undesirable Effects

Some access designs (e.g., the opening in a fence along U.S. Highway 93 (south) in Montana), have not been evaluated yet with regard to wildlife potentially using the structure to get into the right of way.

Not all access designs are accessible to handicapped individuals.

Costs

No costs were identified in the literature review.

Guidelines

No guidelines were identified in the literature review.

BOULDERS IN THE RIGHT OF WAY

Large boulders have been placed in the right of way, outside of the clear zone, as an alternative to wildlife fencing. Large boulders are thought to make it hard for animals, especially ungulates, to walk across an area. Boulders have been used for this purpose along State Route 260 in Arizona (Terry Brennan, U.S. Forest Service, personal communication; Norris Dodd, Arizona Game and Fish Department, personal communication) (figure 55 and figure 56). The boulder barrier was not extended through areas with steep slopes, since it was thought that wildlife would not move through these steep areas. However, animals have traveled through these areas. The barrier is thought to be effective with exception of the gaps in the steep areas. (Norris Dodd, Arizona Game and Fish Department, personal communication).



Figure 55. Photo. Large boulders pPlaced in the right of way as a barrier to elk and deer along State Route 260 in Arizona (copyright: Marcel Huijser).



Figure 56. Photo. Large boulders placed in the right of way as a barrier to elk and deer with a view of State Route 260 (under construction) in Arizona (copyright: Marcel Huijser).

Case Studies and Contacts

For information about the use of boulders as an alternative to wildlife fencing along State Route 260 in Arizona, contact Terry Brennan, Tonto National Forest, (602) 225-5375, tbrennan@fs.fed.us; and Norris Dodd, Arizona Game and Fish Department, Pinetop, AZ 85935, (928) 367-5657, doddbenda@cybertrails.com.

Direct Benefits

The large boulders are believed to be an effective alternative to wildlife fencing if all the gaps are eliminated.

Indirect Benefits

In contrast to wildlife fences, large boulders are natural and, depending on the landscape, can address the landscape aesthetics concern associated with wildlife fences.

Undesirable Effects

If boulders are indeed an absolute barrier to ungulates and/or other species groups, safe passage may have to be provided for wildlife at selected locations. See the previous section on wildlife fencing on addressing undesirable effects of wildlife fencing.

Costs

Costs for the Arizona case study were less than \$197 per m (less than \$60 per linear ft) (Norris Dodd, Arizona Game and Fish Department, personal communication).

Guidelines

No guidelines were identified in the literature review.

LONG TUNNELS AND LONG BRIDGES OVER LANDSCAPE

In this section, long tunnels (or landscape bridges) are defined as tunnels that are at least several hundreds of meters long, sometimes many kilometers. They may include “cut and cover” strategies, where a “roof” is constructed over the road rather than a tunnel, leaving the landscape above intact. Long bridges (or elevated road sections) are defined as bridges that are at least several hundreds of meters long, sometimes many kilometers. Long tunnels and bridges are primarily constructed because of the nature of the terrain (e.g., through a mountain, across a floodplain), but in some cases they are constructed to avoid areas that are ecologically very sensitive and where no alternatives are available. If the nature of the terrain permits, animals can move freely over long tunnels or under long bridges, and because the animals are physically separated from traffic, WVCs are eliminated. While long tunnels and long bridges may be among the most effective mitigation measures to reduce roadkill, they are rarely specifically designed to reduce WVCs.

Long tunnels and long bridges should not be confused with wildlife overpasses or wildlife underpasses. Wildlife overpasses and underpasses are typically combined with wildlife fencing, and it is the wildlife fencing that keeps the animals from entering the roadway, whereas the primary function of wildlife overpasses and wildlife underpasses is to mitigate the barrier effect of the wildlife fencing and to provide safe crossing opportunities. Long tunnels and long bridges are not necessarily combined with wildlife fencing. They allow for free animal movements over or under the road, as well as other ecosystem processes, including those related to soil and hydrology (figure 57).



Figure 57. Photo. Long bridge on Arizona State Route 260 constructed in such a way as to minimize the impact to soil and vegetation (copyright: Marcel Huijser).

Case Studies and Contact

At one section of the U.S. 61 reconstruction project in Minnesota, Silver Creek Cliff, a tunnel was constructed. To meet the design standards for the reconstruction, the cliff top needed to be removed (estimated to be a million cubic yards of cut). Environmental and aesthetic concerns led to what was actually a less expensive solution. The Minnesota Department of Transportation was able to use the existing highway as a bypass during tunnel construction, which they would not have been able to do if a typical cut would have been used. This approach resulted in cost savings of earthwork (to remove the cliff top which was estimated to be one million cubic yards (765,000 cubic meters)) and no need for a construction of a bypass (estimated at \$2 million due to the terrain restrictions). Additionally, this alternative was a much more environmentally friendly and aesthetically pleasing. The tunnel was constructed using the new Australian Tunneling Method (Scott Bradley, Minnesota Department of Transportation, personal communication). For further information, contact Scott Bradley, FASLA, Chief Landscape Architecture, MNDOT, (651) 284 3758, scott.bradley@dot.state.mn.us.

When State Route 40 in Florida was constructed, a long bridge over dry land was built in anticipation of a planned canal (figure 58). The canal was never built, but the bridge allows wildlife to pass unharmed underneath.



Figure 58. Photo. Long bridges do not have to be excessively large to provide ample space for wildlife crossings. While not exceedingly long, this bridge provides plentiful space for both the stream and wildlife to cross.

There are numerous other examples of long bridges and tunnels. A cut and cover option was used for a long tunnel in the United Kingdom (A12 Hackney to M11 link). A long bridge was constructed on roadway A9, over an important wetland surrounding the Mino River near Galicia, Spain. Interstate 70 in Glenwood Canyon, CO, has several sections that are elevated viaducts.

Direct Benefits

No data are available, but since there is a physical separation of the vehicles and animals, WVCs should be reduced by 100 percent or close to 100 percent.

Indirect Benefits

Long tunnels and long bridges allow for connectivity at the landscape level for a wide array of species. In multifunctional and agricultural landscapes, they also allow for humans, forest products, crops and livestock to freely move from one side of the road to the other.

Undesirable Effects

No undesirable effects were identified in the literature review.

Costs

A 200-m (660-ft)-long tunnel was constructed for Can\$24,000,000. A 200-m (660-ft)-long elevated roadway (long bridge) cost Can\$12,500,000 (Anthony P. Clevenger, Western Transportation Institute, Montana State University, personal communication).

Guidelines

No guidelines were identified in the literature review.

WILDLIFE UNDERPASSES AND OVERPASSES

Wildlife underpasses and overpasses are not always installed in combination with wildlife fencing (see earlier section on wildlife fencing in this chapter).⁽³⁸²⁾ In some cases, the landscape in the surroundings of the crossing structures may guide the animals to the crossing structures, reducing the need for wildlife fencing. In other cases, wildlife fencing may not be an option, for example because of landscape aesthetics. For a discussion on wildlife underpasses and overpasses see the earlier section on addressing the undesirable effects of wildlife fencing in this chapter.

CHAPTER 9. PLANNING AND DESIGN CONSIDERATIONS

Many of the WVC mitigation measures discussed in this paper focus on spot or corridor solutions where WVCs are already a problem on existing roadways. However, integration of transportation planning and wildlife management on a regional level can impact WVCs. Typically these planning efforts are focused on mitigating environmental impacts. The context-sensitive design and context-sensitive solution (CSD/CSS) process may be a way to incorporate consideration of WVCs in planning and design. This section discusses selected planning efforts that can have an impact on reducing WVCs, including the following:

- Identifying and prioritizing WVC problem areas.
- Improved data collection and monitoring.
- Adjusting the road alignment by:
 - Considering the no-build option.
 - Considering alternative alignments.
 - Road removal.
- Consideration of design features of roadways.

IDENTIFYING AND PRIORITIZING WVC PROBLEM AREAS

WVC “hot spots” can be identified with crash and carcass data. To develop an understanding of the root causes of WVCs, one must also consider a context broader than simply the site of an animal carcass. This approach is multidisciplinary in nature and involves landscape ecology (a discipline that stresses understanding of the interactions of physical and biological phenomena at multiple spatial and temporal scales) and conservation biology (a discipline that integrates biological, social and physical sciences to develop a sound basis for the conservation, management, and restoration of biological resources). These scientific fields of study can lend understanding to the effects of spatial patterns, ecological processes, animal behavior, and related factors. Design of transportation systems and ecological networks (habitat linkage zones or greenways) should be based on such concepts. In turn, this scientific knowledge can be used in coordinated planning at multiple scales (e.g., site, local and regional planning) to address WVCs in broader contexts, thus avoiding such conflicts whenever possible.

In order to focus limited resources, some states have identified and prioritized habitat linkage zones that act as corridors for animals to move between major areas of habitat (e.g., development of Wildlife Habitat Linkage Plans). Again, the primary motivation is to improve habitat connectivity for wildlife and not necessarily to reduce WVCs. However, with proper planning these habitat corridors can focus animal movement to specific locations along the highway, which in turn allows for more focused mitigation of WVCs at those crossing locations.

There are a number of methods for prioritizing habitat linkage zones. One method is to look at existing WVC data to identify hot spots. Although this is a primary input for many prioritization methods, by itself it is not very forward looking, because changes in land use patterns can cause changes in animal movements. Also, there are many other sources of information that can be

used to identify potential future WVC problem areas, such as known locations of threatened and endangered species and known migration corridors.

Ruediger has been involved in a number of regional and statewide wildlife habitat linkage plans.⁽³⁸³⁾ In formulating such plans, he suggests using a variety of data including aerial photos, vegetation maps, topography maps, wildlife habitat and range maps, and roadkill information. Another important source of information is local knowledge, which can be accessed by holding a workshop with appropriate stakeholders. The aforementioned data should be collected and presented on maps for this workshop. Also, a method for selecting prioritized linkage zones should be determined prior to the meeting. It is important to record information about the linkage zones identified (e.g., location, species of concern, local agencies and individuals with special knowledge of the linkage zone, major purpose of the linkage zone, and a prioritization ranking for the linkage zone).

According to Levy, a prioritized linkage zone map was created for Arizona.⁽³⁸⁴⁾ The map was created during Arizona's Missing Linkages Workshop in April 2004. The workshop included representatives from ADOT, FHWA, U.S. Fish and Wildlife Service, Arizona Game and Fish Department, U.S. Department of the Interior's Bureau of Land Management, Tonto National Forest, and Northern Arizona University. This initial map was refined during six ecoregional workshops in November 2004. Geographic Information Systems (GIS) databases were helpful in obtaining some of the data that were used in prioritizing the linkage zones.

The University of Alaska Anchorage produced a "toolbox" for the Alaska Department of Transportation and Public Facilities to assess how Alaskan roads affect habitat quality and connectivity.⁽³⁸⁵⁾ The project specifically addressed the use of GIS to assist transportation planners with project development. Based on workshops, GIS data sets, and relevant literature, the effort identified high-priority areas for habitat linkage based on four criteria:

- Places where good data exist on habitat features and that represent the diversity of ecosystems.
- Riparian corridors.
- Places where funding can be leveraged.
- Places that can provide a source of baseline data.

The Florida Department of Transportation has created a program to identify and prioritize habitat linkage zones that intersect with highways.⁽³⁸⁶⁾ The purpose of this program is to consider underpasses or culverts on a statewide level in order to restore habitat connectivity and ecological processes. This method uses a rule-based GIS model to assimilate multiple factors such as roadkill hot spots, riparian areas, greenways, protected conservation lands, and known wildlife movement routes.

The Idaho Transportation Department identified wildlife connectivity areas using an approach that integrated GIS spatial data, GIS linkage model analysis, and expert workshops to identify areas of interest for mitigation consideration in the southeast corner of the state.⁽³⁸⁷⁾ A number of

models predict optimal crossing locations for specific species such as Key deer in Big Pine Key, FL, and grizzly bear in the area around Evaro Hill, MT.^(388,389)

Once habitat linkage zones are identified and prioritized, efforts need to be made to preserve them. A crossing structure can be constructed in a high WVC zone only to have development adjacent to the highway block animal movement so the animals cross at another location along the highway.

This type of effort is inherently multi-agency in nature and should involve local land grants, cities, counties, special interest groups, land owners, resource agencies, rail lines, and State DOTs. A team is attempting to follow this process for Interstate 90 on Bozeman Pass in Montana. The team includes Gallatin Valley Land Trust, Forest Service, Montana Department of Transportation, Montana Rail Link, American Wildlands, and others. This location is clearly a habitat corridor as two areas of the Gallatin National Forest are separated by a corridor that includes private land under heavy development, an interstate, and a rail line. Any effort to preserve the corridor by a single agency would be ineffective, because increased interstate traffic and increased development each threaten to block animal movement. However, by prioritizing specific crossing locations, land trusts can focus efforts to preserve adjacent lands, and the Montana Department of Transportation can optimize its investment in mitigation measures on the interstate.

The effort must go beyond prioritizing greenways to incorporation of linkage zones into transportation and conservation planning elements (of comprehensive plans) that are developed at both local and state levels of government. At a minimum, the statewide transportation improvement program should be reviewed annually for reconstruction projects that cross these habitat linkage zones. Incorporating WVC mitigations into a reconstruction project (especially at the initial project planning stage) will be much less expensive than installing them as separate projects.

Case Studies and Contacts

For information on efforts in Arizona, contact Steve Thomas, Environmental Program Manager, FHWA Arizona Division, steve.thomas@fhwa.dot.gov.

For information on Florida's prioritization efforts, contact Dan Smith, Western Transportation Institute, (406) 994-6114, dan.smith@coe.montana.edu.

For general methodologies for prioritizing habitat linkage zones, contact Bill Ruediger, Wildlife Consulting Resources, (contracted by USDA Forest Service, Wildlife, Fish and Watershed Unit, Washington Office) bruediger@fs.fed.us.

For information on the Bozeman Pass collaboration in Montana, contact Deborah Wambach, Montana Department of Transportation, (406) 444-0461, dwambach@mt.gov; or Josh Burnim, American Wildlands, (406) 586-8175, jburnim@wildlands.org.

For general information on the planning process, consult chapter 6 in National Research Council, chapter 3 in NCHRP Synthesis 305 by Evink, chapters 6 and 7 in Moore and Thorsnes, and the

following Web sites: FHWA, www.fhwa.dot.gov/planning/, and American Planning Association, www.planning.org.^(86,302,390)

DATA COLLECTION AND MONITORING

Like prioritizing habitat linkage zones (discussed in the previous section), data collection and monitoring will not have direct benefits in reductions of WVCs, but without good data on the magnitude, location, and type of WVCs, all other mitigations discussed in this report cannot be installed at the locations where they will have the most impact. WVC data are crucial in justifying and prioritizing locations for mitigation. Additionally, in order to utilize the most effective mitigations for WVCs, the effectiveness of currently installed measures must be evaluated.

As discussed in the chapter on Causes and Factors, there are three primary sources of WVC data: insurance data (which are not spatially located), crash reports, and animal carcass counts. The NCHRP Project 20-05–Topic 37-12 provides a current state of the practice on WVC data collection. The report for this project is currently in draft form.⁽³¹⁾ A survey conducted as part of this report asked states if they collected WVC data (crashes or carcasses). Of the 30 State transportation departments that responded to the survey, 19 collected crash data on WVCs, 13 collected carcass data, and 8 collected neither. It should be noted that although the states reported that they did not collect WVC data, a review of crash reports shows that every state except one has “animal” as a check box on the crash form. Of the 30 responding state departments of natural resources, 9 said they collected crash data, 15 said they collected carcass data, and 12 said they collected neither. There is also a dramatic drop in data collection on local and collector roads compared to interstates and arterials. Many states discussed problems with the data, including inconsistencies, location accuracy, and underreporting.

There are currently efforts underway to improve WVC data. For collecting carcass data, the Maryland Department of Transportation has a program Large Animal Accident Removal Reporting System (LARRS) that is implemented from the top down so that there is a consistent standard within the department. This program is integrated with an existing form for maintenance tasks that maintenance workers are required to fill out regardless of carcass data collection. Since maintenance workers are required to fill out the form anyway, they are more likely to accurately complete the required form (as opposed to adding another form exclusively for carcass data). To assist with data collection of carcasses, GPS-enabled handheld computers (personal digital assistants) have been developed, mostly as prototypes. One such system is the Roadkill Observation Collection System (ROCS) currently under development by the Western Transportation Institute. Another potential source of data is the use of volunteers.

Case Studies and Contacts

For information on the Maryland LARRS carcass data collection method, contact William Branch, Maryland Department of Transportation, (410) 545-8626, WBranch@sha.state.md.us.

For more information on handheld GPS units for automatically collecting data (ROCS), contact Amanda Hardy, Western Transportation Institute, (406) 994-2322, ahardy@coe.montana.edu.

ALTERNATIVE ALIGNMENT, ROAD REMOVAL, OR NO NEW ROAD

Integration of transportation and conservation planning at multiple scales is essential to addressing WVCs. With this integration, the transportation network can be developed with consideration of ecologically sensitive areas, and some efforts can be made to minimize environmental impacts in locating new roads and possibly closing existing roads. Typically these efforts are aimed at conservation but can have an impact on reducing WVCs.

There are several models that are used to assess the ecological impact of new roadway alignment options on wildlife. Maurer developed one such model for the Pennsylvania Department of Transportation.⁽³⁹¹⁾ A community-based, landscape-level terrestrial decision support system was developed with the objective to maintain the ecological integrity of Pennsylvania ecosystems. This model is founded on seven basic characteristics: comparison, reasonableness, practicality, sensitivity, data, process, and decision making. Variables for Assessing Reasonable Mitigation in New Transportation (VARMINT) include habitat importance, stewardship, patch size and shape, connectivity, proximal land use, relative significance, natural processes, diversity, anthropic use, and intangibles. Each site is assigned scores for each of these criteria. Comparison of scores determines relative ranking.

CSD/CSS processes are used to incorporate community values, aesthetics, and environmental and other priorities into the design process. Using the CSD/CSS process could result in alignments that minimize the impact of WVCs. For more information on the overall CSD/CSS process, refer to the following reports:

- NCHRP 480, *A Guide to Best Practices for Achieving Context Sensitive Solutions*.⁽³⁹²⁾
- *AASHTO Guide for Achieving Flexibility in Highway Design*.⁽³⁹³⁾
- NCHRP Report 69, *Performance Measures for Context Sensitive Solutions: A Guidebook for State DOTs*.⁽³⁹⁴⁾ Note that this report details how to develop a CSD/CSS program and track performance with surveys. Although there is some discussion on developing performance criteria (at the project and programmatic level), specific measures are not discussed as the title may imply.

In 2003, the California Department of Transportation closed a functional but little-used highway interchange (e.g., on ramps, off ramps and underpass) on State Route 91 called the Coal Canyon Interchange. The mainline is eight lanes with 200,000 vehicles per day, but the interchange was used by fewer than 150 motorists per day. The main motivation for the closure was connecting habitat between Chino Hills and Cleveland National Forest. However, WVCs were another consideration due to mountain lion roadkills.⁽³⁹⁵⁾ The underpass (in combination with fencing) now serves as a critical connection in a wildlife migration route.⁽³⁹⁵⁾

Closing the Coal Canyon Interchange was seen by one city as a loss of tax revenue since it limited development on one side of the highway. There will likely be heavy opposition to such closures by some landowners based on concerns regarding reduced property values and ability to develop property. Obviously, significant resources went into the original construction and maintenance of the roadway and removing a roadway essentially wastes that initial investment in

infrastructure. A better option is to more strategically plan the transportation network (e.g., do not build the road in the first place). However, in some cases it may be feasible to remove a roadway given the right mix of limited development, public grass roots support, and preservation of surrounding habitat.

The Coal Canyon project cost \$440,000 to remove the roadway underpass, remove the on/off ramps, provide a median turnaround for emergency vehicles, and provide fencing to guide animals to the underpass. Note that \$40,000,000 was used to purchase the surrounding land to protect the habitat.

Most other examples of removing roadways in the United States involve gravel roads on public lands (e.g., forest service roads). As Switalski and others point out, the impact to wildlife has not been monitored or researched.⁽³⁹⁶⁾ Switalski and others suggest costs for road removal are as follows:

- Gating the roadway ends and leaving the road intact: \$1,000–2,800.
- Blocking the roadway ends with permanent traffic barriers such as boulders and berms: \$800–1,000.
- Ripping roadbed: \$400–1,200 per km (\$650–1,950 per mi).
- Stream crossing restoration: \$500–150,000 per crossing.
- Full recontour of slopes: \$3,000–200,000 per km (\$4,850–322,000 per mi).⁽³⁹⁶⁾

Figure 59 shows a road removal in process in Belgium. In this case there was an alternate route, and this roadway was considered unneeded. It was replaced by a nonmotorized multiuse pathway.



Figure 59. Photo. Road removal in progress in Belgium (note that a path for pedestrians and bicyclists remains in place.) (copyright: Bethanie Walder).

Case Studies and Contacts

For further information on the Coal Canyon Interchange removal, contact California Department of Transportation, District 12, (949) 724-2000.

Although primarily focused on roads on public lands, a good source of information on road removal is the Wildlands Center for Preventing Roads, <http://www.wildlandscpr.org/> (accessed January 25, 2007).

CONSIDERATION OF DESIGN FEATURES

Consideration of some basic WVC mitigation principles in designing various elements of a highway could minimize the potential for WVCs. Some of these items have been discussed in the previous chapters but could be implemented as part of the initial design and thus are mentioned here. The following items should be considered when designing roadways that have a high likelihood for WVCs (see chapter 2), such as two-lane, rural/suburban, low-/medium-volume highways that pass through wildlife habitat:

- Steep side slopes can hide approaching animals from the driver's view. The AASHTO Green Book recommends slopes of one foot vertical to four feet horizontal or flatter.⁽¹⁾ It further recommends that slope transitions should be gently rounded. This slope is clearly visible (whether cut or fill) by the driver. Designers should use steeper fill slopes with caution, as drivers may not be able to see deer approaching the roadway until the animal

leaps over the guardrail. If a steeper side slope is used, consider a landing on the top for animals to be visible to drivers (and visa versa) before jumping over the guardrail.

- At locations where the roadway crosses drainages, known migration corridors, or known animal habitat, the designer should take extra caution to make animals visible to drivers. At these locations avoid curves, steep side slopes, and narrow clear zones.
- At locations where culverts or bridges are installed, consider making the culverts and bridges wide enough to include opportunities for animals to cross under the road. This consideration relates especially to terrestrial animals that may require a bank on either side of a stream or river to cross under the road.
- When designing drainage, consider the impact on wildlife movement and attraction. Avoid creating pooled water in the right of way which can create attractive vegetation. Some wildlife will avoid crossing rip-rap. If rip-rap funnels animals to an undesirable crossing location, consider filling gaps in the rip-rap with sand and gravel (which may make it more conducive for animals to cross) or extend the rip-rap to a more suitable crossing location.
- When considering seeding mixes for the roadside, consider unpalatable species. Also consider plants that do not grow so tall as to visually obscure animals approaching the roadway.
- Concrete median barriers can cause problems for wildlife. When crossing the roadway, wildlife may pause at the barrier or turn around, increasing their time in the roadway. A summary of the literature by Clevenger and Kociolek found that “the general hypothesis is that concrete Jersey barriers may increase the risk of direct vehicle mortality [of wildlife].”⁽³¹⁰⁾ Mitigations include gaps in the barrier at strategic hot spot locations, cutouts at the bottom for small animals, or using cable barrier designs instead.
- Aside from the basic principles listed here, the designer should estimate the potential magnitude of the WVC problem when designing a road. If there are areas along the route that have a high potential for WVCs, the designer should consider including some of the mitigations mentioned in this report (e.g., wildlife fencing).

CHAPTER 10. EVALUATION OF MITIGATION METHODS BY TECHNICAL WORKING GROUP

The WTI-Berger Team convened a Technical Working Group Meeting on January 25, 2007, at FHWA Headquarters. The Technical Working Group consisted of a panel of seven national experts in the area of WVCs. The experts were identified and selected by the FHWA Project Committee during the June 30, 2006, kickoff meeting. An effort was made to include representation from academia, State transportation departments, Federal agencies, and nongovernment organizations. The Technical Working Group members are listed in table 9.

Table 9. Technical working group members.

| Name | Organization |
|--------------------|---|
| Bill Branch | Maryland DOT |
| Michael Pawlovich* | Iowa DOT |
| Scott Jackson | U.S. Fish and Wildlife Service |
| Susan Hagood | The Humane Society of the United States |
| Brent Haglund | Sand County Foundation |
| Sandy Jacobson | Forest Service |
| Keith Knapp | Texas Transportation Institute |

*Participated by phone

The Technical Working Group reviewed a draft version of this report and helped identify other sources of information that would be beneficial. Another purpose of this meeting was to have a group of national experts evaluate the effectiveness of the mitigations based on their knowledge. Initially, the Project Committee (FHWA) and the WTI-Berger Team wanted to use the NCHRP 500 categories for safety mitigations. The categories defined in the NCHRP 500 report are:

Tried (T)—Those strategies that have been implemented in a number of locations and may even be accepted as standards or standard approaches but for which valid evaluations have not been found. These strategies, while in frequent or even general use, should be applied with caution, carefully considering the attributes cited in the guide and relating them to the specific conditions for which they are being considered. Implementation can proceed with some degree of assurance that there is not likely to be a negative impact on safety and very likely to be a positive one. As the experiences of implementation of these strategies continues under the AASHTO Strategic Highway Safety Plan initiative, appropriate evaluations will be conducted, so that effective information can be accumulated to provide better estimating power for the user, and the strategy can be upgraded to a “proven” one.⁽³⁹⁷⁾

Experimental (E)—Those strategies that have been suggested and that at least one agency has considered sufficiently promising to try on a small scale in at least one location. These strategies should be considered only after the others have proven not to be appropriate or feasible. Even where considered, their implementation should initially occur using a very controlled and limited pilot study that includes

a properly designed evaluation component. Only after careful testing and evaluations show the strategy to be effective should broader implementation be considered. As the experiences of such pilot tests are accumulated from various state and local agencies, the aggregate experience can be used to further detail the attributes of this type of strategy so that it can be upgraded to a “proven” one.⁽³⁹⁷⁾

Proven (P)—Those strategies that have been used in one or more locations and for which properly designed evaluations have been conducted that show it to be effective. These strategies may be employed with a good degree of confidence, but with the understanding that any application can lead to results that vary significantly from those found in previous evaluations. The attributes of the strategies that are provided will help the user judge which strategy is the most appropriate for the particular situation.⁽³⁹⁷⁾

A properly designed evaluation for the “proven” category has a fairly strict definition in the safety field, including a Bayesian analysis of crash data. (Note: Bayesian analysis evaluates the consistency or inconsistency of new evidence with a given hypothesis.) Bayesian analysis does require the a priori assignment of probabilities to hypotheses, which, depending on the question, may be subjective. As an example, a mitigation that has been proven to keep animals off the road would not be proven if no studies on WVCs with a Bayesian analysis were completed, even though logically these would be known to be effective. The Technical Working Group concluded that under this definition, none of the mitigations would be defined as proven, and almost all of the mitigation measures would be classified in the “tried” category. The Working Group members felt that the strict safety definitions would not do justice to their experience with certain mitigation measures and effectiveness data gathered on them. The meaning of “properly designed evaluation” was left up to the individual members of the Technical Working Group and did not require a Bayesian analysis of crash data. To avoid confusion with the safety definitions, the names of the above three definitions were changed. Also, two categories were added. The new definitions adopted by the Technical Working Group for this evaluation were:

- Successful (similar to “proven” safety definition): Mitigation measures that have been used in one or more locations and for which properly designed evaluations have been conducted that show them to be effective.
- Demonstrated (similar to “tried” safety definition): Mitigation measures that have been implemented in multiple locations and that may even be accepted as standards or standard approaches but for which valid evaluations have not been found.
- Attempted (similar to “experimental” safety definition): Mitigation measures that have been suggested and that at least one agency has considered sufficiently promising to try on a small scale in at least one location. However, data on effectiveness have not been documented or have not yet been published.
- Unknown: Mitigation measures that have not been tried or that have been tried, but not for WVC reduction, were not implemented correctly, or are only recently being tried.

- Failed: Mitigation measures that have been used in one or more locations and for which properly designed evaluations have been conducted and show them NOT to be effective.

The procedure for voting was as follows. The mitigation was described by the WTI-Berger Team. The panel members were asked to base their vote on the effectiveness in reducing DVCs. The vote was not based on mitigation for other effects related to roads and traffic (e.g., barrier effect) or for species other than deer (white-tailed and mule deer combined). Deer are involved with the majority of all reported WVCs (chapter 2). If panel members had been asked to consider multiple species representing very different species groups, the procedure would have had to have been repeated for each species or species group. Limited data are available to evaluate the effectiveness of many of the mitigation measures for species other than deer.

After hearing a description of each individual mitigation measure, the Technical Working Group voted. If the vote was unanimous, the next mitigation was considered. If there was contention, the panel discussed the rationale for their votes, and the members were allowed to change their votes based on new information provided by the other panel members. However, a unanimous vote or consensus was not required.

The results of this process are shown in table 10. The mitigation “reduce speed by posting advisory speed signs” was not included since the Group felt this was very similar to warning signs. The mitigation “carcass removal” was also not included since the Group felt that this mitigated for scavengers only and not for deer. The mitigation “increase visibility of animals to drivers: reduce height of snow banks” was not included because this section was added to the report after the ranking meeting. Most of the mitigations that provide crossing opportunities are not included, since their purpose is to mitigate the barrier effect of fencing and are not mitigations for WVCs by themselves.

Table 10. Technical working group rankings.

| Measure | Votes Received | | | | |
|--|-----------------|-------------------|-----------------|--------------|--------|
| | Suc- cessful | Demon- strated | Attemp- -ted | Un- known | Failed |
| Mitigations that attempt to influence driver behavior | | | | | |
| Public information and education | | 7 | | | |
| Standard wildlife warning signs | | 2 | | | 5 |
| Large, nonstandard wildlife warning signs | 1 | 5 | | | 1 |
| Seasonal wildlife warning signs | | 7 | | | |
| Roadside animal detection systems (RADS) | | 2 | 5 | | |
| In-vehicle (veh.) warnings: RADS to on-board | | | | 7 | |
| In-veh. warning: on-board animal detectors | | | 7 | | |
| Increase visibility: roadway lighting | | 7 | | | |
| Increase visibility: vegetation removal | | 7 | | | |
| Increase visibility: wider road striping | | | | 7 | |
| Reflective collars (buffalo) | | | | 7 | |
| Reduce traffic volume on road network | | | | 7 | |
| Seasonal closure | | | | 7 | |
| Reduce speed by reducing posted speed limit | | 6 | 1 | | |
| Reduce speed by traffic calming | 1 | 5 | 1 | | |
| Wildlife crossing guards | 4* | 3 | | | |
| Mitigations that attempt to influence animal behavior or population size | | | | | |
| Deer reflectors and mirrors | | 6 | | | 1 |
| Audio signals in row or deer whistles | | 1 | | | 6 |
| Olfactory repellants | | 3 | 4 | | |
| Deer flagging models | | | 6 | 1** | |
| Hazing | | 3 | 4 | | |
| Investigate deicing alternatives | | | 7 | | |
| Intercept feeding | | | 7 | | |
| Influence species/nutritional value in ROW | | 7 | | | |
| Expanded median | | | | 7 | |
| Mitigations that seek to reduce wildlife population size | | | | | |
| Wildlife culling | | 7 | | | |
| Wildlife relocation | | 6 | | | 1 |
| Anti-fertility treatment | | 7 | | | |
| Habitat alteration | | | 4 | 3 | |
| Mitigations that attempt to physically separate animals from the roadway | | | | | |
| Wildlife fencing | 4 | 3 | | | |
| Boulders fence | | | 7 | | |
| Long tunnels and long bridges | 7* | | | | |
| Underpasses and overpasses | | 7 | | | |
| Underpasses/overpasses and fencing | 7 | | | | |

*Although this mitigation has not been proven through evaluation procedures, it is intuitive that it definitely works.

**Although this technique has been tried, it was not implemented appropriately.

Note: ROW = right of way.

Although the above table gives good insight into what works and what does not, most of the mitigations fall into the uncertain categories (demonstrated, attempted, or unknown). Also, it does not take into account costs of implementation, feasibility of implementation, and overall effectiveness. As a follow-up, the Technical Working Group was asked (by email) to categorize the same mitigation measures as the following:

- Recommended for implementation.
- Recommended for further research.
- Not recommended for implementation or further research.

The results of this categorization are presented in table 11. Note that, relative to this second categorization effort, there are some mitigations where one or more members of the group did not vote.

Table 11. Technical working group recommendations.

| Measure | Votes Received | | |
|--|----------------|------------------|-----------------|
| | Recommended | Further Research | Not Recommended |
| Mitigations that attempt to influence driver behavior | | | |
| Public information and education | | 7 | |
| Standard wildlife warning signs | | 2 | |
| Large, nonstandard wildlife warning signs | 1 | 5 | |
| Seasonal wildlife warning signs | | 7 | |
| Roadside animal detection systems (RADS) | | 2 | 5 |
| In-vehicle (veh.) warnings: RADS to on-board | | | |
| In-veh. warning: on-board animal detectors | | | 7 |
| Increase visibility: roadway lighting | | 7 | |
| Increase visibility: vegetation removal | | 7 | |
| Increase visibility: wider road striping | | | |
| Reflective collars (buffalo) | | | |
| Reduce traffic volume on road network | | | |
| Seasonal closure | | | |
| Reduce speed by reducing posted speed limit | | 6 | 1 |
| Reduce speed by traffic calming | 1 | 5 | 1 |
| Wildlife crossing guards | 4 | 3 | |
| Mitigations that attempt to influence animal behavior or population size | | | |
| Deer reflectors and mirrors | | 1 | 5 |
| Audio signals in row or deer whistles | | 1 | 6 |
| Olfactory repellants | | 3 | 4 |
| Deer flagging models | | 1 | 6 |
| Hazing | | 2 | 5 |
| Investigate deicing alternatives | 1 | 4 | 2 |
| Intercept feeding | | 2 | 5 |
| Influence species/nutritional value in ROW | | 5 | 1 |
| Expanded median | | 4 | 2 |
| Mitigations that seek to reduce wildlife population size | | | |
| Wildlife culling | 2 | 4 | 1 |
| Wildlife relocation | | 1 | 6 |
| Anti-fertility treatment | | 3 | 4 |
| Habitat alteration | 1 | 3 | 3 |
| Mitigations that attempt to physically separate animals from the roadway | | | |
| Wildlife fencing | 6 | 1 | |
| Boulders fence | 2 | 5 | |
| Long tunnels and long bridges | 2 | 4 | 1 |
| Underpasses and overpasses | 2 | 4 | 1 |
| Underpasses/overpasses and fencing | 4 | 1 | |

Note: ROW = right of way.

Referring to table 11, the panel voted on whether each mitigation measure should or should not be implemented or whether further research should be undertaken. A majority of votes (four or

more) was required to make a positive recommendation for implementation of the mitigation measure. Also, a majority of votes (four or more) for “not recommended” resulted in the rejection of the mitigation measure. Finally, if a majority did not cast votes to recommend implementation, but at least four votes were divided between “recommended” and “further research,” the panel’s recommendation was that further research should be undertaken for that particular mitigation measure.

When interpreting the results, it is important to keep in mind that these opinions only relate to deer and to mitigating DVCs. The opinions do not necessarily relate to other species or mitigating other effects associated with roads and traffic such as habitat loss, reduced habitat quality, and barrier effect (except for direct road mortality). The subsequent outcome of this process is as follows:

- Where feasible and appropriate, the following mitigations should be implemented:
 - Public information and education.
 - Wildlife fencing.
 - Underpasses and overpasses with fencing.
- Research or construction resources should **not** be used for the following mitigations:
 - Standard wildlife warning signs.
 - Deer reflectors and mirrors.
 - Audio signals in the right of way or deer whistles on vehicles.
 - Olfactory repellents.
 - Deer flagging models.
 - Hazing.
 - Intercept feeding.
 - Wildlife relocation in order to reduce population size.
 - Anti-fertility treatment in order to reduce population size.
 - Seasonal road closures.
 - Reflective collars placed on wildlife.

- Mitigations that may be promising, but require further investigation include the following:
 - Reduce traffic volume on road network.
 - Reduce speed by reducing the posted speed limit.
 - Reduce speed by traffic calming or reducing the design speed.
 - Wildlife crossing guards.
 - Large, nonstandard wildlife warning signs.
 - Seasonal wildlife warning signs.
 - Animal detection systems.
 - In-vehicle warnings: roadside animal detection system communicating with on-board computers.
 - In-vehicle warnings: on-board animal detectors.
 - Increase visibility through roadway lighting.
 - Increase visibility through vegetation removal.
 - Investigate deicing alternatives.
 - Influence plant species in the roadside to limit nutritional value.
 - Reduce population size through wildlife culling.
 - Reduce population size through habitat alteration.
 - Boulders forming a barrier.
 - Long tunnels and long bridges.
 - Overpasses and underpasses by themselves.
 - Wider more reflective striping along white line.
 - Expanded median.

CHAPTER 11. GAPS IN CURRENT KNOWLEDGE

This chapter summarizes the challenges that currently prevent a systematic, nationwide approach to WVC reduction.

DATA ISSUES

Generally, the greatest challenge to reducing WVCs is the absence of reliable information and documentation on mitigation measures such as effectiveness, historic use, challenges, etc. This lack of data is characterized by the fact that the Technical Working Group (chapter 10), categorized 20 of the 34 mitigations as “recommended for further research.” There are numerous syntheses (including this one) that summarize potential solutions to WVCs. However, the effectiveness of a number of mitigation measures is still uncertain due to lack of evaluation, inaccurate data collection, and inconsistent measures of effectiveness.

One of the challenges relating to monitoring the effectiveness of WVC mitigations is the lack of reliable standardized and spatially precise data on the location of WVCs and animal carcasses. The national databases, summarized in chapter 2, all have some shortcomings in these regards. Most importantly, location data are not included in the national databases (i.e., GES, FARS, and State Farm Insurance Claims). Most of these datasets suffer from underreporting. Inconsistently collected data make it difficult to accurately characterize WVC issues and properly address them (e.g., identifying the best location to deploy a mitigation measure to address a particular situation). Problems also arise when attempts are made to use such data to evaluate the effectiveness of various mitigation measures after they have been installed. Furthermore, data that have been collected are not always readily available or even analyzed. All of these issues pose major challenges for the current study of WVCs.

ANALYSIS ISSUES

Effectiveness of mitigation measures can be evaluated relative to many different criteria. Each criterion has its own associated characteristics and methods of measurement, which can make evaluation of mitigation measures based on multiple criteria a difficult task. For example, effectiveness can relate to collision reduction (the criteria used in this study) but also to habitat connectivity. These are very different parameters, namely, safety and nature conservation, that are measured in very different ways. Development of sound methodologies to both singly and collectively consider these various criteria in evaluating mitigation measures would be useful.

Relative specifically to safety issues, some crash models exclude WVCs altogether. If AVCs are included in crash models, they tend to focus on road, traffic, and right of way characteristics only, and ecological parameters that extend away from the road are rarely included. Only a limited number of studies have looked at both groups of parameters at the same time.

Relative to specific WVC problem locations, the tendency is to identify such locations using past roadkill data. Given the investment and life span of some of the mitigation measures, it is advisable, however, to project 50–80 years into the future. The potential presence, population viability, and needs of selected wildlife species will likely change in this time period.

NEEDED TOOLS

With respect to specific mitigation technology used, basic research needs to be conducted to understand how existing mitigation measures can be made more effective. There should be a continuous drive to make these measures cheaper, smaller, more robust, and as mobile as possible to address costs, landscape aesthetics, safety concerns, operation and maintenance efforts, and a highly dynamic environment.

Modeling should be further developed and applied to assist in the optimization of the location, type, and dimensions of mitigation measures. Basic data collection is required to obtain inputs for these models. Existing long-term monitoring studies may need to be supplemented with studies that address specific questions that may not have been addressed yet. Once the recommendations based on these models have been implemented, the mitigation measures should be monitored for their effect on population viability parameters to verify that the models simulate the real world environment to an acceptable degree.

Addressing the broader picture, tools and procedures should be developed to measure the effects of roads and traffic on ecosystem processes, how these effects can be minimized, and how the disrupted processes can be restored.

SUMMARY

To summarize, future research should focus on the following:

- Developing and implementing guidelines and standards for collecting and reporting WVCs.
- Developing and implementing guidelines for the evaluation of mitigation measures.
- Evaluating the effectiveness of mitigation measures that have been recommended for further research.
- Conducting research and development to improve existing mitigation measures.
- Developing and applying population viability models that assist with the location, type, and dimensions of mitigation measures.

CHAPTER 12. COST-BENEFIT ANALYSES OF DEER COLLISION REDUCTION MEASURES

This chapter summarizes the costs of the mitigation measures reviewed in this report and their effectiveness in reducing WVCs, specifically DVCs. The information in this chapter should be considered inclusively with the reviews on over 34 mitigation measures from information available in the literature (chapters 5–8) and the rankings of these measures by the Technical Working Group (chapter 10).

The costs are presented (where possible) as cost per kilometer of road length per year. These costs were calculated from the various estimates found in the literature for the cost of each mitigation measure, as reported in the earlier chapters of this report. The potential benefits as a result of reducing DVCs will vary greatly depending on the measure, animal population density, type of roadway, and effectiveness of the measure. For this analysis, researchers used a hypothetical 1 km (0.62 mi) road section of a four-lane road (two lanes in each direction) that had five DVCs per year (see table 12). The benefits of mitigation were simply calculated as the avoided costs associated with the collisions prevented as a result of the mitigation measure. For this analysis, the cost associated with one DVC was estimated at \$8,388 (see chapter 3). The avoided cost with the mitigation in place was then calculated by multiplying the cost of the collisions (five collisions times \$8,388 per collision equals \$41,940) times the effectiveness of the mitigation (expressed in terms of percent reduction in DVC). Effectiveness was estimated from information presented in the literature. Finally, the annual balance (dollar amount saved per kilometer per year) was calculated as benefit minus cost. It is important to note that the costs for these mitigation measures are primarily the responsibility of transportation agencies, while the benefits are mostly for insurance companies. Thus a positive balance between benefits and costs for a given mitigation measure generally indicates that the mitigation measure concerned could be a wise investment for society as a whole, but the costs and benefits are paid for and received by different groups in society.

It should be noted that the costs and benefits in table 12 are based on the literature reviewed. The costs do not necessarily include all costs, such as maintenance, financing, and impact of construction on traffic. Benefits, as discussed in chapter 11, are measured inconsistently in the literature. Costs and benefits can vary widely for different sites and situations (e.g., geographic locations, effectiveness, frequency of WVCs, surrounding terrain). For these reasons, the dollar values presented in this chapter should be viewed as indicative rather than precise estimates.

For some mitigation measures, the costs could not be translated to costs per kilometer per year, and no cost-benefit calculations were conducted. However, this does not necessarily mean that these mitigation measures are not effective in reducing DVCs or that they are not a wise investment. Instead it may only indicate that further research or analysis would be necessary to quantify their costs and benefits.

The calculations presented here do not include inflation indexes, and discounting was not applied. Table 12 provides the best guess about costs, effectiveness, and benefits based on the information currently available. Nonetheless, the calculations only provide an initial insight into the balance between the costs and benefits of different mitigation measures and how the balance

compares between measures. Note that measures for which no cost estimates and no effectiveness estimates were available were excluded from table 12.

The remainder of this chapter discusses the values in table 12 for each mitigation measure for which sufficient data were available to conduct analysis.

Table 12. Summary cost-benefit of mitigation measures for five DVCs per km per yr.

| Mitigation measure | Cost (\$/km/yr) | % DVC Reduction | Benefit (\$/km/yr) | Balance (\$/km/yr) |
|----------------------------------|------------------------|------------------------|---------------------------|---------------------------|
| Standard warning signs | \$18 | 0% | \$0 | -\$18 |
| Enhanced wildlife warning signs | \$249 | ? | ? | ? |
| Seasonal wildlife warning signs | \$27 | 26% | \$10,904 | \$10,878 |
| Animal detection systems (ADS) | \$31,300 | 82% | \$34,391 | \$3,091 |
| ADS linked to on-board computer | ?* | 82% | \$34,391 | ? |
| On-board animal detectors | \$2,225* | ? | ? | ? |
| Vegetation removal | \$500 | 38% | \$15,937 | \$15,437 |
| Deer reflectors and mirrors | \$495 | 0% | \$0 | -\$495 |
| Deer whistles | \$23.5* | 0% | \$0 | ? |
| Carcass removal | \$250* | ? | ? | ? |
| Population culling | \$2,508 | 50% | \$20,970 | \$18,462 |
| Relocation | \$10,260 | 50% | \$20,970 | \$10,710 |
| Anti-fertility treatment | \$61,702 | 50% | \$20,970 | -\$40,732 |
| Fence (including dig barrier) | \$3,760 | 87% | \$36,488 | \$32,728 |
| Boulders in right of way | \$2,461 | ? | ? | ? |
| Long bridges | \$781,250 | 100% | \$41,940 | -\$739,310 |
| Long tunnels or long bridges | \$1,500,000 | 100% | \$41,940 | -\$1,458,060 |
| Fence with gap and warning signs | \$3,772 | 0% | \$0 | -\$3,772 |
| Fence with gap and crosswalk | \$5,585 | 40% | \$16,776 | \$11,191 |
| Fence with gap and ADS | \$9,930 | 82% | \$34,391 | \$24,461 |
| Fence with underpasses | \$5,860 | 87% | \$36,488 | \$30,628 |
| Fence with overpasses | \$26,485 | 87% | \$36,488 | \$10,003 |
| Fence with under- and overpasses | \$7,510 | 87% | \$36,488 | \$28,978 |

Assumes 1 km with 5 DVCs per year.

* Costs not in dollars/km/year, but in a different unit; see text.

? = Unknown or uncertain.

The costs and the potential reductions in WVCs resulting from a reduction in traffic volume, reduction of traffic speed, and the efforts of wildlife crossing assistants are unknown. Therefore these mitigation measures were not included in the analyses.

Standard wildlife warning signs are relatively inexpensive: \$62 for a 76 by 76 cm (30 by 30 inches) sign.⁽¹⁹⁵⁾ The costs per kilometer per year (two signs per km, one sign for each travel direction, assumed life span of 7 years, no maintenance) are \$18, but since standard wildlife warning signs are considered ineffective in reducing WVCs (i.e., \$0 benefit), the final cost for this mitigation measure remains at

\$18 per km (\$30 per mi) per year.⁽¹⁹⁵⁾ The effectiveness of enhanced wildlife warning signs is largely unknown, causing them to be excluded from the analyses. Seasonal wildlife warning signs (two signs per km, one sign for each travel direction, and an assumed life span of 10 years, no maintenance) may result in a 26 percent reduction of DVCs, and could end up saving \$10,878 per km (\$17,517 per mi) per year. However, keep in mind that these types of signs are only applicable in situations where deer (or other large animals) display road crossing behavior that is concentrated in space and time. Animal detection systems (life span 10 years, costs include maintenance) cost more, but because of their effectiveness in reducing WVCs by 82 percent, they still result in a positive balance of \$3,091 per km (\$4977 per mi) per year.

Too little is known about the costs or effectiveness of animal detection systems linked to an on-board computer or on-board animal detectors for these measures to be included in the analyses. Furthermore, the costs and benefits for these mitigation measures depend on the number of vehicles equipped with this technology rather than a standard cost per kilometer of road length per year.

There are insufficient data available to evaluate the cost-benefit relationship for roadway lighting measures and public information and education programs. Vegetation removal, however, demonstrates more potential and may result in a positive balance of \$15,437 per km (\$24,858 per mi) per year.

Assuming that deer reflectors and mirrors (life span 12.5 years, costs include maintenance) are indeed not effective in reducing DVCs, they have a negative balance of \$495 per km (\$797 per mi) per year. The costs for deer whistles are per vehicle rather than per kilometer per year; therefore, this mitigation measure was not included in the analyses. However, this measure is not considered effective. There are insufficient data available to analyze the cost-benefit relationship of audio and visual warning signals in the right of way, olfactory repellents, deer flagging, hazing, reducing or replacing road salt, intercept feeding, influencing the species composition and the nutritional quality of right-of-way vegetation, and carcass removal. Some carcass removal data were available, and costs were expressed in costs per kilometer per year based on the removal of five deer carcasses.

Population culling is cheaper than wildlife relocation or anti-fertility treatment. The costs for these mitigation measures are typically expressed in costs per animal. These costs were translated to dollars per kilometer per year based on the following assumptions and estimates. The width of the zone that the culling, relocation, or anti-fertility treatment would be conducted in was based on the home range of white-tailed deer in a suburban environment (43 to 144 ha (106 to 356 acres)).^(326,398,399) Assuming a home range of 75 ha (185 acres), a deer living within 977 m (3237 ft) (the diameter of the home range), could cross the road. For a 1-km (0.6-mi)-long road section, this zone is 97.7 ha (241 acres) for one road side and 195.4 ha (482 acres) for both road sides. Population densities of (suburban) white-tailed deer that are considered a “problem” have been estimated at 50–91 individuals per km².^(57,400) Assuming a population density of 70 individuals per km², there are 136.8 deer in 195.4 ha. The cost for culling, relocation, and anti-fertility treatment was set at \$110, \$450, and \$1,128 (females only), respectively. Assuming that a population can only be reduced by 50 percent before the culling, relocation or anti-fertility treatment effort becomes much more labor intensive, and the one-time culling and relocation of 68.4 deer costs \$7,524 and \$30,780 (reduction of 68.4 deer), respectively. Suburban white-tailed

deer populations can double their population size every 2–5 years, depending on the circumstances.⁽²⁸⁷⁾ Assuming a closed population (no immigration from adjacent areas), and a doubling of population size every 3 years, the culling and relocation effort would have to be repeated every 3 years, resulting in an annual cost per km of \$2,508 and \$10,260 (\$4,038 and \$16,512 per mi) for culling and relocation, respectively. For the anti-fertility treatment it was assumed that 80 percent of the females (80 percent of 68.4 female deer is 54.7 female deer, assuming an equal sex ratio), would have to be treated annually to stabilize or reduce the population density.^(287,336) This results in an annual cost for anti-fertility treatment of \$61,702 per km (\$99,300 per mi). The above calculations result in a positive balance for culling and relocation and in a negative balance for anti-fertility treatment. Bear in mind that if the population is open to immigration from adjacent areas, the effectiveness for the culling, relocation, and anti-fertility treatment efforts will be much reduced or potentially eliminated.

Wildlife fences (life span 25 years, not including maintenance) reduce collisions with ungulates by 87 percent on average and have a positive balance of \$32,728 per km (\$52,702 per mile) per year. While insufficient data were available in the literature to evaluate cost-benefit for boulders in right of way (as an alternative to wildlife fences), assuming a life span of 80 years, the costs were estimated at \$2,461 per km (\$3,963 per mile) (boulders on both sides of the road) per year. The costs for long bridges and long tunnels were set at \$781,250 and \$1,500,000 per km (\$1,258,051 and \$2,415,459 per mile) per year respectively (80-year life span). Both long bridges and tunnels have a strongly negative balance.

To accommodate animal movements from one side of a road to the other, wildlife fences are often combined with measures that allow animals to cross the road at grade or to cross under or over the road through crossing structures. This section focuses on crossing opportunities for large animals only (deer size and up). The cost-benefit analysis assumed one crossing opportunity per 2 km (1.2 mi) (0.5 crossing opportunity per km) (e.g., along Trans-Canada Highway in Banff National Park, Canada), even though higher concentrations of crossing structures for large mammals may be required.⁽³⁵²⁾ In addition, gaps were set at a width of 100 m (328 ft), and the number of escape ramps between gaps was set at 2 per roadside (1 every 300 m (984 ft) between gaps). In addition, the animals could “escape” through the gaps. The number of escape ramps between crossing structures was set at 4 per roadside (two immediately next to a crossing structure (50 on either side from center), and two in between at 300-m (984-ft)-intervals between the crossing structures). The escape ramps on either side of a crossing structure are required because of the contiguous wildlife fencing and the assumption that animals will want to cross the road most often at the location of the crossing structures, as that should be one of the most important criteria for the placement of these crossing structures. The length of the fence was not reduced because of gaps or crossing structures because of possible additional fencing at gaps and overpasses and the contiguous nature of fencing for underpasses. In addition, for at-grade crossings, it was assumed that all deer movements that would have taken place in the unmitigated road section (and that resulted in 5 DVCs per km per year), would be funneled through these gaps, and that the number of DVCs is not reduced as the result of a potential reduction in the number of deer crossings because of the presence of the wildlife fence.

The life span of the material associated with crosswalks was set at 10 years, while the life span for wildlife crossing structures was set at 80 years. The cost for the mitigation measure that includes a combination of wildlife fencing and under- and overpasses was based on 0.5 crossing

structures per km, all of them underpasses except for one overpass every 25 km (15.5 mi). The cost for an underpass was set at \$200,000, while the cost for an overpass was set at \$3,500,000. The cost for an escape ramp was set at \$8,500 (life span 80 years). Following this analysis, wildlife fences with gaps that are mitigated by warning signals have a negative balance, while wildlife fences in combination with a crosswalk, an animal detection system, wildlife underpasses, wildlife overpasses, or a combination of wildlife under- and overpasses all have a positive balance.

Many of the mitigation measures showed a positive balance. Some of the mitigation measures (long tunnels, long bridges, and anti-fertility treatment) showed a strongly negative balance. Because of their strongly negative balance, these mitigation measures are not recommended, at least not from a strictly monetary perspective. The other mitigation measures had a positive or slightly negative balance. However, it is also important to evaluate mitigation measures on the balance of the problem that may not have been solved; none of the mitigation measures are 100 percent effective in reducing collisions, and if a substantial number of collisions and associated costs remain, a mitigation measure may not be attractive, despite a potential positive balance.

Figure 60 shows the individual mitigation measures (excluding long tunnels, long bridges, and anti-fertility treatment) in relation to their balance and effectiveness. The figure has several groupings. Based on the rough estimates in this chapter, wildlife fencing, with or without wildlife underpasses or a combination of wildlife underpasses and overpasses, and animal detection systems with wildlife fencing have high effectiveness and a high return on investment. (identified by solid oval, measures 8, 11, 12, and 14 in figure 60). Animal detection systems without wildlife fences or wildlife fences with a high density of wildlife overpasses (identified by dashed oval, measures 3 and 13 in figure 60) also have high effectiveness, but their positive financial balance is less strong.

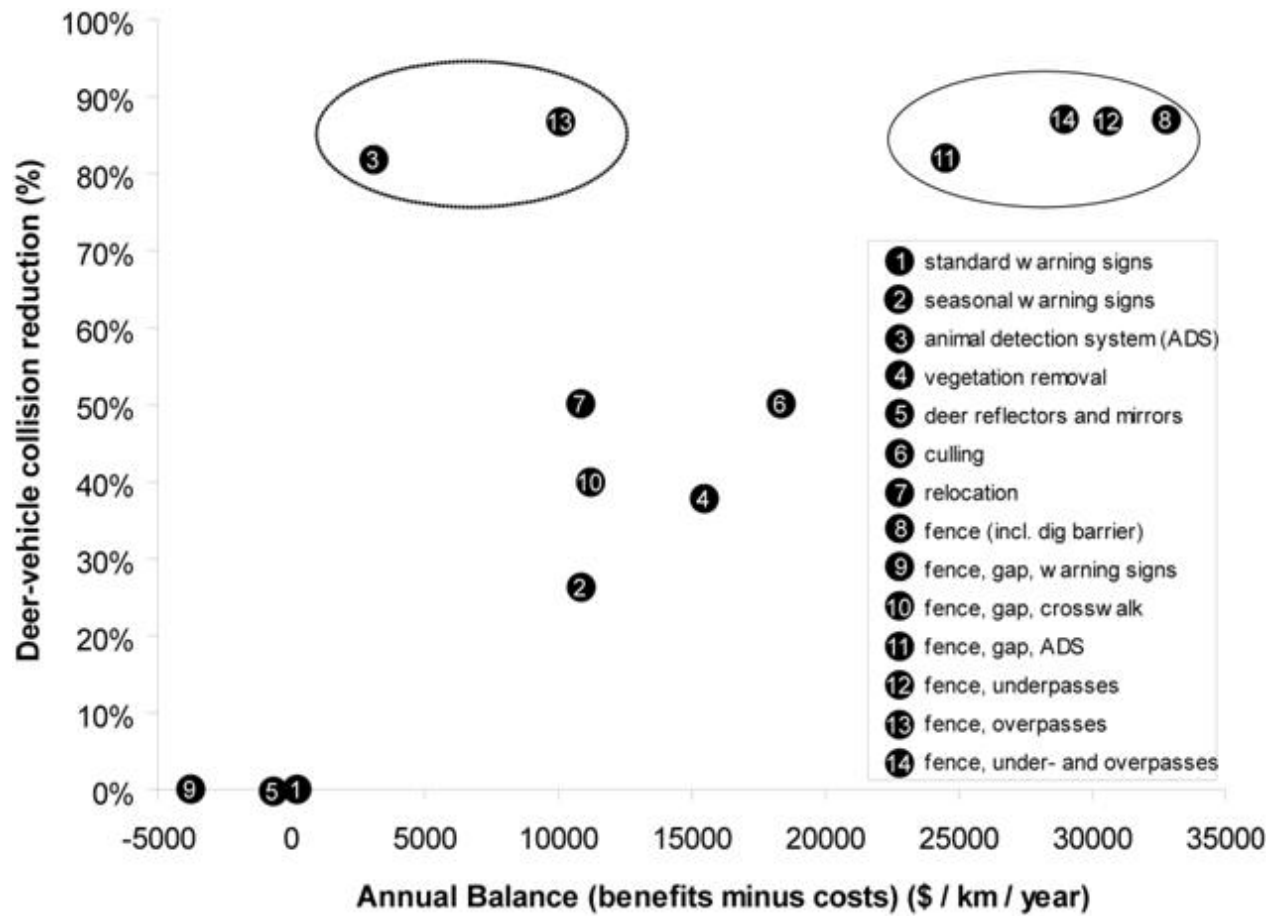


Figure 60. Graph. Annual balance and collision reduction for the different mitigation measures (further explanation in text).

CHAPTER 13. CONCLUSION

This report has summarized the considerable body of existing knowledge on the impacts and mitigations of WVCs. Based on several data sources, it was estimated that one to two million WVCs occur annually (focusing on large animals) and that they continue to be a significant challenge, costing society billions of dollars. WVCs also result in human injuries and fatalities, although this is relatively rare compared to other types of accidents. WVCs are also a serious safety risk for animals, not only for the individuals involved, but in some cases for populations or the entire species. This report identified 21 federally threatened and endangered species for which road mortality was identified as one of the major threats to their long-term survival.

This report reviewed over 34 mitigation measures aimed at reducing WVCs. Wildlife fencing, with or without wildlife crossing structures, animal detection systems, and long tunnels or bridges were found to provide the greatest reduction of WVCs. Site-specific conditions will dictate the appropriate mitigation measure(s), as there is no single, low-cost solution for WVCs that can or should be applied everywhere. A successful mitigation strategy requires a detailed analysis of the problem and the local situation and often involves a combination of different types of mitigation measures. Moreover, improved objective evaluation of the mitigation measures will help States and others make better informed decisions.

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REFERENCES

1. American Association of State Highway Transportation Officials (AASHTO). 2004a. *A Policy on Geometric Design of Highways and Streets (Green Book) 5th edition*. ISBN 1-56051-263-6.
2. U.S. Department of Transportation, National Highway Traffic Safety Administration 2005. *Traffic Safety Facts 2005*. DOT HS 810 631. Washington, DC.
3. Romin, L.A., and J.A. Bissonette. 1996. Deer vehicle collisions: status of state monitoring activities and mitigation efforts. *Wildlife Society Bulletin* 24: 276–283.
4. Conover, M.R., W.C. Pitt, K.K. Kessler, T.J. DuBow, and W.A. Sanborn. 1995. Review of human injuries, illnesses and economic losses caused by wildlife in the United States. *Wildlife Society Bulletin* 23: 407–414.
5. Miles, M. *Deer Counts 2003–2005 External*. E-mail communication with attached spreadsheet sent 7/25/06. State Farm Insurance.
6. Marcoux, A. 2005. *Deer-Vehicle Collisions: An Understanding of Accident Characteristics and Drivers' Attitudes, Awareness and Involvement*. Master's Thesis, Michigan State University, Department of Fisheries and Wildlife, East Lansing, MI.
7. Road Management & Engineering Journal. 2000. Vehicle-wildlife collisions increasing: how to avoid this happening to you. U.S. Roads publication reprinted in *Motoring USA*, June 2000.
8. Joyce, T.L., and S.P. Mahoney. 2001. Spatial and temporal distributions of moose vehicle collisions in Newfoundland. *Wildlife Society Bulletin* 29(1): 281–291.
9. Putman, R.J. 1997. Deer and road traffic accidents: options for management. *Journal of Environmental Management* 51: 43–57.
10. Hughes, W.E., R.A. Reza, and J.F. Paniati. 1996. Vehicle-animal crashes: An increasing safety problem. *Institute of Transportation Engineers Journal* 66: 24–28.
11. Sudharsan, K., S.J. Riley, and S.R. Winterstein. 2006. Relationship of autumn hunting season to the frequency of deer–vehicle collisions in Michigan. *Journal of Wildlife Management* 70(4): 1161–1164.
12. Wells, S. D. 2003. Determining criteria to evaluate mitigation measures to reduce wildlife-vehicle collisions: Teton County, Wyoming. University of Wyoming, Department of Geography and Recreation.
13. Williams, A.F., and J.K. Wells. 2004. *Characteristics of Vehicle-Animal Crashes in which Vehicle Occupants Are Killed*. Insurance Institute for Highway Safety. Arlington, VA.

14. Jones, M. 2000. *Deer Vehicle Crash Injuries, Fatalities Reach All-Time High in Wisconsin*. The Milwaukee Journal Sentinel newspaper article, 14 April 2000.
15. Conn, J.M., J.L. Annest, and A. Dellinger. 2004. Nonfatal motor-vehicle animal crash-related injuries—United States, 2001–2002. *Journal of Safety Research* 35: 571–574.
16. Reilly, R.E., and H.E. Green. 1974. Deer mortality on a Michigan interstate highway. *Journal of Wildlife Management* 38: 16–19.
17. Meyer, E., and I. Ahmed. 2004. Modeling of deer vehicle crash likelihood using roadway and roadside characteristics. In: *Transportation Research Board 2004 Annual Meeting Compendium of Papers CD-ROM*. Washington, DC.
18. Knapp, K., B. Persaud, C. Lyon and N. Schowalter-Hay. 2007. Safety data analysis aspects. In: Bissonette, J.A. (ed.). pp. 47–83. Evaluation of the use and effectiveness of wildlife crossings. NCHRP 25–27, Final Report, Transportation Research Board, Washington DC.
19. Langevelde, F., and C.F. Jaarsma. 2004. Using traffic flow theory to model traffic mortality in mammals. *Landscape Ecology* 19: 895–907.
20. Jaarsma, C.F., and G.P.A. Willems. 2002. Reducing habitat fragmentation by minor rural roads through traffic calming. *Landscape and Urban Planning* 58: 125–135.
21. Huijser, M.P., P.J.M. Bergers, and C.J.F. Ter Braak. 2000. Road, traffic and landscape characteristics of hedgehog traffic victim sites. In: Huijser, M.P. (ed.). *Life on the Edge. Hedgehog Traffic Victims and Mitigation Strategies in an Anthropogenic Landscape*. Ph.D. Thesis, Wageningen University, Wageningen, The Netherlands.
22. Trocmé, M., S. Cahill, J.G. de Vries, H. Farrall, L. Folkesson, G. Fry, C. Hicks, and J. Peymen (eds.) 2003. *COST 341: Habitat Fragmentation Due to Transportation Infrastructure: The European Review*. Office for Official Publications of the European Communities, Luxembourg.
23. Seiler, A. 2003. *The Toll of the Automobile: Wildlife and Roads in Sweden*. Doctoral Thesis, Swedish University of Agricultural Sciences, Uppsala, Sweden.
24. Alexander, S.M., N.M. Waters, and P.C. Paquet. 2005. Traffic volume and highway permeability for a mammalian community in the Canadian Rocky Mountains. *The Canadian Geographer/Le Géographe Canadien* 49(4): 321–331.
25. Seiler, A. 2005. Predicting locations of moose vehicle collisions in Sweden. *Journal of Applied Ecology* 42: 371–382.
26. Cottam, C. 1931. Birds and motor cars in South Dakota. *Wilson Bulletin* 43: 313–314.

27. Cramer, P.C., and K.M. Portier. 2001. Modeling Florida panther movements in response to human attributes of the landscape and ecological settings. *Ecological Modelling* 140: 51–80.
28. Carbaugh, B.T. 1970. Activity and Behavior of White-Tailed Deer (*Odocoileus virginianus*) Along an Interstate Highway in a Forest Region of Pennsylvania. Dissertation. The Pennsylvania State University, State College, PA.
29. Pynn T.P., and B.R. Pynn. 2004. Moose and other large animal wildlife vehicle collisions: implications for prevention and emergency care. *Journal of Emergency Nursing* 30: 542–547.
30. Finder, R.A., J.L. Roseberry, and A. Woolf. 1999. Site and landscape conditions at white-tailed deer vehicle collision locations in Illinois. *Landscape and Urban Planning* 44: 77–85.
31. Huijser, M.P., J. Fuller, M.E. Wagner, A. Hardy, and A.P. Clevenger. 2007. Animal-vehicle collision data collection. A synthesis of highway practice. NCHRP Synthesis 370. Project 20-05/Topic 37-12. Transportation Research Board of the National Academies, Washington DC. Available from the Internet, accessed 14 April, 2008. URL: http://www.trb.org/news/blurbs_detail.asp?id=8422
32. Puglisi, M.J., J.S. Lindzey, and E.D. Bellis. 1974. Factors associated with highway mortality of white-tailed deer. *Journal of Wildlife Management* 38(4): 799–807.
33. Munding, J. 1979. Population ecology and habitat relationships of white-tailed deer in coniferous forest habitat of northwestern Montana. In: Mackie, R.J. (ed.). *Statewide Deer Research: Job Progress Report, Research Project Segment*: 5–65. Montana Department of Fish and Game, Helena, MT.
34. Leach, R.H. 1982. Statewide White-Tailed Deer Ecology Studies. Population Ecology and Habitat Relationships of White-Tailed Deer in Coniferous Forest Habitat in Northwestern Montana (Summer Range Ecology of White-Tailed Deer in the Coniferous Forests of Northwestern Montana). Thesis. University of Montana, Missoula, MT.
35. Arno, S.F., G.E. Gruell, J.G. Munding, and W. Schmidt. 1987. Developing silvicultural prescriptions to provide both deer winter habitat and timber. *Western Wildlands* Winter 1987: 19–24.
36. Leach, R.H., and W.D. Edge. 1994. Summer home range and habitat selection by white-tailed deer in the Swan Valley, Montana. *Northwest Science* 68(1): 31–36.
37. Nielsen, C.K., R.G. Anderson, and M.D. Grund. 2003. Landscape influences on deer vehicle accident areas in an urban environment. *Journal of Wildlife Management* 67: 46–51.

38. Rogers, E. 2004. *An Ecological Landscape Study of Deer Vehicle Collisions in Kent County, Michigan*. Report by White Water Associates Inc. Prepared for Kent County Road Commission, Grand Rapids, MI.
39. Malo, J.E., F. Suarez, and A. Diez. 2004. Can we mitigate animal vehicle accidents using predictive models? *Journal of Applied Ecology* 41: 701–710.
40. Bashore T.L., W.M. Tzilkowski, and E.D. Bellis. 1985. Analysis of deer vehicle collision sites in Pennsylvania. *Journal of Wildlife Management* 49: 769–774.
41. Lehnert, M.E., and J.A. Bissonette. 1997. Effectiveness of highway crosswalk structures at reducing deer vehicle collisions. *Wildlife Society Bulletin* 25(4): 809–818.
42. Gordon, K.M., M.C. McKinstry, and S.H. Anderson. 2004. Motorist response to a deer sensing warning system. *Wildlife Society Bulletin* 32: 565–573.
43. Sullivan, T.L., A.E. Williams, T.A. Messmer, L.A. Hellinga, and S.Y. Kyrychenko. 2004. Effectiveness of temporary warning signs in reducing deer vehicle collisions during mule deer migrations. *Wildlife Society Bulletin* 32(3): 907–915.
44. D'Eon, R.G., and R. Serrouya. 2005. Mule deer seasonal movements and multi-scale resource selection using global positioning system radio telemetry. *Journal of Mammalogy* 86(4): 736–744.
45. Romin, L.A., and J.A. Bissonette. 1994. Executive Summary: Factors Associated with Mule-Deer Highway Mortality, Jordanelle Reservoir, Utah. Utah State University, Logan, UT.
46. McClure, M.F., J.A. Bissonette, and M.R. Conover. 2005. Migratory strategies, fawn recruitment, and winter habitat use by urban and rural mule deer (*Odocoileus hemionus*). *European Journal of Wildlife Research* 51: 170–177.
47. Sawyer, H., R.M. Nielson, F. Lindzey, and L.L. McDonald. 2006. Winter habitat selection of mule deer before and during development of a natural gas field. *Journal of Wildlife Management* 70(2): 396–403.
48. Poole, K.G., and G. Mowat. 2005. Winter habitat relationships of deer and elk in the temperate interior mountains of British Columbia. *Wildlife Society Bulletin* 33(4): 1288–1302.
49. VerCauteren, K.C., J.A. Shivik, and M.J. Lavelle. 2005. Efficacy of an animal-activated frightening device on urban elk and mule deer. *Wildlife Society Bulletin* 33(4): 1282–1287.
50. Alexander, S.M., and N.M. Waters. 2000. The effects of highway transportation corridors on wildlife: a case study of Banff National Park. *Transportation Research Part C: Emerging Technologies* 8: 307–320.

51. Pellet, N.R. 2004. *Roadway and Landscape Characteristics Leading to Increases in Ungulate-Vehicle Collisions*. MSc. Thesis. Civil Engineering Department, Montana State University – Bozeman, MT.
52. Doerr, M.L., J.B. McAninch, and E.P. Wiggers. 2001. Comparison of four methods to reduce white-tailed deer abundance in an urban community. *Wildlife Society Bulletin* 29(4): 1105–1113.
53. Knapp, K.K., X. Yi, T. Oakasa, W. Thimm, E. Hudson, and C. Rathmann. 2004. *Deer Vehicle Crash Countermeasure Toolbox: A Decision and Choice Resource*. Final report. DVCIC-02. Midwest Regional University Transportation Center, Deer vehicle Crash Information Clearinghouse, University of Wisconsin-Madison, Madison, WI.
54. Iowa Department of Natural Resources. 2005. *White-Tailed Deer Harvest and Population Trends*. Available from the Internet, accessed 12 January 2007. (<http://www.iowadnr.com/wildlife/pdfs/deerlog.pdf>)
55. Côté, S.D., T.P. Rooney, J.P. Tremblay, C. Dussault, and D.M. Waller. 2004. Ecological impacts of deer overabundance. *Annual Review of Ecology, Evolution, and Systematics* 35: 113–147.
56. *Deer Vehicle Crash Information Clearinghouse*. 2007. Wisconsin data. Available on the Internet, accessed 12 January 2007. (<http://www.deercrash.com/states/wisconsin.htm>)
57. Porter, W.F., and H.B. Underwood. 1999. Of elephants and blind men: deer management in the U.S. National Parks. *Ecological Applications* 9(1): 3–9.
58. Putman, R.J., J. Langbein, and B.W. Staines. 2004. *Deer and Road Traffic Accidents: A Review of Mitigation Measures: Costs and Cost-Effectiveness*. Report for the Deer Commission for Scotland; Contract RP23A, UK.
59. Waring, G.H., J.L. Griffis, and M.E. Vaughn. 1991. White-tailed deer roadside behavior, wildlife warning reflectors, and highway mortality. *Applied Animal Behavior Science* 29: 215–223.
60. Lehnert, M.E., J.A. Bissonette, and J.W. Haefner. 1998. Deer (Cervidae) highway mortality: using models to tailor mitigative efforts. *Gibier Faune Sauvage Wild.* 15: 835–841.
61. Danielson, B.J., and M.W. Hubbard. 1998. *A Literature Review for Assessing the Status of Current Methods of Reducing Deer Vehicle Collisions*. Report for The Task Force on Animal Vehicle Collisions, The Iowa Department of Transportation, and The Iowa Department of Natural Resources, Iowa.
62. Schwabe, K.A., P.W. Schuhmann, M.J. Tonkovich, and E. Wu. 2002. An analysis of deer vehicle collisions: the case of Ohio. In: Clark, L. (ed.). *Human Conflicts with Wildlife: Economic Considerations*: 91–103. National Wildlife Research Center. Fort Collins, CO.

63. Turner-Fairbank Highway Research Center. 2001. *Young Drivers and Highway Design and Operations: Findings and Recommended Research*. TechBrief. Publication No. FHWA-RD-01-120. August 2001.
64. U.S. Department of Transportation, Bureau of Transportation Statistics. 2001. *The 2001 National Household Travel Survey: Daily Trip File and Person Files*. Available on the Internet, accessed 22 November 2006.
(http://www.bts.gov/publications/highlights_of_the_2001_national_household_travel_survey/html/table_a17.html)
65. U.S. Department of Commerce, Bureau of the Census. 2000. *National Population Counts by Age*. Available on the Internet, accessed 22 November 2006.
(<http://www.census.gov/main/www/cen2000.html>)
66. U.S. Department of Transportation. 1994. *Technical Advisory. Motor Vehicle Accident Costs*. T 7570.2 October 31, 1994. U.S. Department of Transportation, Federal Highway Administration. Available on the Internet, accessed 9 March 2007.
(<http://www.fhwa.dot.gov/legisregs/directives/techadvs/t75702.htm>)
67. Economagic. 2007. Series Title: *Gross Domestic Product: Implicit Price Deflator: Index 2000=100: SA*. Available on the Internet, accessed 9 March 2007.
(<http://www.economagic.com/em-cgi/data.exe/fedstl/gdpdef+1>)
68. L-P Tardiff, and Associates, Inc. 2003. *Collisions Involving Motor Vehicle and Large Animals in Canada*. Final Report to Transport Canada Road Safety Directorate, Nepean, Ontario, Canada.
69. Clayton Resources Ltd. and Glen Smith Wildlife Consultants. 1989. *Wildlife Fencing and Control on the Okanagan Connector Highway: A Benefit Cost Analysis*. Clayton Resources Ltd.: Victoria, British Columbia, Canada.
70. Biggs, J., S. Sherwood, S. Michalak, L. Hansen, and C. Bare. 2004. Animal-related vehicle accidents at the Los Alamos National Laboratory, New Mexico. *Southwestern Naturalist* 49(3): 384–394.
71. Rea, R.V. 2004. *Investigating Methods to Reduce Urban Moose-Related Vehicular Collisions Within the City of Prince George, British Columbia*. Ecosystem Science and Management Program. University of Northern British Columbia, Prince George, British Columbia, Canada.
72. Sielecki, L.E. 2004. *WARS 1983–2002—Wildlife Accident Reporting and Mitigation in British Columbia: Special Annual Report*. Ministry of Transportation, Engineering Branch. Environmental Management Section. Victoria, British Columbia, Canada.
73. U.S. Department of Transportation. 2002. *Considering Safety in the Transportation Planning Process*. U.S. Department of Transportation. Washington, DC.

74. Groot Bruinderink, G.W.T.A, and E. Hazebroek. 1996. Ungulate traffic collisions in Europe. *Conservation Biology* 10(4): 1059–1067.
75. Haikonen, H., and H. Summala. 2001. Deer vehicle crashes: extensive peak at 1 hour after sunset. *American Journal of Preventative Medicine* 21(3): 209–213.
76. Lavsund, S., and F. Sandegren. 1991. Moose vehicle relations in Sweden: a review. *Alces* 27: 118–126.
77. Government of Newfoundland and Labrador. 1997. *Results of Review of Moose Vehicle Collisions*. News release 11 July 1997. Available from the Internet. (<http://www.gov.nf.ca/releases/1997/forest/0711n02.htm>)
78. Thomas, S.E. 1995. *Moose Vehicle Accidents on Alaska's Rural Highways*. Alaska Department of Transportation and Public Facilities, Central Region, Design and Construction Division, Alaska.
79. Garrett, L.C., and G.A. Conway. 1999. Characteristics of moose vehicle collisions in Anchorage, Alaska, 1991-1995. *Journal of Safety Research* 30(4): 219–223.
80. Rattey, T.E., and N.E. Turner. 1991. Vehicle-moose accidents in Newfoundland. *Journal of Bone and Joint Surgery* 73(10): 1487–1491.
81. Allen, R.E., and D.R. McCullough. 1976. Deer-car accidents in southern Michigan. *Journal of Wildlife Management* 40: 317–325.
82. Bissonette, J.A., and M. Hammer. 2000. Effectiveness of earthen ramps in reducing big game highway mortality in Utah: Final report. *Utah Cooperative Fish and Wildlife Research Unit Report Series* 2000(1): 1–29.
83. Forman, R.T.T., and L.E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics* 29: 207–231.
84. Spellerberg I.F. 1998. Ecological effects of roads and traffic: a literature review. *Global Ecology and Biogeography Letters* 7: 317–333.
85. Forman, R.T.T., D. Sperling, J.A. Bissonette, A.P. Clevenger, C.D. Cutshall, V.H. Dale, L. Fahrig, R. France, C.R. Goldman, K. Heanue, J.A. Jones, F.J. Swanson, T. Turrentine, and T.C. Winter. 2003. *Road Ecology: Science and Solutions*. Island Press: Washington, DC.
86. National Research Council. 2005. *Assessing and Managing the Ecological Impacts of Paved Roads*. Committee on Ecological Impacts of Road Density, Board on Environmental Studies and Toxicology, Division on Earth and Life Studies, Transportation Research Board, National Research Council of the National Academies. The National Academies Press: Washington, DC.
87. Lalo, J. 1987. The problem of road kill. *American Forests* 93(9/10): 50–52, 72.

88. Huijser, M.P., K.E. Gunson, and C. Abrams. 2006. *Animal Vehicle Collisions and Habitat Connectivity Along US Highway 83 in the Seeley-Swan Valley: A Reconnaissance*. FHWA/MT-06-002/8177. Western Transportation Institute, Montana State University, Bozeman. Available from the Internet, accessed 22 November 2006. (http://www.mdt.mt.gov/research/docs/research_proj/seeley/final_report.pdf)
89. Maine Department of Transportation. 2001. *Collisions between Large Wildlife Species and Motor Vehicles in Maine*. Interim report. Maine Interagency Work group on Wildlife-Motor Vehicle Collisions, Maine Department of Transportation: Augusta, ME.
90. Slater, F.M. 2002. An assessment of wildlife road casualties: the potential discrepancy between numbers counted and numbers killed. *Web Ecology* 3: 33–42.
91. Carr, L.W., and L. Fahrig. 2001. Effect of road traffic on two amphibian species of differing vagility. *Conservation Biology* 15(4): 1071–1078.
92. Gibbs, J.P., and W.G. Shriver. 2002. Estimating the effects of road mortality on turtle populations. *Conservation Biology* 16(6): 1647–1652.
93. Jaeger J.A.G., J. Bowman, J. Brennan, L. Fahrig, D. Bert, J. Bouchard, N. Charbonneau, K. Frank, B. Gruber, and K. Tluk von Toschanowitz. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. *Ecological Modelling* 185: 329–348.
94. Fahrig, L., J.H. Pedlar, S.E. Pope, P.D. Taylor, and J.F. Wegner. 1995. Effect of road traffic on amphibian density. *Biological Conservation* 73(3): 177–182.
95. Huijser M.P., and P.J.M. Bergers. 2000. The effect of roads and traffic on hedgehog (*Erinaceus europaeus*) populations. *Biological Conservation* 95: 111–116.
96. Boarman, W.I., and M. Sazaki. 2006. A highway's road-effect zone for desert tortoises (*Gopherus agassizii*). *Journal of Arid Environments* 65: 94–101.
97. Mader, H.J. 1984. Animal habitat isolation by roads and agricultural fields. *Biological Conservation* 29: 81–96.
98. Ewing R., J. Kostyack, D. Chen, B. Stein, and M. Ernst. 2005. *Endangered by Sprawl: How Runaway Development Threatens America's Wildlife*. National Wildlife Federation, Smart Growth America and NatureServe: Washington, DC.
99. Vos, C.C., and J.P. Chardon. 1998. Effects of habitat fragmentation and road density on the distribution pattern of the moor frog (*Rana arvalis*). *Journal of Applied Ecology* 35(1): 44–56.
100. Gibbs, J.P., and W.G. Shriver. 2005. Can road mortality limit populations of pool-breeding amphibians? *Wetlands Ecology and Management* 13: 281–289.

101. Craig, R.D., and S.J. Burgdorf. 1997. Timber rattlesnakes and Louisiana pine snakes of the West Gulf Coastal Plain: hypotheses of decline. *Texas Journal of Science* 49(3 Suppl.): 111–122.
102. Bergers, P.J.M., and W. Nieuwenhuizen. 1999. Viability of hedgehog populations in Central Netherlands. *Lutra* 42(1): 65–75.
103. Bekker, G.J., and K.J. Canters. 1997. The continuing story of badgers and their tunnels. In: Canters, K., A. Piepers, and D. Hendriks-Heersma (eds.). *Proceedings of the 1995 International Conference on Habitat Fragmentation, Infrastructure and the Role of Ecological Engineering*: 344–353. Maastricht and The Hague, The Netherlands.
104. Clarke, G.P., P.C.L. White, and S. Harris. 1998. Effects of roads on badger (*Meles meles*) populations in south-west England. *Biological Conservation* 86(2): 117–124.
105. Guter, A., A. Dolev, D. Saltz, and N. Kronfeld-Schor. 2005. Temporal and spatial influences on road mortality in otters: conservation implications. *Israel Journal of Zoology* 51(3): 199–207.
106. Robitaille, J.F., and S. Laurence. 2002. Otter (*Lutra lutra*) occurrence in Europe and in France in relation to landscape characteristics. *Animal Conservation* 5(4): 337–344.
107. Haines, A.M., M.E. Tewes, L.L. Laack, W.E. Grant, and J. Young. 2005. Evaluating recovery strategies for an ocelot (*Leopardus pardalis*) population in the United States. *Biological Conservation* 126: 512–522.
108. Maehr, D.S., E.D. Land, and M.E. Roelke. 1991. Mortality patterns of panthers in southwest Florida. In: Eversole, A.G. (ed.). *Proceedings of the Annual Conference of the Southeastern Fish and Wildlife Agencies*: 201–207. Southeastern Fish and Wildlife Agencies, White Sulphur Springs, WV.
109. Ferreras, P., P. Gaona, F. Palomares, and M. Delibes. 2001. Restore habitat or reduce mortality? Implications from a population viability analysis of the Iberian lynx. *Animal Conservation* 4: 265–274.
110. Harveson, P.M., R.R. Lopez, N.J. Silvy, and P.A. Frank. 2004. Source-sink dynamics of Florida Key deer on Big Pine Key, Florida. *Journal of Wildlife Management* 68(4): 909–915.
111. U.S. Fish and Wildlife Service. 2006. *USFWS Threatened and Endangered Species System (TESS)*. Available from the Internet, accessed 22 August 2006. (http://ecos.fws.gov/tess_public/StateListing.do?state=all)
112. IUCN. 2006. *2006 IUCN Red List of Threatened Species*. Available from the Internet, accessed 28 August 2006. URL: <http://www.iucnredlist.org>.
113. Fish and Wildlife Service. 2004. Part II. Department of the Interior, Fish and Wildlife Service, 50 CFR Part 17. Endangered and Threatened Wildlife and Plants; Determination

- of Threatened Status for the California Tiger Salamander; and Special Rule Exemption for Existing Routine Ranching Activities; Final Rule. Wednesday, August 4, 2004/Rules and Regulations. *Federal Register* 69(149): 47,212–47,248.
114. Barry, S.J., and H.B. Shaffer. 1994. The status of the California tiger salamander (*Ambystoma californiense*) at Lagunita: a 50-year update. *Journal of Herpetology* 28(2): 159–164.
 115. Jennings, M.R., and M.P. Hayes. 1994. *Amphibian and Reptile Species of Special Concern in California*. Final report. California Department of Fish and Game, Rancho, Cordova, CA.
 116. Pyke, C. R. 2005. Assessing suitability for conservation action: prioritizing interpond linkages for the California tiger salamander. *Conservation Biology* 19(2): 492–503.
 117. Fish and Wildlife Service. 1999. Department of the Interior, Fish and Wildlife Service, 50 CFR Part 17, RIN 1018–AE38. Endangered and Threatened Wildlife and Plants; Final Rule To List the Flatwoods Salamander as a Threatened Species. Thursday, April 1, 1999/Rules and Regulations. *Federal Register* 64(62): 15,691–15,704.
 118. Peterson, M.N., S.A. Allison, M.J. Peterson, T.R. Peterson, and R.R. Lopez. 2004. A tale of two species: habitat conservation plans as bounded conflict. *Journal of Wildlife Management* 68(4): 743–761.
 119. Fish and Wildlife Service. 2005. Department of the Interior, Fish and Wildlife Service, 50 CFR Part 17, RIN 1018-AI41. Endangered and Threatened Wildlife and Plants; Reclassifying the American Crocodile Distinct Population Segment in Florida From Endangered to Threatened and Initiation of a 5-Year Review; Proposed Rule. March 24, 2005. *Federal Register* 70(56): 15,052–15,063.
 120. Mazzotti, F.J., and M.S. Cherkiss. 2003. Status and Conservation of the American Crocodile in Florida: Recovering an Endangered Species While Restoring an Endangered Ecosystem. Technical Report. University of Florida, Ft. Lauderdale Research and Education Center, Ft. Lauderdale, FL.
 121. Richards, P.M., W.M. Mooij, and D.L. DeAngelis. 2004. Evaluating the effect of salinity on a simulated American crocodile (*Crocodylus acutus*) population with applications to conservation and Everglades restoration. *Ecological Modelling* 180: 371–394.
 122. Fish and Wildlife Service. 1989. Department of the Interior, Fish and Wildlife Service, 50 CFR Part 17, RIN 1018–AB35. Endangered and Threatened Wildlife and Plants; Emergency Determination of Endangered Status for the Mojave Population of the Desert Tortoise; Emergency rule. Friday, August 4, 1989/Rules and Regulations. *Federal Register* 54(149): 32,326–32,331.
 123. Boarman, W.I. 2002. *Threats to Desert Tortoise Populations: A Critical Review of the Literature*. U.S. Geological Survey, Western Ecological Research Center: Sacramento, CA.

124. Von Seckendorff Hoff, K., and R.W. Marlow. 2002. Impacts of vehicle road traffic on desert tortoise populations with consideration of conservation of tortoise habitat in southern Nevada. *Chelonian Conservation and Biology* 4(2): 449–456.
125. Hagood, S. 2006. *Road Mortality as a Primary Threat to Federal Listed Chelonians*. Unpublished document. Humane Society: Washington, DC.
126. Fish and Wildlife Service. 1987. Department of the Interior, Fish and Wildlife Service, 50 CFR Part 17. Endangered and Threatened Wildlife and Plants; Determination of Threatened Status for the Gopher Tortoise (*Gopherus polyphemus*); Final rule. Tuesday, July 7, 1987/Rules and Regulations. *Federal Register* 52(129): 25376–25380.
127. Enge, K.M., J.E. Berish, R. Bolt, A. Dziergowski, and H.R. Mushinsky. 2005. *Draft Biological Status Report: Gopher Tortoise*. Florida Fish and Wildlife Conservation Commission: Tallahassee, FL.
128. U.S. Fish and Wildlife Service. 2006. *Species Accounts: Gopher Tortoise (Gopherus Polyphemus)*. U.S. Fish and Wildlife Service, Division of endangered species. Available from the Internet, accessed 20 November 2006. (<http://www.fws.gov/endangered/i/c/sac2v.html>)
129. Nelson, D.H., and C. Scardamalia-Nelson. 2005. *Vertebrate Road-Kill Survey of the Mobile Bay Causeway 2001–2004*. Abstract for the 2005 annual meeting of the Journal of the Alabama Academy of Science.
130. Fish and Wildlife Service. 1997. Department of the Interior, Fish and Wildlife Service 50 CFR Part 17, RIN 1018–AD05. Endangered and Threatened Wildlife and Plants; Final Rule to List the Northern Population of the Bog Turtle as Threatened and the Southern Population as Threatened Due to Similarity of Appearance; Final rule. Tuesday, November 4, 1997/Rules and Regulations. *Federal Register* 62(213): 59,605–59,623.
131. Fish and Wildlife Service. 1997. Interior, Fish and Wildlife Service, 50 CFR Part 17, RIN 1018–AB75. Endangered and Threatened Wildlife and Plants; Determination of Threatened Status for the Northern Population of the Copperbelly Water Snake; Final rule. Wednesday, January 29, 1997/Rules and Regulations. *Federal Register* 62(19): 4,183–4,192.
132. Roe, J.H., J. Gibson,, and B.A. Kingsbury. 2006. Beyond the wetland border: Estimating the impact of roads for two species of water snakes. *Biological Conservation* 130: 161–168.
133. Bolt, R. 2005. Eastern Indigo Snakes. Habi-Chat, *Newsletter of the Merritt Island Wildlife Association* 11(3): 6.
134. Smith, D.J., and M. Voigt. 2005. *SR 200 Wildlife Impact Study, Final Report*. Florida Department of Transportation, Contract No. BC354-74, Florida Department of Environmental Protection, Office of Greenways and Trails, Contract No. GM 114, and Southwest Florida Water Management District, Contract No. 03CON000078. GeoPlan

Center, Department of Urban and Regional Planning, University of Florida, Gainesville, FL.

135. Hyslop, N.L., M. Meyers, and R.J. Cooper. 2006. *Movements, Survival, and Habitat Use of the Threatened Eastern Indigo Snake (Drymarchon Couperi) in Southeastern Georgia*. Final Report to Georgia Department of Natural Resources, Wildlife Division, Nongame Wildlife and Natural Heritage Section, Social Circle, GA.
136. Fish and Wildlife Service. 1987. Department of the Interior, Fish and Wildlife Service, 50 CFR Part 17. Endangered and Threatened Wildlife and Plants; Determination of Threatened Status for the Florida population of Audubon's Crested Caracara; Final rule. Monday, July 6, 1987/Rules and Regulations. *Federal Register* 52(128): 25229–25232.
137. Morrison, J. 1999. Breeding biology and productivity of Florida's crested caracaras. *Condor* 101: 505–517.
138. Hawai'i Volcanoes National Park. 2004. *Drivers Urged to Watch for Nene on H-11*. Hawai'i Volcanoes National Park news release, 2 December 2004. Available from the Internet, accessed 20 November 2006. (http://www.nps.gov/archive/havo/news/pr_20041202.htm)
139. Fish and Wildlife Service. 1987. Department of the Interior, Fish and Wildlife Service, 50 CFR Part 17. Endangered and Threatened Wildlife and Plants; Threatened Status for the Florida Scrub Jay; Final rule. Wednesday June 3, 1987/Rules and Regulations. *Federal Register* 52(106): 20,715–20,719.
140. Mumme, R.L., S.J. Schoech, G.E. Woolfenden, and J.W. Fitzpatrick. 2000. Life and death in the fast lane: demographic consequences of road mortality in the Florida Scrub-Jay. *Conservation Biology* 14(2): 501–512.
141. Forsy, E.A., and S.R. Humphrey. 1999. Use of population viability analysis to evaluate management options for the endangered Lower Keys marsh rabbit. *Journal of Wildlife Management* 63(1): 251–260.
142. U.S. Fish and Wildlife Service. 1999. Lower Keys Rabbit *Sylvilagus palustris hefneri*. pp: 4-151 – 4-172. *South Florida Multi-Species Recovery Plan*. Atlanta, GA.
143. Lopez, R.R., M.E.P. Viera, N.J. Silvy, P.A. Frank, S.W. Whisenant, and D.A. Jones. 2003. Survival, mortality, and life expectancy of Florida Key deer. *Journal of Wildlife Management* 67(1): 34–45.
144. Fish and Wildlife Service. 1998. Department of the Interior, Fish and Wildlife Service, 50 CFR Part 17, RIN 1018–AB73. Endangered and Threatened Wildlife and Plants; Endangered Status for the Peninsular Ranges Population Segment of the Desert Bighorn Sheep in Southern California; Final rule. Wednesday, March 18, 1998/Rules and Regulations. *Federal Register* 63(52): 13,134–13,150.

145. Cypher, B.L. 2000. Effects of Roads on San Joaquin Kit Foxes: A Review and Synthesis of Existing Data. California State University: Fresno, CA.
146. Fish and Wildlife Service. 1998. Part III Department of the Interior, Fish and Wildlife Service, 50 CFR Part 17. Endangered and Threatened Wildlife and Plants; Notice of Remanded Determination of Status for the Contiguous United States Distinct Population Segment of the Canada Lynx; Clarification of Findings; Final Rule. Wednesday, July 8, 1998/Proposed Rules. *Federal Register* 63(130): 6,993–37,013.
147. Shenk, T. 2006. *Lynx Fact Sheet*. Wildlife Commission Meeting: November 8, 2006. (<http://wildlife.state.co.us/NR/ronlyres/56F725F1-39DD-45E2-8F6F-5EE51AD03E2F/0/LynxUpdateNov92006.pdf>)
148. Haines, A.M., M.E. Tewes, and L.L. Laack. 2005. Survival and sources of mortality in ocelots. *Journal of Wildlife Management* 69(1): 255–263.
149. Taylor, S.K., C.D. Buergelt, M.E. Roelke-Parker, B.L. Homer, and D.S. Rotstein. 2002. Causes of mortality of free-ranging Florida panthers. *Journal of Wildlife Diseases* 38(1): 107–114.
150. Whiles, M.R., J.B. Jensen, J.G. Palis, and W.G. Dyer. 2004. Diets of larval flatwoods salamanders (*Ambystoma cingulatum*) from Florida and South Carolina. *Journal of Herpetology* 38(2): 208–214.
151. Means, D.B., J.G. Palis, and M. Baggett. 1996. Effects of slash pine silviculture on a Florida population of flatwoods salamander. *Conservation Biology* 10(2): 426–437.
152. Bury, R.B., and R.A. Luckenbach. 2002. Comparison of desert tortoise (*Gopherus agassizii*) populations in an unused and off-road vehicle area in the Mojave Desert. *Chelonian Conservation and Biology* 4(2): 457–463.
153. Doak, D., P. Kareiva, and B. Klepetka. 1994. Modeling population viability for the desert tortoise in the western Mojave desert. *Ecological Applications* 4(3): 446–460.
154. Kristan, W.B. III, and W.I. Boarman. 2003. Spatial pattern of risk of common raven predation on desert tortoises. *Ecology* 84(9): 2432–2443.
155. Longshore, K.M., J.R. Jaeger, and J.M. Sappington. 2003. Desert tortoise (*Gopherus agassizii*) survival at two eastern Mojave desert sites: death by short-term drought? *Journal of Herpetology* 37(1): 169–177.
156. Fish and Wildlife Service. 1987. Department of the Interior, Fish and Wildlife Service, 50 CFR Part 17. Endangered and Threatened Wildlife and Plants; Determination of Endangered Status for the Alabama Red-Bellied Turtle; Final rule. Tuesday, June 16, 1987/Rules and Regulations. *Federal Register* 52(115): 22,940–22,943.
157. Fish and Wildlife Service. 1978. Department of the Interior, Fish and Wildlife Service, 50 CFR Part 17. Endangered and Threatened Wildlife and Plants; Listing of the Eastern

- Indigo Snake as a Threatened Species; Final rule. Tuesday, January, 1978/Rules and Regulations. *Federal Register* 43(21): 4,026–4,029.
158. Rave, E.H., A. Cooper, D. Hu, R. Swift, and K. Misajon. 2005. Population and reproductive trends of Nene *Branta sandvicensis* in Hawaii Volcanoes National Park, 1989–1999. *Wildfowl* 55: 7–16.
159. Breininger D.R., B. Toland, D.M. Oddy, and M.L. Legare. 2006. Landcover characterizations and Florida scrub-jay (*Aphelocoma coerulescens*) population dynamics. *Biological Conservation* 128: 169–181.
160. Fish and Wildlife Service. 1990. Endangered and Threatened Wildlife and Plants; Endangered Status for the Lower Keys Rabbit and Threatened Status for the Squirrel Chimney Cave Shrimp; Final rules. Thursday, June 21, 1990/Rules and Regulations. *Federal Register* 55(120): 25,588–25,591.
161. Cypher, B.L., C.D. Bjurlin, and J.L. Nelson. 2005. *Effects of Two-Lane Roads on Endangered San Joaquin Kit Foxes*. California State University: Fresno, CA.
162. Mowat, G., and B. Slough. 2003. Habitat preference of Canada lynx through a cycle in snowshoe hare abundance. *Canadian Journal of Zoology* 81(10): 1,736–1,745.
163. Poole, K.G. 2003. A review of the Canada lynx (*Lynx canadensis*) in Canada. *Canadian Field-Naturalist* 117(3): 360–376.
164. U.S. Fish and Wildlife Service. 2007. *Biological Opinion Route 161 Reconstruction and Widening Project Cross Lake, T17 R4, Aroostook County, Maine*. U.S. Fish and Wildlife Service, Maine Field Office, Old Town, ME, USA.
165. Fish and Wildlife Service. 1982. Department of the Interior, Fish and Wildlife Service, 50 CFR Part 17. Endangered and Threatened Wildlife and Plants; Endangered Status for US Population of the Ocelot; Final rule. Wednesday, July 21, 1982/Rules and Regulations. *Federal Register* 47(140): 31,670–31,672.
166. Foster, M.L., and S.R. Humphrey. 1995. Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin* 23(1): 95–100.
167. Main, M.B., F.M. Roka, and R.F. Noss. 1999. Evaluating costs of conservation. *Conservation Biology* 13(6): 1,262–1,272.
168. Kautz, R., R. Kawula, T. Hctor, J. Comiskey, D. Jansen, D. Jennings, J. Kasbohm, F. Mazzotti, R. McBride, L. Richardson, and K. Root. 2006. How much is enough? Landscape-scale conservation for the Florida panther. *Biological Conservation* 130: 118–133.
169. Fish and Wildlife Service. 1991. Department of the Interior, Fish and Wildlife Service, 50 CFR Part 17, RIN 1018–AB62. Endangered and Threatened Wildlife and Plants; Determination of Experimental Population Status for an Introduced Population of Red

- Wolves in North Carolina and Tennessee; Final rule. Monday, November 4, 1991/Rules and Regulations. *Federal Register* 56(213): 56,325–56,334.
170. Fredrickson, R.J., and P.W. Hedrick. 2006. Dynamics of hybridization and introgression in red wolves and coyotes. *Conservation Biology* 20(4): 1,272–1,283.
 171. Brown, J.W. 2006. *Eco-logical: An Ecosystem Approach to Developing Infrastructure Projects*. Report no. DOT-VNTSC-FHWA-06-01, U.S. Department of Transportation, Research and Innovative Technology Administration, Volpe National Transportation Systems Center: Cambridge, MA.
 172. Walker, D. 2004. Parks working to reduce wildlife deaths on highways. *The Jasper Booster* newspaper article, 28 July 2004. Available on the Internet, accessed 20 November 2006. (<http://cgi.bowesonline.com/pedro.php?id=69&x=story&xid=110923>)
 173. Hardy, A.R., S. Lee, and A.F. Al-Kaisy. 2006. Effectiveness of animal advisory messages as a speed reduction tool: A case study in Montana. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1973, pp. 64–72.
 174. Evink, G. 1996. Florida Department of Transportation initiatives related to wildlife mortality. In: Evink, G.L., P. Garrett, D. Zeigler, and J. Berry (eds.). *Proceedings of the Transportation Related Wildlife Mortality Seminar: Trends in Addressing Transportation Related Wildlife Mortality*. FL-ER-58-96. Florida Department of Transportation: Tallahassee, FL.
 175. Jacobs, W. 2001. *Roadside Wildlife Study*. Humane Society of the United States: Washington, DC.
 176. Knapp, K. 2005. Crash reduction factors for deer vehicle crash countermeasures. *Transportation Research Record* 1908: 172–179.
 177. Riley, S., and A. Marcoux. 2006. *Deer Vehicle Collisions: An Understanding of Accident Characteristics and Drivers' Attitudes, Awareness, and Involvement*. Research Report RC-1475. Michigan Department of Transportation: Lansing, MI.
 178. Buckingham, A. 1997. Licensed British Columbia drivers' attitude towards wildlife warning signs. In: Clevenger, A.P., and K. Wells (eds.). *Proceedings of the Second Roads, Rails and the Environment Workshop*: 55–59. Parks Canada, Banff National Park, Alberta & Columbia Mountains Institute of Applied Ecology: Revelstoke, Canada.
 179. DiGiorgio, M. 2006. Colorado on the Move Campaign: A wildly successful road ecology awareness campaign. In: Irwin, C.L., P. Garrett, and K.P. McDermott (eds.). *Proceedings of the 2005 International Conference on Ecology and Transportation: On the Road to Stewardship*: 570. San Diego, California. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.
 180. http://www.dps.state.ia.us/commis/pib/Releases/2006/10-05-2006_Deer.htm

181. Hindelang, M., D. Premo, E. Rogers, and K. Premo. 1999. Addressing deer vehicle accidents with a ecological landscape GIS approach. In: Evink, G.L., P. Garret, and D. Zeigler (eds.). *Proceedings of the Third International Conference on Wildlife Ecology and Transportation*: 185–192. Missoula, MT. FL-ER-73-99. Florida Department of Transportation, Tallahassee, FL.
182. Sullivan, T.L., and T. Messmer. 2003. Perceptions of deer vehicle collision management by state wildlife agency and department of transportation administrators. *Wildlife Society Bulletin* 31(1): 163–173.
183. Knapp, K.K., and X. Yi. 2004. Deer vehicle crash patterns and proposed warning sign installation guidelines. In: *Transportation Research Board 2004 Annual Meeting Compendium of Papers CD-ROM*. Washington, DC.
184. Krisp, J.M., and S. Durot. 2007. Segmentation of lines based on point densities: an optimization of wildlife warning sign placement in southern Finland. *Accident Analysis and Prevention* 39: 38–46.
185. Pojar, T.M., R.A. Prosence, D.F. Reed, and T.N. Woodard. 1975. Effectiveness of a lighted, animated deer crossing sign. *Journal of Wildlife Management* 39: 87–91.
186. Katz, B.J., G.K. Rousseau, and D.L. Warren. 2003. Comprehension of warning and regulatory signs for speed. In: *Proceedings of the 73rd Institute of Transportation Engineers Annual Meeting and Exhibit*. Seattle, WA.
187. Hammond, C., and M.G. Wade. 2004. *Deer Avoidance: The Assessment of Real World Enhanced Deer Signage in a Virtual Environment*. Final Report. Minnesota Department of Transportation. St. Paul, MN.
188. Green, M. 2000. How long does it take to stop? Methodological analysis of driver perception-brake times. *Transportation Human Factors* 2(3): 195–216.
189. Kloeden, C.N., A.J. McLean, V.M. Moore, and G. Ponte. 1997. *Traveling Speed and the Risk of Crash Involvement. Volume 1—Findings*. NHMRC Road Accident Research Unit. University of Adelaide, Australia. CR 172. Federal Office of Road Safety, Canberra, Australia.
190. Meyer, E. 2006. *Assessing the Effectiveness of Deer Warning Signs*. Final report K-TRAN: KU-03-6. The University of Kansas, Lawrence, KS.
191. Al-Ghamdi, A.S., and S.A. AlGadhi. 2004. Warning signs as countermeasures to camel-vehicle collisions in Saudi Arabia. *Accident Analysis and Prevention* 36: 749–760.
192. Stanley, L. A. Hardy, and S. Lassacher. 2006. Driver responses to enhanced wildlife advisories in a simulated environment. *TRB 2006 Annual Meeting CD-ROM*. Transportation Research Board: Washington, DC.
193. Williams, J.E. 1964. Deer, death and destruction. *Colorado Outdoors* 13(2): 1–3.

194. Arizona Court of Appeals. 2004. Booth v. State of Arizona. 2 CA-CV 2003-0097. Court of Appeals, State of Arizona, Division Two. Opinion Filed: 30 January 2004. Available from the Internet, accessed 29 November 2006.
(<http://www.apltwo.ct.state.az.us/Decisions/CV20030097Opinion.pdf>)
195. USA Traffic Signs. 2007. *Warning For Deer Crossing Sign*. USA Traffic Signs, Binghamton, New York. Available on the Internet, accessed 15 January 2007.
(<http://signs.safeshopper.com/84/cat84.htm>)
196. U.S. Department of Transportation, Federal Highway Administration. 2004. *Manual on Uniform Traffic Control Devices for Streets and Highways*. 2003 Edition Including Revision 1. November 2004. Washington, DC.
197. Huijser, M.P., P.T. McGowen, W. Camel, A. Hardy, P. Wright, A.P. Clevenger, L. Salsman, and T. Wilson. 2006. *Animal Vehicle Crash Mitigation Using Advanced Technology. Phase I: Review, Design and Implementation*. SPR 3(076). FHWA-OR-TPF-07-01, Western Transportation Institute, Montana State University, Bozeman, MT. Available from the Internet, accessed 20 November 2006.
(http://www.oregon.gov/ODOT/TD/TP_RES/ResearchReports.shtml)
198. Kistler, R. 1998. *Wissenschaftliche Begleitung der Wildwarnanlagen Calstrom WWA-12*. S. Juli 1995–November 1997. Schlussbericht. Infodienst Wildbiologie & Oekologie: Zürich, Switzerland.
199. Muurinen, I., and T. Ristola. 1999. Elk accidents can be reduced by using transport telematics. *Finncontact* 7(1): 7–8.
200. Kinley, T.A., N.J. Newhouse, and H.N. Page. 2003. *Evaluation of the Wildlife Protection System Deployed on Highway 93 in Kootenay National Park During Autumn, 2003*. Sylvan Consulting Ltd., Invermere, British Columbia, Canada.
201. Gordon, K.M., and S. H. Anderson. 2002. Motorist response to a deer-sensing warning system in western Wyoming. In: *Proceedings of the 2001 International Conference on Ecology and Transportation: A Time for Action*: 549–558. Keystone, CO. The Center for Transportation and the Environment, North Carolina State University: Raleigh, NC.
202. Kistler, R. 2002. Wildwarnanlagen bewähren sich. *CH Wild Info* (1): 1–2. Available from the Internet, accessed 12 August 2003.
(http://www.wild.unizh.ch/wininfo/wininfo_pdf/wininfo021.pdf)
203. Romer, J., and C. Mosler-Berger. 2003. Preventing wildlife vehicle accidents: the animal detection system CALSTROM: In: *Proceedings of the 2003 Infra Eco Network Europe Conference: Habitat Fragmentation Due to Transport Infrastructure and Presentation of the COST 341 Action*, Brussels, Belgium. Available from the Internet, accessed 27 September 2004. (<http://www.iene.info/>)
204. Mosler-Berger, C., and J. Romer. 2003. Wildwarnsystem CALSTROM. *Wildbiologie* 3: 1–12.

205. Bendix Commercial Vehicle Systems. 2002. *Bendix Xvision System Service Data*. Available from the Internet, accessed 28 November 2006.
(<http://www.bendix.com/downloads/195160.pdf>)
206. General Motors Corporation. 2003. *Cadillac DeVille Night Vision*. Available from the Internet, accessed 9 September 2003.
(<http://www.cadillac.com/cadillacjsp/models/feature.jsp?model=devilleandfeature=nightvision>)
207. Hirota, M., Y. Nakajima, M. Saito, M., and M. Uchiyama. 2004. Low-cost infrared imaging sensors for automotive applications. In: Valldorf, J., and W. Gessner (eds.). *Advanced Microsystems for Automotive Applications 2004*: 63–84. Available from the Internet, accessed 26 September 2004.
(http://www.springeronline.com/sgw/cda/pageitems/document/cda_downloadaddocument/0,11996,0-0-45-110604-0,00.pdf)
208. Honda Motor Co., Ltd. 2004. *Intelligent Night Vision System Able to Detect Pedestrians and Provide Driver Cautions*. Available from the Internet, accessed 26 September 2004.
(<http://www.all4engineers.de/preview.php?cms=andlng=enandalloc=34andid=560>)
209. gunson, K.E., and A.P. Clevenger. 2003. Large animal vehicle collisions in the central Canadian Rocky Mountains: patterns and characteristics. In: Irwin, C.L., P. Garrett, and K.P. McDermott (eds.). *Proceedings of the 2003 International Conference on Ecology and Transportation: Making Connections*: 355–366. Lake Placid, NY. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.
210. Farrell, T.M., and K.I. Morris. 1996. Moose-motor vehicle collisions: an increasing hazard in northern New England. *Archives of Surgery* 131: 377–381.
211. Schafer J.A., and S.T. Penland. 1985. Effectiveness of Swareflex reflectors in reducing deer vehicle accidents. *Journal of Wildlife Management* 49: 774–776.
212. Beier, P. 2006. Effects of artificial night lighting on terrestrial mammals. In: Rich, C., and T. Longcore (eds.). *Ecological Consequences of Artificial Night Lighting*: 19–42. Island Press: Washington, DC.
213. Biota Research and Consulting, Inc. 2003. *Jackson Hole Roadway and Wildlife Crossing Study, Teton County, Wyoming*. Final report for Jackson Hole Wildlife Foundation, Jackson, WY.
214. Hedlund, J.H, P.D. Curtis, G. Curtis, and A.F. Williams. 2003. *Methods to Reduce Traffic Crashes Involving Deer: What Works and What Does Not*. Prepared for Insurance Institute for Highway Safety, Virginia.
215. Transport Canada. 2003. *Overview of Technologies Aimed at Reducing and Preventing Large Animal Strikes*. Standards Research and Development Branch, Road Safety and Motor Vehicle Regulation Directorate, Ottawa, Canada.

216. Farrell J.E., L.R. Irby, and P.T. McGowen. 2002. Strategies for ungulate-vehicle collision mitigation. *Intermountain Journal of Sciences* 8: 1–18.
217. Reed, D.F., and T.N. Woodard. 1981. Effectiveness of highway lighting in reducing deer vehicle accidents. *Journal of Wildlife Management* 45(3): 721–726.
218. Miller, H. 1985. *Moose Vehicle Collisions in Newfoundland*. Research Report #34, Newfoundland Department of Transportation Planning and Research Division. (As cited in L-P Tardiff and Associates, Inc., 2003).
219. McDonald, M.G. 1991. Moose movement and mortality associated with the Glenn Highway expansion, Anchorage, Alaska. *Alces* 27: 208–219. (as cited in Biota Research and Consulting, Inc., 2003 and Wildlife Crossing Toolkit).
220. *Wildlife Crossing Toolkit*. Information on McDonald (1991). Available on the Internet, accessed 22 April 2008. (<http://www.fs.fed.us/r9/forests/shawnee/recreation/rogs/snake-migration.pdf>)
221. Griffith, M. 1994. Comparison of the safety of lighting options on urban freeways. *Public Roads* 58(2): 8–15.
222. Beier, P. 1995. Dispersal of juvenile cougars in fragmented habitat. *Journal of Wildlife Management* 59(2): 228–237.
223. Mode, N.A., E.J. Hackett, and G.A. Conway. 2005. Unique occupational hazards of Alaska: animal-related injuries. *Wilderness and Environmental Medicine* 16: 185–191.
224. U.S. Department of Transportation, Federal Highway Administration. 1978. *Roadway Lighting Handbook*. Implementation Package 78-15. Reprinted April 1984. Washington, DC.
225. U.S. Department of Transportation, Federal Highway Administration. 1983. *Roadway Lighting Handbook: Addendum to Chapter 6: Designing the Lighting System Using Pavement Luminance*. Addendum to Implementation Package 78-15. Washington, DC.
226. Gleason, J.S., and J.A. Jenks. 1993. Factors influencing deer vehicle mortality in east central South Dakota. *Prairie Naturalist* 25(4): 281–289.
227. Andreassen, H.P., H. Gundersen, and T. Storaas. 2005. The effect of scent-marking, forest clearing, and supplemental feeding on moose-train collisions. *Journal of Wildlife Management* 69(3): 1125–1132.
228. Jaren, V., R. Andersen, M. Ulleberg, P. H. Pedersen, and B. Wiseth. 1991. Moose-train collisions: the effects of vegetation removal with a cost-benefit analysis. *Alces* 27: 93–99.
229. Maine DOT, Department of Inland Fisheries and Wildlife, Secretary of State, Maine Turnpike Authority, and Department of Public Safety. 2004. State of Maine Multi-

- Agency Animal Crash Task Force. *Summary of 2004 Moose Collision Deterrents State of Maine, Maine*. URL <http://www.maine.gov/ifw/pdf/2004mooseactivities.pdf>.
230. Messmer, T.A., and B. West (eds.). 2000. *Wildlife and Highways: Seeking Solutions to an Ecological and Socio-Economic Dilemma*. 7th Annual Meeting of The Wildlife Society, Nashville, TN.
 231. D'Angelo, G.J., R.J. Warren, K.V. Miller, and G.R. Gallagher. 2004. *Literature Review: Evaluation of Strategies Designed to Reduce Deer Vehicle Collisions*. Prepared for Georgia Department of Transportation, GA.
 232. Higman, R. 1997. *Developing an Integrated Transport Policy*. Report by Friends of the Earth. Submitted to the Department of the Environment, Transport and the Regions, UK.
 233. Delaware Water Gap National Recreation Area. 2003. Cover me! "Nights of Migrating Dangerously" end as the park closes River Road to protect amphibians. U.S. Dept. of the Interior National Park Service. *Spanning the Gap* 25(1): Spring 2003.
 234. National Park Service. 2006. *Park Road Temporarily Closed for Amphibian Migration*. NPS Digest. Delaware Water Gap National Recreation Area, U.S. Dept. of the Interior National Park Service. Press release March 15, 2006.
(<http://home.nps.gov/applications/digest/printheadline.cfm?type=Announcements&id=4256>)
 235. Shawnee National Forest. 2006. *Snake Migration LaRue-Pine Hills*. Shawnee National Forest Mississippi Bluffs Ranger District.
(<http://www.fs.fed.us/r9/forests/shawnee/recreation/rogs/snake-migration.pdf>)
 236. Todaro, V. 2006. Salamander season has sprung: Lizard-like amphibians begin annual migration across Beekman Road. *Sentinel* (newspaper) March 16, 2006.
(http://ebs.gmnews.com/news/2006/0316/Front_Page/006.html)
 237. Bertwistle, J. 1999. The effects of reduced speed zones on reducing bighorn sheep and elk collisions with vehicles on the Yellowhead Highway in Jasper National Park. In: Evink, G.L., P. Garrett, and D. Zeigler (eds.). *Proceedings of the Third International Conference on Wildlife Ecology and Transportation*: 89–97. Missoula, MT. FL-ER-73-99. Florida Department of Transportation, Tallahassee, FL.
 238. National Research Council. 1998. *Managing Speed: Review of Current Practices for Setting and Enforcing Speed Limits*. Transportation Research Board, National Research Council of the National Academies. The National Academies Press: Washington, DC.
 239. West, B.H., R.N. McGill, J.W. Hodgson, S.S. Sluder, and D.E. Smith. 1997. *Development and Verification of Light-Duty Modal Emissions and Fuel Consumption Values for Traffic Models*. Federal Highway Administration, U.S. Department of Transportation.

240. Solomon, D. 1964. *Accidents on Main Rural Highways Related to Speed, Driver and Vehicle*. Federal Highway Administration, U.S. Department of Transportation.
241. Cerrelli, E. 1981. *Safety Consequences of Raising the National Speed Limit from 55 mph to 60 mph*. National Highway Traffic Safety Administration, U.S. Department of Transportation: Washington, DC.
242. Garber, N., and R. Gadiraju. 1988. *Speed Dispersion and Its Influence on Accidents*. AAA Foundation for Traffic Safety.
243. Gunther, K., M. Biel,, and H. Robinson. 1998. Factors influencing the frequency of road killed wildlife in Yellowstone National Park. In: Evink, G.L., P. Garrett, D. Zeigler, and J. Berry (eds.). *Proceedings of the International Conference on Wildlife Ecology and Transportation*: 32–42. Fort Myers, FL. FL-ER-69-98. Florida Department of Transportation, Tallahassee, FL.
244. Jones, M.E. 2000. Road upgrade, road mortality and remedial measures: impacts on a population of eastern quolls and Tasmanian devils. *Wildlife Research* 27: 289–296.
245. Cochran, M. 2006. ‘Bugle Corps’ clears the way for randy elk. *USA Today* newspaper article 24 September 2006. Available on the Internet, accessed 27 November 2006. (http://www.usatoday.com/news/nation/2006-09-24-bugle-corps_x.htm)
246. D’Angelo, G. J., J.G. D’Angelo, G.R. Gallagher, D.A. Osborn, K.V. Miller, and R.J. Warren. 2006. Evaluation of wildlife warning reflectors for altering white-tailed deer behavior along roadways. *Wildlife Society Bulletin* 34(4): 1175–1183.
247. Ford, S.G., and S.L. Villa. 1993. *Reflector Use and the Effect They Have on the Number of Mule Deer Killed on California Highways: Final Report*. Report FHWA-CA-PD94-01. California Department of Transportation: Sacramento, CA.
248. Reeve, A.F., and S.H. Anderson. 1993. Ineffectiveness of Swareflex reflectors at reducing deer vehicle collisions. *Wildlife Society Bulletin* 21: 127–132.
249. Cottrell, B. H. 2003. *Technical Assistance Report: Evaluation of Deer Warning Reflectors in Virginia*. VTRC 03-TAR6. Virginia Transportation Research Council in cooperation with U.S. Department of Transportation and Federal Highway Administration: Charlottesville, VA.
250. Pafko, F., and B. Kovach. 1996. *Experience with Deer Reflectors*. Trends in addressing transportation-related wildlife mortality. Minnesota Department of Transportation, Office of Environmental Services, Minnesota.
251. Barlow, C. 1997. Performance evaluation of wildlife reflectors in British Columbia. In: Clevenger, A.P., and K. Wells (eds.). *Proceedings of the Second Roads, Rails and the Environment Workshop*: 60–64. Parks Canada, Banff National Park, Alberta & Columbia Mountains Institute of Applied Ecology, Revelstoke, Canada.

252. Gulen, S., G. McCabe, and S.E. Wolfe. 2000. *Evaluation of Wildlife Reflectors in Reducing Vehicle-Deer Collisions on Indiana Interstate 80/90*. SPR-3 (076). Indiana Department of Transportation, Divisions of Research and Toll Roads, Indiana.
253. Grenier, R.H. 2002. *A Study of the Effectiveness of Strieter-Lite Wild Animal Warning Reflector Systems*. Available from the Internet, accessed 22 April 2008. (http://www.strieter-lite.com/images/scientific_report.pdf)
254. Sielecki, L.E. 2001. Evaluating the effectiveness of wildlife accident mitigation installations with the Wildlife Accident Reporting System (WARS) in British Columbia. In: *Proceedings of the 2001 International Conference on Ecology and Transportation: A Time for Action*: 473–489. Keystone, CO. The Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.
255. Sivic, A., and L. Sielecki. 2001. *Wildlife Warning Reflectors Spectrometric Evaluation*. Ministry of Transportation, British Columbia, Canada.
256. Page, M.A. 2006. A toolkit for reducing wildlife and domestic animal vehicle collisions in Utah. In: *Transportation Research Board 2006 Annual Meeting Compendium of Papers CD-ROM*. Washington, DC.
257. Zacks, J.L. 1986. Do white-tail deer avoid red? An evaluation of the premise underlying the design of Swareflex wildlife reflectors. *Transportation Research Record* 1075: 35–43.
258. TranSafety, Inc. 1997. Deer vehicle collisions are numerous and costly: do countermeasures work? *Road Management & Engineering Journal*, TranSafety, Inc., Available from the Internet, accessed 19 November 2006. (<http://www.usroads.com/journals/rmj/9705/rm970503.htm>)
259. TranSafety, Inc. 1997. Roadside wildlife reflectors: do they work? *Road Management & Management Journal*. Available on the Internet, accessed 18 November 2006 (<http://www.usroads.com/journals/rmj/9705/rm970504.htm>)
260. Ramp, D., and D. Croft. 2002. *Saving Wildlife: Saving People on Our Roads: Annual Report*. The University of New South Wales, School of Biological, Earth and Environmental Sciences. Prepared for the International Fund for Animal Welfare, Roads and Traffic Authority and the New South Wales Wildlife Information and Rescue Service, Australia.
261. Ujvari M., H.J. Baagoe, and A.B. Madsen. 1998. Effectiveness of wildlife warning reflectors in reducing deer vehicle collisions: a behavioral study. *Journal of Wildlife Management* 62: 1,094–1,099.
262. *Strieter-Lite*, Strieter Corp., Rock Island, IL. www.strieter-lite.com.
263. Romin, L., and L.B. Dalton. 1992. Lack of response by mule deer to wildlife warning whistles. *Wildlife Society Bulletin* 20: 382–384.

264. Bender, H. 2001. *Deterrence of kangaroos from roadways using ultrasonic frequencies: efficacy of the Shu Roo*. University of Melbourne, Department of Zoology Report. Prepared for NRMA Insurance Limited, Royal Automobile Club of Victoria, Road Traffic Authority of South Wales and Transport South Australia, Australia.
265. Gilsdorf, J.M., S.E. Hyngstrom, and K.C VerCauteren. 2002. Use of frightening devices in wildlife damage management. *Integrated Pest Management Review* 7: 29–45.
266. Hedlund, J.H, P.D. Curtis, G. Curtis, and A.F. Williams. 2004. Methods to reduce traffic crashes involving deer: What works and what does not. *Traffic Injury Prevention* 5: 122–131.
267. Bushman, R., J. Vinek, and E. McCaig. 2001. Development of a warning system for the reduction of animal/vehicle collisions. *Rural Advanced Technology & Transportation Systems 2001 International Conference*. Available from the Internet, accessed 28 November 2006. (<http://www.irdinc.com/library/pdf/wws-summary.pdf>)
268. Hunin, J. 2005. *Nepgeluiden klopjacht redden dierenlevens*. Volkskrant 21 May 2005. The Netherlands.
269. Firma Günter Josef Folda. 2007. *WIWASOL-II. Wildwarngerät der neuesten Generation*. (<http://www.wildwarner.at/pages/31alhomepag.html>)
270. ORF Tirol. 2007. *Verkehrssicherheit*. ORF Titol. (<http://tirol.orf.at/stories/144027/>)
271. Ujvari M., H.J. Baagoe, and A.B. Madsen. 2004. Effectiveness of acoustic road markings in reducing deer vehicle collisions: a behavioral study. *Wildlife Biology* 10: 155–159.
272. Scheifele, P.M., D.G. Browning, and L.M. Collins-Scheifele. 2003. Analysis and effectiveness of “deer whistles” for motor vehicles: frequencies, levels, and animals threshold responses. *Acoustics Research Letters Online* 4: 71–76.
273. Risenhoover, K., J. Hunter, R. Jacobson, and G. Stout. 1997. *Hearing Sensitivity in White Tailed Deer*. Texas A&M University Report, College Station, TX. Available on the Internet, last accessed 18 November 2006. (<http://lutra.tamu.edu/klr/hearing.htm>)
274. Muzzi, P. D., and A.R. Bisset. 1990. Effectiveness of ultrasonic wildlife warning devices to reduce moose fatalities along railway corridors. *Alces* 26: 37–43.
275. Kinley, T.A., and J. Newhouse. 2003. *Problem Statement: Potential to Develop an Area Repellant System to Deter Ungulates from Using Highways*. Prepared for Insurance Corporation of British Columbia, Kamloops, Canada.
276. Castiov, F. 1999. *Testing Potential Repellents for Mitigation of Vehicle-Induced Mortality of Wild Ungulates in Ontario*. MSc. Thesis. School of Graduate Studies and Research, Laurentian University, Ontario, Canada.

277. Lutz, W. 1994. Ergebnisse der Anwendung eines sogenannten Duftzaunes zur Vermeidung von Wildverlusten durch den Strassenverkehr nach Gehege- und Freilandorientierungen. *Zeitschrift für Jagdwissenschaft* 40: 91–108.
278. Johnson, K. 2001. All creatures great and small: states work to reduce animal-related crashes. *Traffic Safety* 1(5): 20–22.
279. Baker S.E., S.A. Ellwood, R. Watkins, and D.W. MacDonald. 2005. Non-lethal control of wildlife: Using chemical repellents as feeding deterrents for the European badger *Meles meles*. *Journal of Applied Ecology* 42: 921–931.
280. Brown, W.K., W.K. Hall, L.R. Linton, R.E. Huenefeld, and L.A. Shipley. 2000. Repellency of three compounds to caribou. *Wildlife Society Bulletin* 28(2): 365–371.
281. Shipley, L.A. 2001. Evaluating Wolfin™ as a Repellent to Wildlife on Roads in Washington and the Feasibility of Using Deer-Activated Warning Signs to Reduce Deer-Automobile Collisions on Highways in Washington. Research Project #T9902. Department of Natural Resource Sciences, Washington State University: Pullman, WA.
282. Kerzel, H., and U. Kirchberger. 1993. Erfolge im Kampf gegen Wildunfälle. *Die Pirsch* 18:3–5.
283. Lebersorger, P. 1993. Verkehrspartner Wild. *Weidwerk* 11: 47–48.
284. Law, M. 2005. Evaluation of Non-1080 Non-Lethal Techniques for Commercial Control of Marsupial Herbivores. Tasmanian Conservation Trust, Hobart, Tasmania, Australia.
285. Caro, T.M., L. Lombardo, A.W. Goldizen, and M. Kelly. 1995. Tail-flagging and other antipredator signals in white-tailed deer: new data and synthesis. *Behavioral Ecology* 6(4): 442–450.
286. Graves, H.B., and E.D. Bellis. 1978. *The Effectiveness of Deer Flagging Models as Deterrents to Deer Entering Highway Rights-Of-Way*. Institute for Research on Land and Water Resources, Pennsylvania State University, University Park, PA.
287. DeNicola, A.J., K.C. VerCauteren, P.D. Curtis, and S.E. Hygnstrom. 2000. *Managing White-Tailed Deer in Suburban Environments: A Technical Guide*. A publication of the Cornell Cooperative Extension, The Wildlife Society–Wildlife Damage Management Working Group, and the Northeast Wildlife Damage Research and Outreach Cooperative.
288. Peterson, M.N. 2003. *Management Strategies for Endangered Florida Key Deer*. MSc. Thesis. Texas A&M University, College Station, TX.
289. Klopppers, E.L., C.C. St. Clair, and T.E. Hurd. 2005. Predator-resembling aversive conditioning for managing habituated wildlife. *Ecology and Society* 10(1): 31. Available on the Internet, accessed 18 November 2006.
(<http://www.ecologyandsociety.org/vol10/iss1/art31/>)

290. VerCauteren, K.C., J.M. Gilsdorf, S.E. Hygnstrom, P.B. Fioranelli, J.A. Wilson, and S. Barras. 2006. Green and blue lasers are ineffective for dispersing deer at night. *Wildlife Society Bulletin* 34(2): 371–374.
291. Gibeau, M.L., and K. Heuer. 1996. Effects of transportation corridors on large carnivores in the Bow River Valley, Alberta. In: Evink, G.L., P. Garrett, D. Zeigler, and J. Berry (eds.). *Proceedings of the Transportation Related Wildlife Mortality Seminar: Trends in Addressing Transportation Related Wildlife Mortality*. FL-ER-58-96. Florida Department of Transportation, Tallahassee, FL.
292. Brownlee, L., P. Mineau, and A. Baril. 2000. Canadian Environmental Protection Act Priority Substances List: Supporting Documents for Road Salts: Road Salts and Wildlife: An Assessment of the Risk. Report submitted to the Environmental Resource Group on Road Salts, Commercial Chemicals Evaluation Branch, Environment Canada: Hull, Quebec, Canada.
293. Miller B.K., and J.A. Litvaitis. 1992. Use of roadside salt licks by moose (*Alces alces*) in northern New Hampshire. *Canadian Field-Naturalist* 106: 112–117.
294. Feldhamer, G.A., J.E. Gates, D.M. Harman, A.J. Loranger, and K.R. Dixon. 1986. Effects of interstate highway fencing on white-tailed deer (*Odocoileus virginianus*) activity. *Journal of Wildlife Management* 50(3): 497–503.
295. Bertwistle, J. 1997. Performance evaluation of mitigation measures in Jasper National Park, Alberta. In: Clevenger, A.P., and K. Wells (eds.). *Proceedings of the Second Roads, Rails and the Environment Workshop*: 65–71. Parks Canada, Banff National Park, Alberta & Columbia Mountains Institute of Applied Ecology, Revelstoke, Canada.
296. Fraser, D., and E.R. Thomas. 1982. Moose vehicle accidents in Ontario: relation to highway salt. *Wildlife Society Bulletin* 10: 261–265.
297. D'Itri, F.M. 1992. *Chemical Deicers and the Environment*. Lewis Publishers, Inc.: Chelsea, MI.
298. Wood, P., and M.L. Wolfe. 1988. Intercept feeding as a means of reducing deer vehicle collisions. *Wildlife Society Bulletin* 16: 376–380.
299. Case, R.M. 1978. Interstate highway road-killed animals: a data source for biologists. *Wildlife Society Bulletin* 6: 8–13.
300. Cain, A.T., V.R. Tuovila, D.G. Hewitt, and M.E. Tewes. 2003. Effects of a highway and mitigation projects on bobcats in Southern Texas. *Biological Conservation* 114(2): 189–197.
301. Hyman, W.A., and D. Vary. 1999. NCHRP Synthesis 272: Best Management Practices for Environmental Issues Related to Highway and Street Maintenance. Transportation Research Board, National Research Council: Washington, DC.

302. Evink, G.L. 2002. NCHRP Synthesis 305: Interaction Between Roadways and Wildlife Ecology: A Synthesis of Highway Practice. Transportation Research Board. National Academies: Washington, DC.
303. Wells, P., J. Woods, G. Bridgewater, and Morrison. 1999. Wildlife mortalities on railways: monitoring methods and mitigation strategies. In: Evink, G.L., P. Garrett, and D. Zeigler (eds.). *Proceedings of the Third International Conference on Wildlife Ecology and Transportation*: 85–88. Missoula, MT. FL-ER-73-99. Florida Department of Transportation: Tallahassee, FL.
304. Rea, R.V. 2003. Modifying roadside vegetation management practice to reduce vehicular collisions with moose (*Alces alces*). *Wildlife Biology* 9(2): 81–91.
305. Riley, S.J., and K. Sudharsan. 2006. *Environmental Factors Affecting the Frequency and Rate of Deer Vehicle Crashes (DVCs) in Southern Michigan*. Final report RC-1476. Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI. Prepared for Michigan Department of Transportation.
306. Varland, K.L., and P.J. Schaefer. 1998. Roadside management trends in Minnesota. In: Evink, G.L., P. Garrett, D. Zeigler, and J. Berry (eds.). *Proceedings of the International Conference on Wildlife Ecology And Transportation*: 214–228. Fort Myers, FL. FL-ER-69-98. Florida Department of Transportation: Tallahassee, FL.
307. Rea, R.V., and M.P. Gillingham. 2001. The impact of timing of brush management on the nutritional value of woody browse for moose (*Alces alces*). *Journal of Applied Ecology* 38: 710–719.
308. Brown, D.L., J. Laird, W.D. Summers, and A. Hamilton. 1999. Methods used by the Arizona Department of Transportation to reduce wildlife mortality and improve highway safety. In: Evink, G.L., P. Garret, and D. Zeigler (eds.). *Proceedings of the Third International Conference On Wildlife Ecology and Transportation*: 175-178. Missoula, MT. FL-ER-73-99. Florida Department of Transportation: Tallahassee, FL.
309. New York State Department of Transportation Region 8. 2006. *Road-Kill Deer Carcass Composting: Operation and Maintenance Manual*. New York.
310. Clevenger, A.P., and A.V. Kociolek. 2006. *Highway Median Impacts on Wildlife Movement and Mortality. State of the Practice Survey and Gap Analysis*. Final report. Research Report Number F/CA/MI-2006/09. Western Transportation Institute, Montana State University (WTI): Bozeman, MT.
311. Craven, S.R., C.M. Pils, and R.E. Rolley. 2000. The impacts of deer population management and roadside vegetation management on deer vehicle collisions in Wisconsin. In: Messmer, T.A., and B. West (eds.). *Proceedings of the 7th Annual Meeting of the Wildlife Society: Wildlife and Highways - Seeking Solutions to an Ecological and Socio-Economic Dilemma*: 148–150. Nashville, TN.

- 312. Brown, T.L., D.J. Decker, S.J. Riley, J.W. Enck, T.B. Lauber, P.D. Curtis, and G.F. Mattfeld. 2000. The future of hunting as a mechanism to control white-tailed deer populations. *Wildlife Society Bulletin* 28(4): 797–807.
- 313. Enck, J.W., D.J. Decker, and T.L. Brown. 2000. Status of hunter recruitment and retention in the United States. *Wildlife Society Bulletin* 28(4): 817–824.
- 314. Rooney, T.P. 2001. Deer impacts on forest ecosystems: a North American perspective. *Forestry* 74(3): 201–208.
- 315. Ditchkoff, S.S., S.T. Saalfeld, and C.J. Gibson. 2006. Animal behavior in urban ecosystems: modifications due to human-induced stress. *Urban Ecosystems* 9(1): 5–12.
- 316. Waller, D.M., and W.S. Alverson. 1997. The white-tailed deer: a keystone herbivore. *Wildlife Society Bulletin* 25(2): 217–226.
- 317. Swihart, R.K., H.P. Jr. Weeks, A.L. Easter-Pilcher, and A.J. DeNicola. 1998. Nutritional condition and fertility of white-tailed deer (*Odocoileus virginianus*) from areas with contrasting histories of hunting. *Canadian Journal of Zoology* 76(10): 1932–1941.
- 318. Riley, S.J., D.J. Decker, J.W. Enck, P.D. Curtis, T.B. Lauber, and T.L. Brown. 2003. Deer populations up, hunter populations down: implications of interdependence of deer and hunter population dynamics on management. *Ecoscience* 10(4): 455–461.
- 319. Nugent, G., and D.T. Choquenot. 2004. Comparing cost-effectiveness of commercial harvesting, state-funded culling, and recreational deer hunting in New Zealand. *Wildlife Society Bulletin* 32(2): 481–492.
- 320. Porter, W.F., H.B. Underwood, and J.L. Woodard. 2004. Movement behavior, dispersal, and the potential for localized management of deer in a suburban environment. *Journal of Wildlife Management* 68(2): 247–256.
- 321. Fulton, D.C., K. Skerl, E.M. Shank, and D.W. Lime. 2004. Beliefs and attitudes toward lethal management of deer in Cuyahoga Valley National Park. *Wildlife Society Bulletin* 32(4): 1166–1176.
- 322. Koval, M.H., and A.G. Mertig. 2004. Attitudes of the Michigan public and wildlife agency personnel toward lethal wildlife management. *Wildlife Society Bulletin* 32(1): 232–243.
- 323. Van Deelen, T.R., B. Dheuy, K.R. McCaffery, and R.E. Rolley. 2006. Relative effects of baiting and supplemental antlerless seasons on Wisconsin's 2003 deer harvest. *Wildlife Society Bulletin* 34(2): 322–328.
- 324. Brown, R.D., and S.M. Cooper. 2006. The nutritional, ecological, and ethical arguments against baiting and feeding white-tailed deer. *Wildlife Society Bulletin* 34(2): 519–524.

325. Cromwell, J.A., R.J. Warren, and D.W. Henderson. 1999. Live-capture and small-scale relocation of urban deer on Hilton Head Island, South Carolina. *Wildlife Society Bulletin* 27(4): 1,025–1,031.
326. Beringer, J., L.P. Hansen, J.A. Demand, J. Sartwell, M. Wallendorf, and R. Mange. 2002. Efficacy of translocation to control urban deer in Missouri: costs, efficiency, and outcome. *Wildlife Society Bulletin* 30(3): 767–774.
327. Miller, R.A., and J.B. Kaneene. 2006. Evaluation of historical factors influencing the occurrence and distribution of mycobacterium bovis infection among wildlife in Michigan. *American Journal of Veterinary Research* 67(4): 604–615.
328. Craven, S., T. Barnes, and G. Kania. 1998. Toward a professional position on the translocation of problem wildlife. *Wildlife Society Bulletin* 26(1): 171–177.
329. Turner, J.W.Jr., I.K.M. Liu, and J.F. Kirkpatrick. 1992. Remotely delivered immunocontraception in captive white-tailed deer. *Journal of Wildlife Management* 56(1): 154–157.
330. Turner, J.W. Jr., J.F. Kirkpatrick, and I.K.M. Liu. 1996. Effectiveness, reversibility, and serum antibody titers associated with immunocontraception in captive white-tailed deer. *Journal of Wildlife Management* 60(1): 45–51.
331. McShea, W.J., S.L. Monfort, S. Hakim, J. Kirkpatrick, I. Liu, J.W.Jr. Turner., L. Chassy, and L. Munson. 1997. The effect of immunocontraception on the behavior and reproduction of white-tailed deer. *Journal of Wildlife Management* 61(2): 560–569.
332. Waddell, R.B., D.A. Osborn, R.J. Warren, J.C. Griffin, and D.J. Kesler. 2001. Prostaglandin F₂-mediated fertility control in captive white-tailed deer. *Wildlife Society Bulletin* 29(4): 1,067–1,074.
333. Naz, R.K., S.K. Gupta, J.C. Gupta, H.K. Vyas, and G.P. Talwar. 2005. Recent advances in contraceptive vaccine development: a mini-review. *Human Reproduction (Oxford)* 20(12): 3271–3283.
334. Boone, J.L., and R.G. Wiegert. 1994. Modeling deer herd management: sterilization is a viable option. *Ecological Modeling* 72(3–4): 175–186.
335. Seagle, S.W., and J.D. Close. 1996. Modeling white-tailed deer (*Odocoileus virginianus*) population control by contraception. *Biological Conservation* 76(1): 87–91.
336. Rudolph, B.A., W.F. Porter, and H.B. Underwood. 2000. Evaluating immunocontraception for managing suburban white-tailed deer in Irondequoit, New York. *Journal of Wildlife Management* 64(2): 463–473.
337. Kirkpatrick, J.F., and A.T. Rutberg. 2001. Fertility control in animals. In: Salem D.J., and A.N. Rowan (eds.). *The State of the Animals 2001*. Humane Society Press: Washington, DC.

338. Kirkpatrick, J.F. J.W. Turner Jr., I.K.M. Liu, R. Fayrer-Hosken, and A.T. Rutberg. 1997. Case studies in wildlife immunocontraception: wild and feral equids and white-tailed deer. *Reproduction, Fertility and Development* 9z: 105–110.
339. Merrill, J.A., E.G. Cooch, and P.D. Curtis. 2003. Time to reduction: factors influencing management efficacy in sterilizing overabundant white-tailed deer. *Journal of Wildlife Management* 67(2): 267–279.
340. Walter, W.D., P.J. Perkins, A.T. Rutberg, and H.J. Kilpatrick. 2002. Evaluation of immunocontraception in a free-ranging suburban white-tailed deer herd. *Wildlife Society Bulletin* 30(1): 186–192.
341. Merrill, J.A., E.G. Cooch, and P.D. Curtis. 2006. Managing an overabundant deer population by sterilization: effects of immigration, stochasticity and the capture process. *Journal of Wildlife Management* 70(1): 268–277.
342. Nettles, V.F. 1997. Potential consequences and problems with wildlife contraceptives. *Reproduction Fertility and Development* 9(1): 137–143.
343. Shea, W.J., S.L. Montfort, S. Hakim, J. Kirkpatrick, I. Liu, J.W. Turner Jr., L. Chassy, and L. Munson. 1997. The effect of immunocontraception on the behavior and reproduction of white-tailed deer. *Journal of Wildlife Management* 61(2): 560–569.
344. Baker, D.L., M.A. Wild, M.M. Connor, H.B. Ravivarapu, R.L. Dunn, and T.M. Nett. 2004. Gonadotropin-releasing hormone agonist: A new approach to reversible contraception in female deer. *Journal of Wildlife Diseases* 40(4): 713–724.
345. Pettorelli, N., J.-M. Gaillard, N.G. Yoccoz, P. Duncan, D. Maillard, D. Delorme, G. Van Laere, and C. Toigo. 2005. The response of fawn survival to changes in habitat quality varies according to cohort quality and spatial scale. *Journal of Animal Ecology* 74(5): 972–981.
346. Gill, R.M.A., A.L. Johnson, A. Francis, K. Hiscocks, and A.J. Peace. 1996. Changes in roe deer (*Capreolus capreolus* L.) population density in response to forest habitat succession. *Forest Ecology and Management* 88(1–2): 31–41.
347. Darimont, C.T., P.C. Paquet, T.E. Reimchen, and V. Crichton. 2005. Range expansion by moose into coastal temperate rainforests of British Columbia, Canada. *Diversity and Distributions* 11: 235–239.
348. Cimino, L., and S. Lovari. 2003. The effects of food or cover removal on spacing patterns and habitat use in roe deer (*Capreolus capreolus*). *Journal of Zoology* (London) 261(3): 299–305.
349. Campbell, T.A., B.R. Lasetera, W.M. Ford, and K.V. Miller. 2004. Movements of female white-tailed deer (*Odocoileus virginianus*) in relation to timber harvests in the central Appalachians. *Forest Ecology and Management* 199: 371–378.

350. Woods, J.G. 1990. Effectiveness of Fences and Underpasses on the Trans-Canada Highway and Their Impact on Ungulate Populations. Report to Banff National Park Warden Service, Banff, Alberta, Canada.
351. Clevenger, A.P., B. Chruszcz, and K. Gunson. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. *Journal of Applied Ecology* 38: 1340–1349.
352. Dodd, N. L., J. W. Gagnon, S.Boe, A. Manzo, and R. E. Schweinsburg. 2007. Evaluation of measures to minimize wildlife-vehicle collisions and maintain permeability across highways: State Route 260, Arizona, USA. Final Project Report (2002-2006). Projects JPA 01-152 and JPA 04-024T. Submitted to Arizona Department of Transportation, Arizona Transportation Research Center, and the Federal Highway Administration. June 2007.
353. Reed, D.F., T.D.I. Beck, and T.N. Woodard. 1982. Methods of reducing deer vehicle accidents: benefit-cost analyses. *Wildlife Society Bulletin* 10: 349–354.
354. Ward, A.L. 1982. Mule deer behavior in relation to fencing and underpasses on Interstate 80 in Wyoming. *Transportation Research Record* 859: 8–13.
355. Boarman, W.I., and M. Sazaki. 1996. Highway mortality in desert tortoises and small vertebrates: success of barrier fences and culverts. In: Evink, G.L., P. Garrett, D. Zeigler, and J. Berry (eds.). *Proceedings of the Transportation Related Wildlife Mortality Seminar: Trends in Addressing Transportation Related Wildlife Mortality*. FL-ER-58-96. Florida Department of Transportation: Tallahassee, FL.
356. Sielecki, L.E. 1999. *WARS-Wildlife Accident Reporting System: 1998 Annual Report, 1994–1998 Synopsis*. British Columbia Ministry of Transportation and Highways, Victoria, Canada.
357. Seamans, T.W., and K.C. VerCauteren. 2006. Evaluation of ElectroBraide™ fencing as a white-tailed deer barrier. *Wildlife Society Bulletin* 34: 8–15.
358. Jaeger, J.A.G., and L. Fahrig. 2004. Effects of road fencing on population persistence. *Conservation Biology* 18(6): 1,651–1,657.
359. Leeson, B. F. 1996. Highway conflicts and resolutions in Banff National Park, Alberta, Canada. In: Evink, G.L., P. Garrett, D. Zeigler, and J. Berry (eds.). *Proceedings of the Transportation Related Wildlife Mortality Seminar: Trends in Addressing Transportation Related Wildlife Mortality*. FL-ER-58-96. Florida Department of Transportation, Tallahassee, FL.
360. Baines, D., and R.W. Summers. 1997. Assessment of bird collisions with deer fences in Scottish Forests. *Journal of Applied Ecology* 34(4): 941–948.
361. Dobson, J.D. 2001. Marking fences to reduce bird collisions in woodlands. *Scottish Forestry* 55(3): 168–169.

362. ElectroBraid. 2007. *Wildlife Exclusion with ElectroBraid™*. Available from the Internet, accessed 22 April 2008. (http://www.electrobraid.com/wildlife/wildlife_fence.html)
363. Griffin, K., and D.H. Pletscher. 2003. *Wildlife Barriers and Fencing*. University of Montana. Montana Department of Transportation Research Bureau, Montana.
364. Aresco, M. 2004. Turtles and highways: crossing the killing zone. *Humane Society of the United States and HSUS Wildlife Trust*, USA.
365. Jones, M.B., and W.M. Longhurst. 1958. Overhanging deer fences. *Journal of Wildlife Management* 22(3): 325–326.
366. Gloyne, C.C., and A.P. Clevenger. 2001. Cougar (*Puma concolor*) use of wildlife crossing structures on the Trans-Canada highway in Banff National Park, Alberta. *Wildlife Biology* 7(2): 117–124.
367. Grande, J., L.S. Katz, and G. Slifer. 2000. *Deer Fence Fact Sheet: High-Tensile Woven Wire Fences for Reducing Wildlife Damage*. Rutgers Cooperative Extension, New Jersey Agricultural Experiment Station, Rutgers University, New Jersey.
368. Clevenger, A.P., B. Chruszcz, K. Gunson, and J. Wierzbowski. 2002. *Roads and Wildlife in the Canadian Rocky Mountain Parks: Movements, Mortality and Mitigation*. Final report to Parks Canada: Banff, Alberta, Canada.
369. Falk, N.W., H.B. Graves, and E.D. Bellis. 1978. Highway right-of-way fences as deer deterrents. *Journal of Wildlife Management* 42: 646–650.
370. Ludwig, J., and T. Bremicker. 1983. Evaluation of 2.4 m fences and one-way gates for reducing deer vehicle collisions in Minnesota. *Transportation Research Record* 913: 19–22.
371. Dodd, N.L., J.W. Gagnon, and R.E. Schweinsburg. 2003. Evaluation of measures to minimize wildlife-vehicle collisions and maintain wildlife permeability across highways in Arizona. In: Irwin, C.L., P. Garrett, and K.P. McDermott (eds.). *Proceedings of the 2003 International Conference on Ecology and Transportation: Making Connections*: 353–354. Lake Placid, NY. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.
372. Kruidering, A.M., G. Veenbaas, R. Kleijberg, G. Koot, Y. Rosloot, and E. Van Jaarsveld. 2005. *Leidraad faunavoorzieningen bij wegen*. Rijkswaterstaat, Dienst Weg-en Waterbouwkunde, Delft, The Netherlands.
373. Iuell, B. (ed.). 2003. *Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions*. KNNV Publishers: Utrecht, The Netherlands.
374. Clevenger, A.P., and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology* 14: 47–56.

375. Clevenger, A.P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation* 121: 453–464.
376. Pfister, H.P., V. Keller, D. Heynen, and O. Holzgang. 2002. Wildtierökologische Grundlagen im Strassenbau. *Strasse und Verkehr* Nr. 3 March 2002: 101–108.
377. Reed, D.F., T.M. Pojar, and T.N. Woodard. 1974. Use of 1 way gates by mule deer. *Journal of Wildlife Management* 38(1): 9–15.
378. Clevenger, A.P., B. Chruszcz, K. Gunson, K., and M. Brumfit. 2002. *Highway Mitigation Monitoring: Three Sisters Parkway Interchange. Final Report*, August 1999–July 2002. Prepared for Alberta Sustainable Resource Development: Canmore, Alberta, Canada.
379. Lehnert, M.E. 1996. Mule Deer Highway Mortality in Northeastern Utah: An Analysis of Population-Level Impacts and a New Mitigative System. MSc. Thesis, Utah State University, Logan, UT.
380. Reed, D.F., T.M. Pojar, and T.N. Woodard. 1974. Mule deer responses to deer guards. *Journal of Range Management* 27(2): 111–113.
381. Peterson, M.N., R.R. Lopez, N.J. Silvy, C.B. Owen, P.A. Frank, and A.W. Braden. 2003. Evaluation of deer-exclusion grates in urban areas. *Wildlife Society Bulletin* 31(4): 1198–1204.
382. Austin, J.M., and L. Garland. 2001. Evaluation of a wildlife underpass on Vermont state highway 289 in Essex, Vermont. In: *Proceedings of the 2001 International Conference on Ecology and Transportation: A Time for Action*: 616–624. Keystone, CO. The Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.
383. Ruediger, B. 2005. *Management Considerations for Designing Carnivore Highway Crossings*. Wildlife Consulting Resources. Contracted by USDA Forest Service - Wildlife Fish and Watershed Unit, Washington, DC. Available on the Internet, accessed 22 November 2006. (http://www.safepassagecoalition.org/files/Mgmt_Con_Carnivores.pdf)
384. Levy, A. 2005. *Where the Wildlife Meets the Road*. Public Roads – U.S. Department of Transportation, Federal Highway Administration, May/June 2005. Available on the Internet, accessed 27 November 2006. (<http://www.tfhr.gov/pubrds/05may/01.htm>)
385. DiBari, J., J. Geck, N. Rees, and C. Van Dyke. 2004. *A Scoping Analysis to Assess the Effects of Roads in Alaska on Habitat Quality and Connectivity*. Final Report. Alaska Department of Transportation and Public Facilities, Alaska.
386. Smith, D. 1999. Identification and prioritization of ecological interface zones on state highways in Florida. In: Evink, G.L., P. Garrett, and D. Zeigler (eds.). *Proceedings of the Third International Conference on Wildlife Ecology and Transportation*: 209–230. FL-ER-73-99. Florida Department of Transportation, Tallahassee, FL.

387. Geodata Services, Inc. 2005. Idaho Transportation Department—District 6 Highway-Wildlife Linkage GIS Layers. Final Report.
388. Grist, R. R., Williams, S. K., and E. Finnen. 1999. Development of a Methodology for Determining Optimum Locations for Wildlife Crossings on State Highways Using a Geographic Information Systems Approach with Application to Key Deer on Big Pine Key, FL. Final report to Federal Highway Administration.
389. Mietz, S.N. 1994. Linkage Zone Identification and Evaluation of Management Options for Grizzly Bears in the Evaro Hill Area. MSc. Thesis. University of Montana, Missoula, MT.
390. Moore, T., and P. Thorsnes. 1994. *The Transportation/Land Use Connection: A Framework for Practical Policy*. 448/449. American Planning Association: Washington, DC.
391. Maurer, M.E. 1999. Development of a community-based, landscape-level terrestrial mitigation decision support system for transportation planners. In: Evink, G.L., P. Garrett, and D. Zeigler (eds.). *Proceedings of the Third International Conference on Wildlife Ecology and Transportation*: 99–110. FL-ER-73-99. Florida Department of Transportation, Tallahassee, FL.
392. Neuman T., M. Schwartz, L. Clark, and J. Bednar. 2002. *A Guide to Best Practices for Achieving Context Sensitive Solutions*. NCHRP Report 480.
393. American Association of State Highway Transportation Officials (AASHTO). 2004. *A Guideline for Achieving Flexibility in Highway Design*. ISBN 1-56051-259-8. May 2004.
394. Transtech Management Inc., Oldham Historic Properties Inc., and Brinckerhoff Quade and Douglas Inc. 2004. *Performance Measures for Context Sensitive Solutions—A Guidebook for State DOTs*. National Cooperative Highway Research Program Project 20-24(30) [Web document 69], October 2004. Last accessed May 21, 2007) (http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w69.pdf)
395. Bethelsen, G. 2003. The wildlife connection: Coal Canyon Preserve Project. *California Transportation Journal* 3(4): 11–18.
396. Switalski, T.A., J.A. Bissonette, T.H. DeLuca, C.H. Luce, and M.A. Madej. 2004. Benefits and impacts of road removal. *Frontiers in Ecology and the Environment* 2(1): 21–28.
397. Neuman, T.R., R. Pfefer, K.L. Slack, F. Council, H. McGee, L. Prothe,, and K. Eccles. 2003. NCHRP Report 500—Guidance for Implementation of the AASHTO Strategic Highway Safety Plan—Volume 6: A Guide for Addressing Run-Off-Road Collisions. National Cooperative Highway Research Program. Washington. DC, 2003.

- 398. Kilpatrick, H.J., and S.M. Spohr. 2000. Movements of female white-tailed deer in a suburban landscape: A management perspective. *Wildlife Society Bulletin* 28(4): 1,038–1,045.
- 399. Grund, M.D., J.B. McAninch, and E.P. Wiggers. 2002. Seasonal movements and habitat use of female white-tailed deer associated with an urban park. *Journal of Wildlife Management* 66(1): 123–130.
- 400. Kilpatrick, H.J., S.M. Spohr, and K.K. Lima. 2001. Effects of population reduction on home ranges of female white-tailed deer at high densities. *Canadian Journal of Zoology* 79(6): 949–954.