Suggested reference for this report:

Wildlife Vehicle Collision Reduction Study

REPORT TO CONGRESS

U.S. Department of Transportation
Federal Highway Administration

August 2007

Making America’s Highways Safer for Drivers and Wildlife
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 between meeting travel needs, human safety, and conserving wildlife.

On behalf of the Federal Highways Administration, the Western Transportation Institute at Montana State University, in partnership with the Louis Berger Group, Inc., has completed a national study that details the causes and impacts of Wildlife Vehicle Collisions (WVCs) 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.

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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 U.S. 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 Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), the US Congress directed the Secretary of Transportation to conduct a national Wildlife Vehicle Collision (WVC) study. This study details the causes and impacts of wildlife vehicle collisions 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.

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: A Collision with a White-Tailed Deer Can Result in Extensive Property Damage (Photo: Marcel Huijser).](image-url)
• 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 U.S. for which road mortality is documented as one of the major threats to their survival.

Figure ES2: Standard Deer Warning Sign Along Montana Highway 83 (Photo: Marcel Huijser).

• 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.

• 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.

Figure ES3: Seasonal Deer Migration Sign in Utah (Photo: Marcel Huijser).

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 and reporting of WVCs.
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- Develop and implement guidelines for the evaluation of 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 DOTs, resource agencies, and other transportation professionals regarding the findings of this study. A handbook and training course on wildlife-vehicle collision 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 wildlife vehicle collisions (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 wildlife vehicle collisions 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 Crashes (AVCs) resulted in no human injury (95.4 percent). Collisions with moose and other large animals can have a higher likelihood to result in a harmful event to the vehicle occupant.

Figure ES5: Collisions with Deer are Often Non-Fatal While Larger Animals Such as Moose are More Serious.
Is the Number of Accidents Increasing?

National trends were studied through reviewing several sources of crash data. The figure below illustrates 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. Looking at the data another way, AVCs now represent approximately 5 percent (or 1 in 20) of all reported motor vehicle collisions.

Figure ES6: Total Vehicle Crashes (top) and Total AVCs (bottom)
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 is associated with many more factors though, 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 surface.
- WVCs occur more frequently in the early morning (5-9 a.m.) and evening (4 p.m. – midnight), 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**

**Impacts on Travelers**

Wildlife vehicle collisions 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 of WVCs. 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.
Safety Risk

Collisions with large animals pose a safety risk to humans as well as wildlife. 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.

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. In the past 5 years (2001-2005), an average of 38,493 fatal crashes occurred (USDOT NHTSA 2005). 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
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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 wildlife vehicle collisions, 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:

- $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

Wildlife vehicle collisions can have other impacts on travelers that are more difficult to quantify in fiscal terms. Accidents with 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

Wildlife vehicle collisions 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 U.S. for which road mortality is among the major threats to the survival of the species. These species include mammals such as the San Joaquin kit fox, birds such as the Hawaiian goose, reptiles such as the desert tortoise, and amphibians such as the California tiger salamander.

Figure ES8: Hawaiian Goose Warning Sign (Photo: Haleakala National Park, National Park Service).

Figure ES9: Desert Tortoise (Photo: Marcel Huijser).

Figure ES10: San Joaquin kit fox (Photo: Brian L. Cypher, California State University, Stanislaus, Endangered Species Recovery Program).
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.

Threatened and Endangered Species

This study identified 21 federally listed threatened or endangered species in the U.S. 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 CA), 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

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

For this study 34 different techniques aimed at reducing the number of wildlife-vehicle collisions were identified and reviewed. This section only presents some examples of the mitigation measures aimed at reducing wildlife vehicle collisions; 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 FHWA is not recommending these measures by including them in this report.

**Influencing Wildlife Behavior**

Wildlife vehicle collisions can be reduced by influencing the behavior of animals. These efforts either attempt to deter animals from approaching the roadway, or to 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 wildlife vehicle collisions and are now used extensively. Wildlife fences typically consist of wire mesh fence material that is 2 to 2.5 meters (8 feet) tall, running parallel to the roadway. 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 ES11: Underpass in Southern Florida that Allows for Ecosystem Processes (Hydrology) as well as Wildlife Use, Including the Florida Panther (Photo: Marcel Huijser)

While correctly installed wildlife fencing is highly effective in reducing collisions, it must be carefully applied to avoid unintentional effects such as the creation of an absolute barrier that keeps animals from having access to 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 they are too few, too small, or too far apart. Therefore wildlife fencing is usually combined with safe crossing opportunities, such as wildlife underpasses 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.
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.

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 sized 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. 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.
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 is scarce. One field test in Minnesota showed that a deer population reduction program reduced winter deer densities by 46 percent and deer vehicle collisions by 30 percent. Sharp shooting 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 sharp shooting by professionals. 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. 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 deer-vehicle collisions at 50 percent. Finally, wildlife culling can be met by 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.
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 its 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 road kill data, animal movement data, aerial photos, and mapping tools to identify habitat linkage zones (areas of high animal movement) and wildlife vehicle collision
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 are implemented and that a reduction in WVCs is obtained.

- 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 evaluate 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. Having good data increases the probability that mitigation measures are implemented and that a reduction in WVCs is obtained.

- 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 animal leaps 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 increase vegetation and attract 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 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 may cause wildlife to pause at the barrier, or turn around, increasing their time in the roadway.
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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 ($\geq 80$ 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 wildlife vehicle collisions? This study identified several challenges that currently prevent a systematic, nationwide approach to WVC reduction.

Gaps in Knowledge/Insufficient Information/Lack of Data

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

There are no standards or guidelines for the collection of data on wildlife vehicle collisions. 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.
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 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 location 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 ES17: Animal Detection System Along US Hwy 191 in Yellowstone National Park, Montana (Photo: 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 wildlife vehicle collisions 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 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.
- 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 wildlife-vehicle collision reduction techniques will be developed by 2008, which will help in making the information available to practitioners.
# METRIC CONVERSION CHART

## SI* (MODERN METRIC) CONVERSION FACTORS

### APPROXIMATE CONVERSIONS TO SI UNITS

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### ILLUMINATION

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*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

In this document three abbreviations are used to describe collisions with animals:

- AVC: Animal Vehicle Collisions (AVCs) refer to collisions with wild and domestic animals in cases where domestic animals could not be separated from the dataset.

- WVC: Wildlife Vehicle Collisions (WVCs) include all species of wild animals.

- DVC: Deer Vehicle Collisions (DVCs) are those 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 is available.

- When information is specific to one type of animal other than deer, no abbreviation is used (e.g., moose vehicle collision).

In addition, the following symbols and abbreviations are used in this report:

“$” followed by a numerical value refer to dollar value. Unless otherwise specified, reported values are in United States dollars.

“Can$” followed by a numerical value refer to Canadian dollars.

“€” followed by a numerical value refers to Euros.

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 (AASHTO 2004a). In this report the time period is always 1 year.

AASHTO refers to the American Association of State Highway and Transportation Officials.

ADOT refers to the Arizona Department of Transportation

ADOT&PF refers to the Alaska Department of Transportation & Public Facilities.

BLM refers to the US Department of the Interior's Bureau of Land Management.
BTS refers to the Bureau of Transportation Statistics of the USDOT.

CaMg is the 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 refers to Dynamic Message Signs, also referred to by some as variable message signs (VMS).

FARS, Fatal Accident Reporting System, is a national dataset that includes all crashes with a human fatality.

FHWA refers to the Federal Highway Administration.

GES, the General Estimates System, is a dataset that enables estimates of national crash numbers based on a national sample.

GIS refers to Geographic Information Systems, which relates to spatial data standards and in some cases, sets of spatial data.

GPS refers to the Global Positioning System.

HSIS, the 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 refers to the International Union for Conservation of Nature.

kph refers to vehicle speed in units of kilometers per hour.
LED refers to Light-Emitting Diode, a technology used for, among other things, lighted signs and flashers.

MNDOT refers to the Minnesota Department of Transportation.

mph refers to speed in units of miles per hour.

MUTCD refers to the Manual on Uniform Traffic Control Devices, which provides national guidance and standards for, among other things, warning signs and signals.

NaCl is the chemical formula for sodium chloride (salt), a common deicing chemical.

NCHRP refers to the National Cooperative Highway Research Program.

NPS refers to the National Park Service.

NYSDOT refers to the New York State Department of Transportation.

ROW or right-of-way refers to the area owned by the transportation agency, including the roadside.

SAFETEA-LU represents Safe Accountable Flexible Efficient Transportation Equity Act: A Legacy for Users, which is the primary congressional bill for surface transportation programs, signed by President George W. Bush on August 2005.

State DOT refers to a state department of transportation in general (i.e., not a specific state).

STIP refers to the Statewide Transportation Improvement Plan (each state has one).

USDOT refers to the US Department of Transportation.

USFWS refers to the US Fish and Wildlife Service.

VMT refers to Vehicle Miles Traveled.
In the recently enacted transportation bill, Safe Accountable Flexible Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU Public Law 109-59), the US Congress directed the Secretary of Transportation to conduct a national wildlife vehicle collision (WVC) study. In response, the Federal Highway Administration (FHWA) sponsored a Wildlife Vehicle Collision 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 US, Canada, Europe, and elsewhere to promote the expertise, coordination, and effectiveness of transportation agencies in addressing WVCs and, ultimately, reduce WVCs on US 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 US, 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 US for which road mortality was documented as a major threat to their survival.

The remainder of this report provides information relating to wildlife vehicle collisions 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:
  - 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; and
  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:

• Best Management Practices Manual; and
• 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. Wildlife Vehicle Collisions (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 is available. When information is specific to one type of animal other than deer, no abbreviation is used (e.g., moose vehicle collision).
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, and
  - 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; and
- 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 (1996). States responded to this survey with a mix of crash record numbers, carcass counts, and estimates. Approximately 500,000 deer vehicle collisions were reported by 35 states. Conover et al. (1995) estimated that deer vehicle collisions 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.

There are three common sources of data for WVCs: carcass counts, insurance industry and police reported crashes. The first source, carcass counts, include 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 (Miles 2006). 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 over estimating 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 (the years are shown as fiscal years July1-June 30). This source of data typically does not contain detailed information about each crash.

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 this 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 is likely the most consistent nationally since more detail and effort go into reporting a fatal crash. However, the dataset is small with typically less than 200 AVC fatal crashes annually. In the past 5 years (2001-2005), an average of 38,493 fatal crashes occurred (USDOT NHTSA 2005). 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 (FARS)**

FARS data include those crashes where at least one person died within 30 days of the collision, from collision-related injury. Data were collected for a 5-year period (2001-2005). 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 website ([http://www-fars.nhtsa.dot.gov/](http://www-fars.nhtsa.dot.gov/)). 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)

The Highway Safety Information System (HSIS) data contains 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 24 January 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>
<thead>
<tr>
<th>State</th>
<th>Years</th>
<th>Thresholds</th>
<th>Animal Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>1998-2002</td>
<td>Differ by municipality: from $500 to $1000 or injury only.</td>
<td>Deer, Livestock, Other Animal (except in 2001)</td>
</tr>
<tr>
<td>Illinois</td>
<td>1999-2003</td>
<td>$500 or injury</td>
<td>Deer, Other Animal</td>
</tr>
<tr>
<td>Maine</td>
<td>2000-2004</td>
<td>$1000 or injury</td>
<td>Deer, Bear, Moose, Other Animal</td>
</tr>
<tr>
<td>Michigan</td>
<td>1993-1997</td>
<td>$400 or injury</td>
<td>Animal Only</td>
</tr>
<tr>
<td>North Carolina</td>
<td>2000-2004</td>
<td>$1000 or injury</td>
<td>Animal Only</td>
</tr>
<tr>
<td>Utah</td>
<td>1996-2000</td>
<td>$750 or injury</td>
<td>Wild or Domestic Animal</td>
</tr>
<tr>
<td>Washington</td>
<td>2000-2004</td>
<td>$750 or injury</td>
<td>Large Domestic, Small Domestic, Wild Animal</td>
</tr>
</tbody>
</table>

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)**

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 1 person was injured; and
- 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 sub-sample (e.g., time of day distributions), straight proportions were used assuming there were random samples across non-sampling unit variables. For these numbers, 2001-2005 GES data without weights was 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 was downloaded from ftp://ftp.nhtsa.dot.gov/ges/ (accessed 24 January 2007).

**Total Vehicle Miles Traveled**

Researchers collected data on vehicle miles traveled 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 vehicle miles traveled (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 US Department of Transportation, Bureau of Transportation Statistics (BTS) website at: \url{http://www.bts.gov/} (accessed 24 January 2007) (USDOT BTS 2005). 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 represents about one-fifth of the US 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 US.

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). In the past 5 years (2001-2005), an average of 38,493 fatal crashes occurred for all crash types (USDOT NHTSA 2005). Hence AVCs represent, on average, less than 0.5 percent of all fatal crashes.

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

<table>
<thead>
<tr>
<th>Source</th>
<th>Annual WVCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSIS</td>
<td>250,000</td>
</tr>
<tr>
<td>GES</td>
<td>292,000</td>
</tr>
<tr>
<td>Insurance Claims</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Carcass Counts</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>

Marcoux (2005) conducted a survey in Michigan and found that of the people involved in a DVC, only 52 percent reported it to their insurance company. 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; and
- 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-$1000 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 (Road Management & Engineering Journal 2000) found that WVCs increased 69 percent from 1985 to 1991.

Since GES data is likely the best source of national numbers, trends were examined using this data source, extending back to 1990. As shown in Figure 2, 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: Total Vehicle Crashes (top) and Total AVCs (bottom)

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 3 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.
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 (Joyce and Mahoney 2001, Putman 1997, Hughes et al. 1996) have shown that WVCs occur more frequently in the morning (5am to 8am), the evening (4pm to midnight), in the fall (October and November) and in the spring (May-June). 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 (e.g. Sudharsan et al. 2006). The spring peak is explained by distribution of young and migration.

Figure 4 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 does 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.
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 5).
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 6) do not have the major peak in November like deer (note All AVCs reported in Figure 4 are primarily deer). Bear vehicle collisions are fairly uniform in the summer, and non-existent in the winter during their hibernation period.

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 (Wells 2003). These numbers contrast sharply with the more regional trends presented in Figure 4.

For time of day, the three data sources all show the expected peaks at early morning and evening (Figure 7). Wildlife, especially deer, typically move around more at dusk and dawn.
SEVERITY

Williams and Wells (2004) looked at 147 fatal WVCs from nine different regions and found that the most common types were 1) a motorcyclist strikes an animal and falls off the vehicle, followed by 2) a passenger vehicle strikes an animal, goes off the road, strikes a fixed object or overturns. Safety measures (i.e., helmets and seat belts) were not used in 60-65 percent of the cases. Jones (2000a) also reported most fatal crashes involved motorcycles. This conclusion was confirmed by the FARS data. On average, 30 percent of the fatal crashes involving animals also involved motorcycles. Conn et al. (2004) investigated 22,498 emergency room visits where a motor vehicle collision with a large animal was identified as the cause. Of these, more than a 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 8 and 9 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 showed 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.
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 (2001) found that among moose vehicle collisions, 0.6 percent were fatal crashes and 26 percent were injury crashes.

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 10).

![Figure 10: Severity Distribution of Moose Vehicle Collisions in Maine (HSIS Data).](image)

**FACILITY TYPE**

Most studies that look at the types of roadways where WVCs occur report that they are most common on rural 2-lane rural roads (Road Management & Engineering Journal 2000). 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 11). This is not to say that upgrading all 2-lane roads would reduce WVCs. Reilly and Green (1974) found that the upgrade from 2 to 4 lanes in constructing Interstate 75 in Michigan initially resulted in a 500 percent increase in DVCs. 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.
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 (Meyer & Ahmed 2004; Knapp et al. In prep.). Using traffic flow theory, Langevelde and Jaarsma (2004) modeled the probability of successful wildlife road crossings based on relevant species, road and traffic characteristics. Traffic volume has a large effect on this probability, especially for slow-moving species (Langevelde & Jaarsma 2004).

Lower traffic volumes do not necessarily equate with fewer road kills (Jaarsma & Willems 2002). 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) (Huijser et al. 2000, Jaarsma & Willems 2002, Trocmé et al. 2003). Trocmé et al. (2003), Seiler (2003) and Alexander et al. (2005) hypothesized a relationship similar to that shown in Figure 12.
When analyzing the national crash data, AVCs are more likely to occur on low volume roads as shown in Figure 13. Almost half of WVCs in the HSIS states occurred on roadways with less than 5,000 average daily traffic (ADT).
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 14 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 88kph (55 mph) 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 88kph (55 mph) design speed in and of itself.
Seiler (2005) found a similar trend with moose in Sweden. Moose vehicle collisions peaked on roads with speed limits of 90 kph (56 mph) and declined at higher speeds. Although an old study, Cottam (1931) found that collisions with birds also occurred more frequently on higher speed roadways. Cramer and Portier (2001) found that Florida panther WVCs increased with an increase in posted speed and traffic flow.

As shown in Figure 15, the likelihood of fatal AVCs occurring on 88kph (55 mph) 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.
Chapter 2 Causes and Characteristics of Wildlife Vehicle Collisions

We refer to the diagram in Figure 15: 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 (1970) found there were fewer deer sightings during precipitation. 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 (Pynn & Pynn 2004).

**ANIMAL SPECIES**

Data regarding animal species affected by WVCs varies considerably by state. Williams and Wells (2004) characterized 147 fatal WVCs from nine states in different regions of the US between 2000 and 2002. 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, page 6). Illinois and Minnesota recorded deer vehicle collisions 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 between 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 animal vehicle collisions (Figure 16).
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 16: Animal Species Involved in Collisions in California (HSIS Data).](image)

In Maine, 81 percent of AVCs were attributable to deer and 15 percent attributable to moose (Figure 17). Maine also recorded whether collisions occurred with bears and other animals.
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 18). Washington reported a preponderance of collisions with wild animals. In Utah, over the 5 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.
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 deer vehicle collisions 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) (Finder et al. 1999, Huijser et al., in prep.). 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 (Puglisi et al. 1974, Mundinger 1979, Leach 1982, Arno et al. 1987, Leach & Edge 1994, Finder et al. 1999, Nielsen et al. 2003, Rogers 2004, Huijser et al., in prep.).

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 (Carbaugh 1970, Malo et al. 2004, Bashore et al. 1985, Nielsen et al. 2003, Seiler 2005, Huijser et al., in prep.).

Mule deer (*Odocoileus hemionus*) vehicle collisions are sometimes associated with seasonal migration corridors (Lehnert & Bissonette 1997, Gordon et al. 2004, Sullivan et al. 2004). Seasonal migration of mule deer typically occurs in mountainous and heavy snow fall areas (D’Eon & Serrouya 2005). Furthermore, mule deer vehicle collisions have been associated with...
large drainages and heavy cover (Romin & Bissonette 1994, McClure et al. 2005). Mule deer tend to avoid sites with human disturbance (Sawyer et al. 2006) and deep snow (Poole & Mowat, 2005). Nonetheless, mule deer can adapt to an urban or suburban environment (McClure et al. 2005, VerCauteren et al. 2005).

The relationship between slopes and DVCs is uncertain. Carbaugh (1970) found that deer favored steep declines and inclines and rarely used level areas. By contrast, Malo et al. (2004) found that lateral embankments, especially with guardrail, negatively correlated with DVCs. Alexander and Waters (2000) 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. Pellet (2004) found that on a section of Interstate 90 near Bozeman, Montana, 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.

**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 non-fatal 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 19), which reinforces the hypothesis that swerving to avoid a WVC may result in a higher severity collision.

![Figure 19: Fatal AVCs by Collision Type (FARS Data).](image-url)
DEER POPULATION DENSITY

A relationship between deer population density and DVCs has been documented in several studies (Doerr et al. 2001, Knapp et al. 2004, Iowa Department of Natural Resources 2005). Over the last century deer population size has increased strongly in most regions in the United States (Côté et al. 2004). 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 (review in Côté et al. 2004). 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 (Deer Vehicle Crash Information Clearinghouse 2007). In Iowa population size estimates for white-tailed deer increased from 500-700 in 1936, to 360,000 in 2004 (Iowa Department of Natural Resources 2005). In Wisconsin, the deer population estimates between 1993 and 2004 were poorly correlated with the number of deer vehicle collisions (Deer Vehicle Crash Information Clearinghouse 2007). 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 (Iowa Department of Natural Resources 2005). The increase has been especially strong since the 1960s (Porter & Underwood 1999, Côté et al. 2004). The increase in deer abundance is correlated with the number of deer vehicle collisions, at least across relatively large areas (Knapp et al. 2004, Putman et al. 2004, Iowa Department of Natural Resources 2005), but this correlation has not been analyzed at a national level.

The relationship between deer population density and the number of deer vehicle collisions seems intuitive, but this is not necessarily the case (Waring et al. 1991, Lehnert et al. 1998). A comprehensive review by Knapp et al. (2004) and Putman et al. (2004) suggests that a reduction of the population size across a relatively wide area can be effective in reducing deer vehicle collisions (Danielson & Hubbard 1998, Doerr et al. 2001, Schwabe et al. 2002, Knapp et al. 2004, Iowa Department of Natural Resources 2005). 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 deer vehicle collisions by 30 percent (Doerr et al. 2001).

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 is shown in Figure 20). The peak in the number of crashes (all types combined) for younger drivers (i.e., ages 16-25), seen in Figure 20, is typically explained by inexperience and more risky driving behavior. Specific attributes of younger drivers include less skill at detecting hazards, less able to conduct some driving tasks automatically, being easily distracted, less skill in performing emergency maneuvers, less perception of risk, and overestimation of driving abilities (Turner Fairbanks Highway Research Center 2001). For middle aged drivers, their chances of being involved in a crash are fairly constant across this age group, but less than that of younger age groups (Figure 20). 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 20).

The unexpected finding is that, in contrast to the distribution for all crashes, WVC crashes have no pronounced spike for young drivers (Figure 20). 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 20: Age Distribution for all Crashes and AVCs (HSIS Data).](image)

To further investigate the relationship between age and WVCs, the national household travel survey (USDOT BTS 2001) and US Census (2000) data were combined to estimate a VMT breakdown by age group. This VMT was used to determine a crash rate by age category for the GES data. Young drivers (age 15 to 19) had a crash rate 3.7 times higher than middle aged drivers (age 25 to 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 factor in being involved in a WVC, it does play a factor in being injured. As noted previously, Conn et al. (2004) found that persons between ages 15 and 24 were by far the highest category of emergency room injuries attributed to WVCs.

**SUMMARY**

This review of the national crash databases showed that animal-vehicle collisions have become more important, both in 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 US. The review of reported crashes for large animals showed that WVCs are more commonly or typically:

- 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);
- The proportion of crashes was comparative for the younger and medium aged 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; and
- 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 sized 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 wildlife vehicle collisions. It focuses on impacts that can be converted to monetary values. There are other impacts associated with wildlife vehicle collisions that may not be easily quantifiable. Nonetheless, the cost estimates that are presented are an important component in justifying potential mitigation measures to reduce wildlife vehicle collisions.

METHODS

WTI researchers estimated the costs for wildlife-vehicle collisions in two ways. First, they estimated the costs for the average wildlife-vehicle collision based on property damage, human injuries and human fatalities. Secondly, they estimated the costs for species specific wildlife vehicle collisions 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 animal-vehicle collisions 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 (USDOT 1994), corrected for the Gross Domestic Product Deflator through the fourth quarter in 2006 (Economagic, 2007). 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 animal-vehicle collisions across the maximum severity categories is based on the data presented in Figure 8 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.

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

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 between 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 which resulted in property damage was estimated at 90.2 percent – 3,524 collisions with property damage out of 3,905 collisions (L-P Tardiff & Associates, Inc. 2003). In Utah this percentage was estimated at 94 percent (Romin & Bissonette 1996). 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 moose. Property damage (repair costs for vehicles) has been estimated by a number of studies:

In British Columbia, the costs for deer collisions with passenger vehicles were estimated at Can$1,222 (Clayton Resources Ltd. & Glen Smith Wildlife Consultants 1989).

The cost for deer collisions on average for different regions in the United States in 1993 were estimated at $1,577 (Conover et al. 1995).

In New Mexico, the average vehicle repair cost of an elk vehicle collision was estimated at $3,448, based on 7 collisions (Biggs et al. 2004).

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 (see review in Rea 2004).

In British Columbia, the estimated average claim for a deer vehicle collision was Can$1,222 and a moose vehicle collision was Can$3,358 (Clayton Resources Ltd. & Glen Smith Wildlife Consultants 1989).


An average value of $2,300 was reported for the United States in 2002 (US Department of Transportation 2002).

Based on these various values, it was assumed for this analysis that the average vehicle repair costs as a result of animal vehicle collisions 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 animal vehicle collision with each species were estimated at $1,840 (deer), $3,000 (elk), and $4,000 (moose).

**HUMAN INJURIES**

Animal vehicle collisions can cause human injuries (Conover et al. 1995, Groot Bruinderink & Hazebroek 1996, L-P Tardiff & Associates, Inc. 2003, Conn et al. 2004, Pynn & Pynn 2004). In the United States, animal vehicle collisions were estimated to result in 26,647 human injuries per year (average for 2001-2002) (Conn et al. 2004). 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 (Conn et al. 2004).

The percentage of white-tailed deer vehicle collisions resulting in human injuries was estimated at 1.3 percent in Finland (Haikonen & Summala 2001); 3.8 percent in the US Midwest (Knapp et al. 2004); 4 percent in Ohio (review in Schwabe et al., 2002), 4 percent (review in Conover et al. 1995), 7.7 percent in Ohio (Schwabe et al. 2002); and 9.7 percent in Nova Scotia (L-P Tardiff & Associates, Inc. 2003).

The percentage of moose vehicle collisions resulting in human injuries was estimated at 9.9 percent in Finland (Haikonen & Summala 2001); 11.2 percent in Sweden (review in Lavsund & Sandegren 1991); 18 percent in Newfoundland and Labrador (Government of Newfoundland and...
Chapter 3 Economic Impacts of Wildlife Vehicle Collisions

Labrador (1997); 21.8 percent in Newfoundland (L-P Tardiff & Associates, Inc. 2003); 23 percent in Maine (Figure 10, Chapter 2); 20 percent in rural Alaska (Thomas 1995); and 23 percent in Anchorage, Alaska (Garrett & Conway 1999). The ratio of moose vehicle collisions to human injuries was estimated at 1:0.201 in Newfoundland (Rathey & Turner 1991) and 1:0.304 in Anchorage, Alaska (Garrett & Conway 1999). 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 animal vehicle collision 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 Tables 4 and 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.

<table>
<thead>
<tr>
<th>Type of Human Injury</th>
<th>Deer</th>
<th>Elk</th>
<th>Moose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible</td>
<td>$627</td>
<td>$1,254</td>
<td>$2,508</td>
</tr>
<tr>
<td>Evident</td>
<td>$887</td>
<td>$1,775</td>
<td>$3,550</td>
</tr>
<tr>
<td>Incapacitating/severe</td>
<td>$1,187</td>
<td>$2,374</td>
<td>$4,749</td>
</tr>
<tr>
<td>Total</td>
<td>$2,702</td>
<td>$5,403</td>
<td>$10,807</td>
</tr>
</tbody>
</table>

HUMAN FATALITIES

While rare, animal vehicle collisions can cause human fatalities (Conover et al. 1995, Groot Bruinderink & Hazebroek 1996, L-P Tardiff & Associates, Inc. 2003, Williams & Wells 2004). 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) (Schwabe et al. 2002); 0.029 percent in North America (review in Schwabe et al. 2002); 0.03 percent in the US Midwest (33 collisions with human fatalities from 125,608 collisions) (Knapp et al. 2004); and 0.05 percent in Nova Scotia (2 collisions with human fatalities from 3,905 collisions) (L-P Tardiff & Associates, Inc. 2003).

White tailed deer are the most common species involved in fatal WVC. 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 (Williams & Wells 2004).
The percentage of moose vehicle collisions resulting in human fatalities was estimated at 0 percent in Anchorage, Alaska (0 fatalities from 519 collisions) (Garrett & Conway 1999); 0.26 percent in Newfoundland (14 fatalities from 5422 collisions) (Joyce & Mahoney 2001), 0.36 percent in Newfoundland (6 collisions with human fatalities from 1662 collisions) (L-P Tardiff & Associates, Inc. 2003), 0.45 percent in Newfoundland (3 fatalities from 661 collisions) (Rattey & Turner 1991); 0.43 percent in Maine (Figure 10, Chapter 2); 0.5 percent in Sweden (review in Lavsund & Sandegren 1991); and 0.50 percent in rural Alaska (Thomas 1995).

For this analysis it was assumed that an animal vehicle collision 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 wildlife vehicle collisions 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 (Clayton Resources Ltd. & Glen Smith Wildlife Consultants 1989). 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 animal vehicle collision.

**MONETARY VALUE OF ANIMALS**

Animals usually die immediately or shortly after having been hit by a vehicle. In Michigan, Allen and McCullough (1976) 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. 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 animal vehicle collision 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 (Sielecki 2004).
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 (Sielecki 2004). The total net return to the economy of British Columbia from recreational wildlife viewing was estimated at Can$174,000,000 per year (Sielecki 2004). 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 hemionus columbianus*), white-tailed deer, elk, moose, and bighorn sheep (*Ovis canadensis*) (Sielecki 2004). 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 (Biggs et al. 2004). In Utah, Romin and Bissonette (1996) estimated the economic value of a deer at $1,313 in 1992. Bissonette and Hammer (2000) estimated the value of deer in Utah in 1999 at $2,420. 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 (Sielecki 2004). 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 wildlife-vehicle collisions, 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 wildlife vehicle collisions is summarized in Table 6. Bear in mind that this analysis is based on a series of assumptions and estimates, which 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 deer vehicle collisions per year in the United States, the estimated total cost associated with wildlife vehicle collisions 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>
<thead>
<tr>
<th>Description</th>
<th>Deer</th>
<th>Elk</th>
<th>Moose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle repair costs per collision</td>
<td>$1,840</td>
<td>$3,000</td>
<td>$4,000</td>
</tr>
<tr>
<td>Human injuries per collision</td>
<td>$2,702</td>
<td>$5,403</td>
<td>$10,807</td>
</tr>
<tr>
<td>Human fatalities per collision</td>
<td>$1,671</td>
<td>$6,683</td>
<td>$13,366</td>
</tr>
<tr>
<td>Towing, accident attendance and investigation</td>
<td>$125</td>
<td>$375</td>
<td>$500</td>
</tr>
<tr>
<td>Monetary value animal per collision</td>
<td>$2,000</td>
<td>$3,000</td>
<td>$2,000</td>
</tr>
<tr>
<td>Carcass removal and disposal per collision</td>
<td>$50</td>
<td>$100</td>
<td>$100</td>
</tr>
<tr>
<td>Total</td>
<td>$8,388</td>
<td>$18,561</td>
<td>$30,773</td>
</tr>
</tbody>
</table>
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 reviews in Forman & Alexander 1998, Spellerberg 1998, Forman et al. 2003, National Research Council 2005). 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 (1976) 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. 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 road kill, sometimes in massive numbers. Seiler (2003) provided a review of estimates of the number of road killed animals. 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 (Humane Society 1960 cited in Lalo 1987). The number of deer vehicle collisions in the United States was estimated to exceed 500,000 per year (Romin & Bissonette 1996); around 538,000 per year (L.A. Romin and J.A. Bissonette, Utah Cooperative Fish and Wildlife Research Unit, unpublished data, cited in Romin & Bissonette 1994); and greater than 1,000,000 per year (Conover et al. 1995).

The number of wildlife vehicle collisions and animal carcasses is often underestimated (as previously discussed in Chapter 2); researchers have calculated the underestimation by 10.3 percent (L-P Tardiff & Associates, Inc. 2003), 25 percent (Sielecki 2004), 50 percent (Conover et al. 1995, L-P Tardiff & Associates, Inc. 2003, Huijser et al. 2006a), 77.5 percent (L-P Tardiff & Associates, Inc. 2003), and 87.9 percent (L-P Tardiff & Associates, Inc. 2003). These estimates for underreporting apply especially to deer, as this species is involved in the vast majority of all reported animal vehicle or large wildlife vehicle collisions in North America; for example, 80 percent in Saskatchewan (L-P Tardiff & Associates, Inc. 2003), and 81.4 percent in Maine (Maine Department of Transportation 2001). 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 (Slater 2002).

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 (Carr & Fahrig 2001, Gibbs and Shriver 2002, Forman et al. 2003, Jaeger et al. 2005).
Roads and traffic can reduce population densities for some species such as different frogs and toads (Fahrig et al. 1995), the western European hedgehog (Erinaceus europaeus) (Huijser & Bergers 2000), and the desert tortoise (Gopherus agassizii) (Boarman & Sazaki 2006). 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 (Mader 1984, Ewing et al. 2005). 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); Vos & Chardon 1998), (leopard frog (Rana pipiens); Carr & Fahrig 2001), (spotted salamander (Ambystoma maculatum); Gibbs & Shriver 2005), reptiles (timber rattlesnakes (Crotalus horridus); Craig and Burgdorf 1997), (land and large bodies pond turtles including the box turtle (Terrapene ornata); Gibbs & Shriver, 2002), mammals (western European hedgehog; Bergers & Nieuwenhuizen 1999), (Eurasian badger (Meles meles); Bekker & Caners 1997, Clarke et al. 1998), (otter (Lutra lutra); Guter et al. 2005, Robitaille & Laurence 2002), (ocelot (Leopardus pardalis) Haines et al. 2005a), (Florida panther (Felis concolor coryi); Maehr et al. 1991), (Iberian lynx (Lynx pardinus); Ferreras et al. 2001), (Florida Key deer (Odocoileus virginianus clavium); Harveson et al. 2004).

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 (US Fish and Wildlife Service 2006b) were combined into one list. If different populations of the same species were listed, they were treated separately. 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 (IUCN 2006); 3) Other sources, including publications on individual species or species groups and expert opinions (Appendix A). 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 twenty-one 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 (US Fish and Wildlife Service, 2006b) for which Direct Road Mortality is among the Major Threats to the Survival Probability of the Species.

<table>
<thead>
<tr>
<th>Species Group</th>
<th>Species Name</th>
<th>Sources Justifying the Inclusion of the Species Concerned in this Table</th>
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<tr>
<td></td>
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<td>Federal Listing Documents</td>
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<tr>
<td>Amphibians</td>
<td>California tiger salamander (Ambystoma californiense), C. CA, S. Barb., Son. county</td>
<td>Fish and Wildlife Service 2004</td>
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<tr>
<td>Amphibians</td>
<td>Flatwoods salamander (Ambystoma cingulatum)</td>
<td>Fish and Wildlife Service 1999</td>
</tr>
<tr>
<td>Amphibians</td>
<td>Houston toad (Bufo houstonensis)</td>
<td>Threats not discussed</td>
</tr>
<tr>
<td>Reptiles</td>
<td>American crocodile (Crocodylus acutus)</td>
<td>Fish and Wildlife Service 2005</td>
</tr>
<tr>
<td>Reptiles</td>
<td>Desert tortoise (Gopherus agassizii), except in Sonoran Desert</td>
<td>Fish and Wildlife Service 1989</td>
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<tr>
<td>Reptiles</td>
<td>Gopher tortoise (Gopherus polyphemus), W of Mobile/Tombigbee Rs.</td>
<td>Fish and Wildlife Service 1987a</td>
</tr>
<tr>
<td>Reptiles</td>
<td>Alabama red-bellied turtle (Pseudemys alabamensis)</td>
<td>Collisions not listed as a threat</td>
</tr>
<tr>
<td>Reptiles</td>
<td>Bog turtle (Muhlenberg) northern population (Clemmys muhlenbergii)</td>
<td>Fish and Wildlife Service 1997a</td>
</tr>
<tr>
<td>Reptiles</td>
<td>Copperbelly water snake (Nerodia erythrogaster neglecta)</td>
<td>Fish and Wildlife Service 1997b</td>
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International Union for Conservation of Nature and Natural Resources

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<th>Sources Justifying the Inclusion of the Species Concerned in this Table</th>
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<tr>
<td>Barry &amp; Shaffer 1994, Jennings &amp; Hayes 1994, Pyke 2005, Dave Johnston, California Department of Fish and Game, California, personal communication</td>
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<tr>
<td>Bruce Means, Coastal Plains Institute and Land Conservancy, Tallahassee, Florida, personal communication, John Palis, Palis Environmental Consulting, Jonesboro, Illinois, personal communication</td>
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<td>Peterson et al. 2004</td>
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<td>Mazzotti &amp; Cherkiss 2003, Richards et al. 2004</td>
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<td>Roe et al. 2006</td>
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<td>Species Group</td>
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Amphibians

The California tiger salamander (*Ambystoma californiense*) is affected by habitat loss due to urbanization and agriculture, unnatural hydrology, predation by non-native 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 non-native tiger salamanders, and storm water road runoff (Barry & Shaffer 1994, Jennings & Hayes 1994, Fish and Wildlife Service 2004, Pyke 2005, IUCN 2006, Dave Johnston, California Department of Fish and Game, California, personal communication).

The Flatwoods salamander (*Ambystoma cingulatum*) was listed because of habitat loss and habitat alteration (Fish and Wildlife Service 1999, Whiles et al. 2004). However, direct mortality (road mortality during migration, capture by bait collectors) is also a potential threat to this species (IUCN 2006, Bruce Means, Coastal Plains Institute and Land Conservancy, Tallahassee, Florida, personal communication, John Palis, Palis Environmental Consulting, Jonesboro, Illinois, personal communication). 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 non-native fish species) are thought to be the primary cause of the decline (Means et al. 1996). 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 (Peterson et al. 2004, IUCN 2006). 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 (Peterson et al. 2004, IUCN 2006). Other threats include predation by non-native species (e.g., Brazil fire ants) (IUCN 2006).

Reptiles

The American crocodile (*Crocodylus acutus*) is affected by changes in hydrology and consequent changes in salinity levels (Richards et al. 2004). In addition, direct mortality of adult American crocodiles is considered higher than the population can sustain (review in Richards et al. 2004). Of the deaths recorded between 1971 and 2001, the majority were hit by cars (Mazzotti & Cherkiss 2003, review in Richards et al. 2004, Fish and Wildlife Service 2005). Warning signs and fences were installed along the major highways throughout crocodile habitat in south Florida (Fish and Wildlife Service 2005). However, it appears that some or all of the planned underpasses may not have been built (US 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, Florida, personal communication).
Chapter 4 Impacts to Wildlife


![Figure 21: Desert Tortoise (Photo: Marcel Huijser).](image)

The Gopher tortoise (*Gopherus polyphemus*) is affected by habitat loss (urbanization, agriculture, silviculture, mining) and habitat degradation (silviculture, fire suppression, non-native plant species) (Fish and Wildlife Service. 1987a, Enge et al. 2005, US Fish and Wildlife Service 2006a). Collection by humans and road mortality also affected the species substantially (Fish and Wildlife Service. 1987a, Enge et al. 2005, US Fish and Wildlife Service 2006a, Hagood 2006). Furthermore, the species is affected by predation, including by non-native fire ants (US Fish and Wildlife Service 2006a). Fences and culverts were installed along a section of Highway 63 in Green County, south of Leakesville, Mississippi (Matthew J. Aresco, Nokuse Plantation, Bruce, Florida, 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 22). Highway 63 has 24.1 km (15 miles) 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) (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 1-2 per year to zero (Chuck Walters, Mississippi Department of Transportation, personal communication).

The Alabama red-bellied turtle (*Pseudemys alabamensis*) is affected by egg predation, human disturbance, and road mortality (Fish and Wildlife Service 1987b, Nelson & Scardamalia-Nelson 2005, Hagood 2006, David Nelson, Department of Biological Sciences, University of South Alabama, personal communication, Matthew J. Aresco, Nokuse Plantation, Bruce, Florida, personal communication). 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 miles from Spanish Fort to Mobile) between 2001 and 2004 reported 324 Alabama red-bellied turtle carcasses (Nelson & Scardamalia-Nelson 2005, David Nelson, Department of Biological Sciences, University of South Alabama, personal communication) (Figures 23 and 24). 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 23: A Section of the Mobile Bay Causeway that has Relatively Many Road-Killed Alabama Red-Bellied Turtles (Photo: Marcel Huijser).

Figure 24: Road-killed Alabama Red-Bellied Turtle (Photo: 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 (Fish and Wildlife Service. 1997a). In addition, roads contribute “significantly” to mortality, especially where roads are adjacent to or within wetlands (Fish and Wildlife Service. 1997a)

The copperbellied 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 (Fish and Wildlife Service 1997b). In addition, predation by pets and vehicle-caused mortality are a concern (Fish and Wildlife Service 1997b, Roe et al. 2006). Traffic mortality may account for mortality of 14–21 percent of the population per year (Roe et al. 2006). The species seems especially vulnerable as it frequently crosses overland to different wetland sites (Roe et al. 2006).

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 (USFWS 1978; Hyslop et al. 2006). In addition, gopher tortoise burrows that are gassed to kill rattlesnakes also unintentionally kill indigo snakes (Fish and Wildlife Service. 1978). Bolt (2005) 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. 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 (Smith & Voigt 2005).

**Birds**

The crested caracara in central Florida (*Polyborus plancus audubonii*) is affected by habitat alteration for agriculture and housing, illegal killing, and vehicle collisions (Fish and Wildlife Service 1987c, Morrison 1999). In a 3-year study, 52 percent of all fledgling mortality (14 out of 27 deaths) was caused by vehicle collisions (Morrison 1999). 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 non native small Indian mongoose (*Herpestes auropunctatus*), dogs and perhaps rats and cats (IUCN 2006). Poaching and road-kills are also important causes of mortality (Hawai‘i Volcanoes National Park 2004, IUCN 2006, Kathleen Misajon, National Park Service, personal communication). Road mortality is the most common known cause of mortality in adults (Rave et al. 2005). The species may also be affected by diseases and parasites, inbreeding depression, loss of adaptive skills in captive-bred birds and dietary deficiencies (IUCN 2006).
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 1 January and 28 August, 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 25). This practice gets the birds habituated 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 26). In addition, there are temporary warning signs that 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 road-kills 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).
Chapter 4 Impacts to Wildlife

Figure 25: "Do Not Feed Nene" Sign (Photo: Hawai'i Volcanoes National Park, National Park Service).

Figure 26: Hawaiian Goose (Nene) Warning Sign (Photo: 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 non-native species (feral cats) and road kill (Fish and Wildlife Service 1987d, Mumme et al. 2000, Breininger et al. 2006, IUCN 2006). Annual mortality rates of the Florida scrub jay have been recorded to be 65 percent higher in road territories compared to non-road territories (Mumme et al. 2000). Furthermore, road-side territories are a population sink, and the high mortality rate appears to be caused by vehicle collisions rather than other factors associated with a road-side environment (Mumme et al. 2000).

**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 (Fish and Wildlife Service 1990; US Fish and Wildlife Service 1999). 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 (Forys & Humphrey 1999). Dispersing sub-adult males seem especially vulnerable to traffic mortality (US Fish and Wildlife Service 1999).

The Florida key deer (*Odocoileus virginianus clavium*) is affected by vehicle collisions, habitat loss, and human disturbance (Lopez et al. 2003, Harveson et al. 2004). Vehicle collisions account for more than 50 percent of the total deer mortality, mostly on US Highway 1 (Lopez et al. 2003).

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 (Fish and Wildlife Service 1998a). This population, especially small groups that have low recruitment, is also threatened by road mortality (Fish and Wildlife Service 1998a).

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, non-native red foxes, and domestic dogs), and vehicle mortality (Cypher 2000, Cypher et al. 2005, IUCN 2006). 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) (Cypher 2000). After predation, vehicle collisions are likely to be the second most common cause of mortality (Cypher 2000).
Canada lynx (*Lynx canadensis*) is likely impacted by urbanization and forestry practices (including fire suppression) and trapping (Mowat & Slough 2003, Poole 2003). In addition, its population size fluctuates with the availability of its main prey species, the snowshoe hare (*Lepus americanus*) (Poole 2003). In the United States, road mortality may limit the reestablishment of the Canada lynx in Wisconsin and Michigan (Fish and Wildlife Service 1998b). A total of 218 adult lynx were released between 1999-2006 and there were 80 known mortalities as of June 30, 2006 (Shenk 2006). 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) (Shenk 2006). Malnutrition and disease or illness accounted for 21.3 percent of the deaths while 32.5 percent of the deaths were from unknown causes (Shenk 2006). 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, US Fish & 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, US Fish & 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 (US Fish and Wildlife Service 2007). Recent data from Minnesota show that Canada lynx have died from shooting, trapping, collisions with trains, and road mortality (Phil Delphrey, US 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 Delphrey, US Fish and Wildlife Service, personal communication).


The Florida panther is affected by habitat loss (agriculture, urbanization), habitat fragmentation, road mortality, and loss of genetic diversity (Foster & Humphrey 1995, Main et al. 1999, Kautz et al. 2006). Road mortality is substantial, 25 out of 73 deaths were caused by vehicles (Taylor et al. 2002).

The Red wolf (*Canis rufus*) went extinct in the wild by 1980 and was re-introduced in 1987 in North Carolina (IUCN 2006). After reintroduction, the species was affected by hybridization with coyotes (*Canis latrans*) (Fish and Wildlife Service 1991, Fredrickson & Hedrick 2006, IUCN 2006). Direct mortality (vehicle collisions, shooting) can be substantial (IUCN 2006).

**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 non-native 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 non-native 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 (e.g. see Brown 2006).
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,
  o Standard signs,
  o Large, non-standard signs,
  o Seasonal signs, and
  o Animal detection systems;
• Improvement of driver attentiveness with in-vehicle warning systems by,
  o In-vehicle warning linked to roadside animal detection systems, and
  o In-vehicle warning linked to on-board animal detectors;
• Increase in visibility to drivers by,
  o Roadway lighting,
  o Vegetation removal,
  o Wider striping,
  o Reflective collars for animals, and
  o Reduce the height of snow banks;
• Reduction in traffic volumes on roadways by,
  o Reduction in traffic volume on road network, and
  o Temporary road closures;
• Reduction of average speeds on roadways by,
  o Reduction of the posted speed limit,
  o Traffic calming/reduction of design speed, and
  o Posting of advisory speed limits; and
• 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 (Walker 2004, Hardy et al. 2006).

The most common WVCs in the US involve deer. Deer vehicle collision (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 (Knapp et al. 2004).

Many transportation professionals and researchers have discussed driver education and public information campaigns as a means to help reduce WVCs (Evink 1996, Jacobs 2001, Pynn & Pynn 2004, Rogers 2004, Knapp 2005) or have conducted research to incorporate their findings into motorist education efforts (Biggs et al. 2004). 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 (Knapp 2005).

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 (Jacobs 2001). 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 (Riley & Marcoux 2006). In British Columbia a survey of 1,882 licensed drivers indicates respondents strongly (81 percent) believe wildlife warning signs reduce WVCs (Buckingham 1997).

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 they can take as drivers 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 wildlife vehicle collisions (see Figure 30). 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 25 January 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 25 January 2007).

The “Colorado Wildlife on the Move” Campaign reached more than 3 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 (DiGiorgio 2006).

As a result of a local outreach campaign in Montana, survey respondents who had heard or seen information on wildlife vehicle collisions increased from 21 to 33 percent (Hardy et al. 2006).

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 Space Center.

The Parks Canada “Drivers for Wildlife” program in Jasper National Park combines public education, which includes bumper stickers (see Figure 27) and roadway billboards (see Figure 28), 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 (Walker 2004).

Figure 27: 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 road kill (which attracts the birds) in concert with the Merritt Island National Wildlife Refuge, which is a 140,000-acre overlay of the Center. The refuge provides a buffer zone for NASA.

The Space Center has developed a website with a video, materials, posters (see Figure 29), stickers and updates on the latest road kill statistics at: http://environmental.ksc.nasa.gov/projects/roadkill.htm (accessed 25 January 2007).

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 ten in 2003 to four in 2005, according to their website (http://www.dps.state.ia.us/commis/pib/Releases/2006/10-05-2006_Deer.htm). 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.
Chapter 5 Mitigation Methods that Attempt to Influence Driver Behavior

Figure 30: Poster Produced by the Maine Department of Transportation (Source: Maine DOT).
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 3 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 18-45 year olds, as they are involved in the highest numbers of AVCs (see Figure 31). In a study in Kent County, Michigan, registered drivers between the ages of 30-39 had the highest number of deer vehicle collisions (Hindelang et al. 1999). If public campaigns or local education programs can be focused for specific age groups, 30-45 years olds should be targeted. Note that Figure 31 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.
Chapter 5 Mitigation Methods that Attempt to Influence Driver Behavior

ROADWAY WARNING SIGNS

Roadway wildlife warning signs are perhaps the most commonly applied WVC mitigation measure (Forman et al. 2003, Sullivan & Messmer 2003). 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 32).

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 (see e.g., Knapp & Yi 2004, Knapp et al. 2004, Krisp & Durot 2007). 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 31: Age Distribution for all Crashes and AVCs (HSIS Data).
Driver awareness and response are influenced by the type of warning sign (Pojar et al. 1975, Katz et al. 2003, Hammond & Wade 2004). 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 (VMS) 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 sec to 0.7 sec if drivers are warned (Green 2000). Assuming a constant vehicle speed of 88 kph (55 mph) 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 (Kloeden et al. 1997). 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 (Kloeden et al. 1997).
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 33).

Meyer (2006) investigated the effectiveness of standard deer warning signs in Kansas by comparing the accident data before and after sign installation. 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 deer vehicle collisions (Meyer 2006). Rogers (2004) also concluded that the number of deer vehicle collisions had not reduced as the result of the installation of deer warning signs. Furthermore, the installation of standard camel crossing signs in Saudi Arabia did not result in reduced vehicle speed (Al-Ghamdi & AlGadhi 2004). Finally, in a driving simulator study, a standard deer warning sign resulted in an average vehicle speed of 123.2 kph (76.6 mph), just over the posted speed limit of 120.7 kph (75 mph) (Stanley et al. 2006). 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, Kansas 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 wildlife vehicle collisions, in general, and deer vehicle collisions, in specific.

Most authors doubt the effectiveness of standard warning signs (Williams 1964 cited in Pojar et al. 1975, Putman, 1997, Sullivan & Messmer 2003, Putman et al. 2004), but only two studies were found that had investigated the effectiveness, confirming the existing doubts (Rogers 2004, Meyer 2006).

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 wildlife vehicle collisions (Arizona Court of Appeals 2004).

Costs

One study estimated costs at $94 (note not adjusted for inflation) per sign (Pojar et al. 1975). USA Traffic Signs (2007) reports the following costs: $55 (61 cm x 61 cm (24 in x 24 in)), $62 (76 cm x 76 cm (30 in x 30 in)), $85 (91 cm x 91 cm (36 in x 36 in)).

Guidelines

The Manual on Uniform Traffic Control Devices (MUTCD) provides guidance on animal warning signs. The standard warning sign (depicted previously in Figure 33) 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.” (USDOT-FHWA 2004)

See Knapp & Yi (2004) for a discussion on guidelines for the installation of standard deer warning signs.
LARGE, NON-STANDARD 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 34 and Figure 35).

![Figure 34: Large Enhanced Warning Sign for Bighorn Sheep Along State Highway 75 in Idaho (Photo: Marcel Huijser, WTI).](image)

Lighted animated deer crossing signs reduced vehicle speed by 4.8 kph (3.0 mph) compared to the same signs when they were turned off (Pojar et al. 1975). The presence of deer carcasses as a ‘supplement’ to the signs resulted in a much greater reduction in vehicle speed: 12.6 kph (7.9 mph) (lights turned off) and 10.0 kph (6.2 mph) (lights turned on) (Pojar et al. 1975). Despite the successful speed reduction of the lighted animated signs, they did not result in a reduction of deer vehicle collisions (Pojar et al. 1975).

Hammond and Wade (2004) 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. The average vehicle speed with standard deer warning signs was 99.6 kph (61.87 mph) (SD=5.16). The enhanced sign with the lights turned off resulted in similar speeds of 99.5 kph (61.80 mph) (SD=4.80), but the enhanced sign with the lights turned on resulted in significantly lower vehicle speed of 95.9 kph (59.55 mph) (SD=4.66), a reduction of 3.7 kph (2.32 mph) (Hammond & Wade 2004).
Enhanced camel warning signs in Saudi Arabia resulted in a significant reduction of vehicle speed whereas standard camel warning signs did not (Al-Ghamdi & AlGadhi 2004). The standard warning signs were triangular where all sides were 110 cm (43 in), 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 kph (2-4 mph) (Al-Ghamdi & AlGadhi 2004).

Hardy et al. (2006) found that wildlife advisory messages posted on permanent and portable Dynamic Message Signs (DMS) can reduce vehicle speeds. The greatest effect occurred during “dark” conditions, when the number of AVCs is higher.

Stanley et al. (2006) 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.

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 Dynamic Message Signs (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, Virginia 24060, Phone (540) 808-5140, lstanley@vtti.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 wildlife vehicle collisions, in general, and deer vehicle collisions, specifically (Pojar et al. 1975). Nonetheless, the observed reduction in vehicle speed (3-7 kph (2-4 mph)) 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 ‘non-standard’ signs may draw attention, a potential downside is that it takes drivers longer to interpret the sign, simply because it is ‘non-standard’.

**Costs**

One cost estimate reported in the literature was $2,000 (note: not adjusted for inflation) per sign (Pojar et al. 1975).
Guidelines

It should be noted that many non-standard 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 & Yi (2004) for a discussion of guidelines for the installation of non-standard deer warning signs.

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 36).

Sullivan et al. (2004) 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. The number of deer vehicle collisions 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 (Sullivan et al. 2004).

Rogers (2004) 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 deer-vehicle collisions. The signs were deployed between October
and January (the peak of deer-vehicle collisions) for three consecutive years. Rogers (2004) found no effect of the seasonal signs on the number of deer-vehicle collisions.

**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, Utah. (Current address: USDA/APHIS Wildlife Services, 5107 Austin Ellipse, Moody Air Force Base, GA 31699).

**Direct Benefits**

Seasonal deer warning signs may reduce deer vehicle collisions; 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 (Sullivan et al. 2004).

**Costs**

Sullivan et al. reported a cost of $268/1,609 m ($435 per mile).

**Guidelines**

See Knapp & Yi (2004) for a discussion of guidelines for the installation of seasonal deer warning signs.

**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 37). The warning signals are extremely time specific. Huijser et al. (2006c) 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. Since August 2007, a number of additional locations were equipped with an animal detection system, including along
SR 260 near Payson, Arizona (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 37: Animal Detection System Along Highway 191 in Yellowstone National Park, Montana (Photo: 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 coverage 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 coverage 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 (Huijser et al. 2006b). 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 (Huijser et al. 2006b).

The effectiveness of animal detection systems has been investigated with regard to a potential reduction in vehicle speed and a potential reduction in animal vehicle collisions. 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 kph \((\geq 3.1 \text{ mph})\)) (Kistler 1998, Muurinen & Ristola 1999, Kinley et al. 2003); minor decreases in vehicle speed (less than 5 kph \((3.1 \text{ mph})\)) (Kistler 1998, Muurinen & Ristola 1999, Gordon & Anderson 2002, Kinley et al. 2003, Gordon et al. 2004, Hammond & Wade 2004); and no decrease or even an increase in vehicle speed (Muurinen & Ristola 1999, Hammond & Wade 2004). 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 (Huijser et al. 2006b).

Kistler (1998, 2002), Romer and Mosler-Berger (2003), and Mosler-Berger and Romer (2003) have reported on the number of animal vehicle collisions before and after seven infrared area cover detection systems were installed in Switzerland (Table 8). These systems reduced the number of animal vehicle collisions by 82 percent on average (1-sided Wilcoxon matched-pairs signed-ranks test, \(P=0.008, n=7\)) (see also Huijser et al. 2006c). 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 wildlife vehicle collisions on short term with a high degree of certainty (Huijser et al. 2006c).
Table 8: Collisions with Large Animals Before and After Detection System Installation in Switzerland.

<table>
<thead>
<tr>
<th>Location</th>
<th>Before Installation</th>
<th>After Installation</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coll. (N)</td>
<td>Yrs</td>
<td>Coll./yr</td>
</tr>
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<td>Warth</td>
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<td>7</td>
<td>2.00</td>
</tr>
<tr>
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<td>11</td>
<td>0.73</td>
</tr>
<tr>
<td>Val Maliens</td>
<td>7</td>
<td>3</td>
<td>2.33</td>
</tr>
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<td>12</td>
<td>4</td>
<td>3.00</td>
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<tr>
<td>Schafrein</td>
<td>26</td>
<td>8</td>
<td>3.25</td>
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<tr>
<td>Duftbächli</td>
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<td>8</td>
<td>2.25</td>
</tr>
<tr>
<td>Grünenwald</td>
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<td>8</td>
<td>0.75</td>
</tr>
<tr>
<td><strong>Average Reduction</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Case Studies and Contacts

For a general overview of technology, reliability and effectiveness, contact Marcel Huijser, Western Transportation Institute, PO Box 174250, Bozeman, Montana 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, Arizona 85935, (928)368-5675, doddnbenda@cybertails.com.


Manufacturer: Calonder Energy AG’s representative in USA: Willy Bärchtold, Swiss Army Vehicles, 1436 Van Asche Drive, Fayetteville, Arkansas 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 (review in Huijser et al. 2006b). 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 (see Huijser et al. 2006b).

Costs

Estimated costs of these systems are $40,000-$96,000 per km ($65,000-$154,000 per mile) (excluding installation costs) (Huijser et al. 2006b, unpublished data, Marcel Huijser, Western Transportation Institute – Montana State University). 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 et al. (2006c) for considerations for planning and design.

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 et al. (2006b). The technology would be designed to warn a driver through a warning signal inside the vehicle that an animal is on or near the road way 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 (review in Huijser et al. 2006b). 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 (see Huijser et al. 2006b).

**Costs**

Estimated costs for these systems are $40,000-$96,000 per km ($65,000-$154,000 per mile) (excluding installation costs), plus additional costs for the on-board computer and communication system (Huijser et al. 2006b, Marcel Huijser, unpublished data, Western Transportation Institute – Montana State University). 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 et al. (2006c) for considerations for planning and design.
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 (e.g., Bendix 2002, General Motors 2003, Hirota et al. 2004, Honda 2004). 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 (review in Knapp et al. 2004).

Guidelines

See Hirota et al. (2004) for design concept.
Chapter 5 Mitigation Methods that Attempt to Influence Driver Behavior

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 seconds (depending on whether the hazard was anticipated or unexpected) to move their foot from the accelerator to the brake (Green 2000). 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 wildlife vehicle collisions occur between dusk and dawn when light, and thus visibility, is limited (see Section on Causes and Factors of WVCs: Temporal Distributions, Rogers 2004, Gunson & Clevenger 2003, Haikonen & Summala 2001, Farrell & Morris 1996, Garrett & Conway 1999, Thomas 1995, Hughes et al. 1996, Putman 1997, Schafer & Penland 1985). 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 (1999) characterized moose vehicle collision occurrences in Anchorage, Alaska, 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. Lavsund and Sandegren (1991) found the risk of moose vehicle collisions in Sweden was six times higher during hours of darkness compared to daylight conditions. It has been hypothesized but not well documented that lighting may help drivers see animals and avoid such collisions in non-daylight hours.

Numerous reviews of WVC mitigation measures mention use of roadway lighting in attempts to reduce WVCs (Beier 2006, Knapp 2005, Biota Research and Consulting, Inc. 2003, Hedlund et al. 2003, L-P Tardiff and Associates, Inc. 2003, Transport Canada 2003, Farrell et al. 2002, Groot Bruinderink & Hazebroek 1996, Putman 1997, Romin & Bissonette 1996). Most of these reviews either do not provide support that highway lighting is effective or conclude that highway lighting is ineffective. Reed (1981a) and Reed and Woodard (1981) found that highway lighting was not effective in reducing deer vehicle collisions in Colorado. L-P Tardiff and Associates, Inc. (2003) cited a study by Miller (1985, as cited in L-P Tardiff and Associates, Inc. 2003) indicating that lighting was ineffective for mitigating wildlife vehicle collisions (no further information was provided and the report was unavailable at the time that this review was drafted). 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 (Transport Canada 2003). Knapp (2005) 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”.

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Despite discrepancies in the tested effectiveness of highway lighting, the practice of using highway lighting has been recommended in certain situations. Garrett and Conway (1999) recommend the installation of street lights, 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. Thomas (1995) also suggests that roadway lighting be considered for reducing moose vehicle collisions in Alaska.

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 (1981a) conducted a 5-year study in Colorado that involved alternately turning roadside lights on and off for 1-week periods to quantify the effect on deer vehicle collisions, observed deer crossings of the highway at night, and vehicle speeds. Lighting did not affect deer vehicle collisions 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 4-year study of the installation of roadway lighting, fencing, one-way gates and bridge modifications along 11.5 km (7.1 miles) of the Glenn Highway near Anchorage, Alaska, revealed a 70 percent decrease in moose vehicle collisions overall (McDonald 1991 as cited in Biota Research and Consulting, Inc. 2003 and Wildlife Crossings Toolkit). The entire area was lighted, while about 5.5 km (3.4 miles) 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 (McDonald 1991 as cited in Biota Research and Consulting, Inc. 2003 and Wildlife Crossings Toolkit).

**Case Studies and Contacts**

For information about roadway lighting and fencing to reduce WVCs, contact Biota Research and Consulting, Inc., [info@biotaresearch.com](mailto: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 (1994) found that highway lighting reduced all “property damage only” (i.e., no human injury) crashes at night. The typical method for comparisons for before/after installation is a reduction in the ratio of night time 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 (Beier 1995). In addition, roadway lighting may temporarily blind certain species as their eyes are adapted to darkness (Beier 2006), potentially increasing their vulnerability to traffic.

Costs

Mode et al. (2005) 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. Hedlund et al. (2003) state that roadway lighting is expensive but did not provide any figures to illustrate the estimated expense. L-P Tardiff and Associates, Inc., (2003) mention Miller’s (1985) report, which states that highway lighting is expensive, but again, no figures accompanied that statement.

Guidelines


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 (1993) found that deer were killed more often than expected in areas adjacent to shelterbelts with canopy vegetation. Puglisi et al. (1974) found that DVC occurrences were less common where wooded areas were more than 23 m (25 yards) away from a highway in Pennsylvania.
Clearing vegetation from roadsides resulted in a 20 percent reduction in moose vehicle collisions in Sweden (Lavsund & Sandegren 1991). 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 (Andreassen et al. 2005). While it is recognized that the results may not translate to a highway setting, the clearing of vegetation across a 20-30 m (70-100 ft) swath on each side of a Norwegian railway reduced moose-train collisions by 56 percent (±16 percent; Jaren et al. 1991).

Thomas (1995) 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. 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 (Finder et al. 1999). Based on results from predictive models, Seiler (2005) 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).

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, Putnam et al. (2004) 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.”

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. (1991) conducted an 8-year study of the effect of vegetation removal on moose-train collisions in Norway and found that clearing vegetation across a 20-30 m (70-100 ft) swath on each side of the railway reduced moose-train collisions by 56 percent (+/-16 percent). Lavsund and Sandegren (1991) showed that clearing of vegetation along transportation corridors resulted in a 20 percent reduction in moose vehicle collisions in Sweden.

Indirect Benefits

Reducing the number of large trees near roads may result in fewer collisions with these stationary obstructions (Hedlund et al. 2003).

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 (Groot Bruinderink & Hazebroek 1996), potentially counteracting the potential safety gains of better visibility with increased probability of drivers encountering wildlife.

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 et al. (1991) 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 miles) moose-train collisions occur. Andreassen et al. (2005) estimate forest clearing for 18 km (11.2 miles) costs $500 per km ($800 per mile) or $9,000 per year, showing that the number of moose saved using this technique could result in a profit of $1,080. Andreassen et al. (2005) states that forest clearing may be more economical compared to scent-marking and supplemental feeding, stating that the initial cutting is the main expense.

Guidelines

Thomas (1995) provides a summary of a variety of vegetation clearing methods used in Alaska including hydroaxing, hand clearing, steam clearing, and spray inhibitors.

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, Maine and along Rt. 6/15 in Shirley, Maine (Maine DOT et al. 2004). 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 (Maine DOT et al. 2004). 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 north east 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 mile) 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 & Conway (1999) suggested reducing the height of snow berms in order to increase drivers’ visibility of moose on the side of the road. 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 (Messmer & West 2000, Putman et al. 2004). 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 (Groot Bruinderink & Hazebroek 1996).
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 & Hubbard (1998), D’Angelo et al. (2004), Putman et al. (2004) and Knapp (2005) did not address this potential mitigation measure on either the local or landscape scale.

Some modeling efforts found a relationship between traffic volume and WVCs and suggest reduced traffic volumes as a potential solution to WVCs (Jaarsma & Willems 2002, Langevelde & Jaarsma 2004, Meyer & Ahmed 2004). 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 (2002) for example, suggest implementing traffic calming on the more minor rural roads in order to shift the traffic onto a few major highways. A similar number of studies found that higher volumes on roadways reduced the number of WVCs (see section in Chapter 2 on Causes and Factors – 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 (Higman 1997). 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 (Trocmé et al. 2003).

**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.
Chapter 5 Mitigation Methods that Attempt to Influence Driver Behavior

Undesirable Effects

Lower traffic volumes do not necessarily equate with fewer road kills (Jaarsma & Willems 2002). 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 pm - 6 am) 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 (Delaware Water Gap National Recreation Area 2003; NPS 2006). 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 (Shawnee National Forest 2006). In East Brunswick, New Jersey, the Beekman Road is closed several nights in the spring to allow spotted salamanders to cross the road during their seasonal migration (Todaro 2006).

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, Illinois 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” (AASHTO 2004a). 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” (AASHTO 2004a). 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 38). Advisory speeds are lower than the posted speed limit and are not enforceable other than by using basic “reasonable and prudent” laws.

![Advisory Speed Sign in the Netherlands Located at a Gap in Exclusionary Wildlife Fencing (Photo: 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 2-lane highway in a national park, with 3.7 m (12 ft) lane widths, and 3 m (10 ft) shoulders (Bertwistle 1999). 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.” (AASHTO 2004a).
Prior to the mitigation, the speed limit for the roadway was 90 kph (56 mph). 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 kph (56 mph) to 70 kph (43 mph) on three sections of the road; 2.5, 4, and 9 km (1.5, 2.5, and 5.6 miles) 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 kph (43 mph) 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 kph (43 mph) speed limit. Bertwistle reported that bighorn sheep collisions actually increased in the reduced speed zones and decreased in the control areas (the 90 kph (56 mph) 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. (2003) summarizes WVCs in the Jackson, Wyoming area. 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 kph (35 mph), 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 38).

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.”
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- 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) (National Research Council 1998).

Indirect Benefits

Indirect benefits cited in the literature include:

- Fines collected from regular enforcement;
- Increased fuel economy: West et al. (1997) showed that for a mix of vehicle types, fuel efficiency peaked at about 88 kph (55 mph);
- Reduced emissions: the exact relationship is unclear but they are closely related to fuel efficiency; and
- 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 (1964) and Cerrelli (1981) found that vehicles traveling close to the average speed had the lowest crash involvement rates. Crash involvement rate not only increased for faster vehicles, but also for slower vehicles. Garber and Gadiraju (1988) 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. 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 initial cost of replacing speed limit signs;
- The cost of regular enforcement;
- Additional costs in increased travel time need to be considered; and
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- 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 et al. (1998) showed that in Yellowstone National Park, roads with higher posted speed limits had higher WVC occurrences. His primary evidence is shown in Figure 39, where a 88 kph (55 mph) roadway has significantly higher roadkill per mile than roadways with lower posted speed limits. Notice, however, that WVC frequencies do not increase until 88 kph (55 mph) speed limit. The 88 kph (55 mph) road (US 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.

![Figure 39: Roadkill by Posted Speed Limit in Yellowstone (Data from Gunther et al. 1998).](image)

Below are three examples of traffic calming applications for wildlife:

One example is shown in Figure 40 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.
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 harrisii*) after the road section in a national park was widened and sealed and modal speed increased by 20 kph (12.4 mph) (Jones, 2000b). 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 centre of the road in or close to locations that had a concentration of road kill (Jones, 2000b). 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 kph (12.3 mph) (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 2 years after the installation of the ‘slow points’ (Jones, 2000b). 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

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 9/24/2006 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.

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 25 January 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.
Chapter 5 Mitigation Methods that Attempt to Influence Driver Behavior

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.
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:

- 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, and
- Increase median width.

DEER REFLECTORS AND MIRRORS


Most studies testing the effectiveness of mirrors and/or reflectors on reducing WVCs found that they had: 1) no effect (Waring et al. 1991, Ford & Villa 1993, Reeve & Anderson 1993, Cottrell 2003, Rogers 2004), 2) mixed results (Paﬁko & Kovach 1996, Barlow 1997), or 3) inconclusive results (Gulen et al. 2000). Differences in experimental design and in the variety of models tested confound the comparison of results (D’Angelo et al. 2004). However, Schafer and Penland (1985) did find a signiﬁcant reduction (88 percent) in WVCs using Swareﬂex reﬂectors in Washington State. Paﬁko and Kovach (1996) found in Minnesota that reﬂectors reduced rural incidences by 50-97 percent, but suburban metropolitan WVC incidences increased.

The Strieter-Lite company suggests there is scientiﬁc proof that their reﬂectors do work (Grenier 2002, unpublished) (78-90 percent reduction in deer vehicle collisions) and that reﬂective luminance (brightness) is not a major factor, because wild animals have acute night vision (Sielecki 2001). Sivic and Sielecki (2001) conducted a spectrometric evaluation of Swareflex
and Strieter-Lite wildlife warning reflectors and noted operational implications of low light reflection intensities. Reflectors require suitable placement, alignment maintenance and regular cleaning (Sielecki 2004); however, in a roadside application it is impossible to keep reflectors clean at all times (Sielecki 2001, Page 2006). Possible reasons why reflectors and mirrors do not result in fewer road kill include: improper installation, lack of maintenance (no replacement of missing reflectors or re-aligning 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 (Page 2006). Thirty-nine percent of Swareflex reflectors used in Wyoming showed deterioration after 3 years (Reeve & Anderson 1993). In British Columbia, reflectors were prone to theft and vandalism (Sielecki 2004). Where mirrors and reflectors work in reducing WVCs, it may be a result of driver behavior (Zacks 1986), particular site characteristics (Barlow 1997), or rural versus suburban landscapes (Pafko & Kovach 1996).

Mirrors and reflectors are addressed in several literature reviews and annotated bibliographies (Reeve & Anderson 1993, Knapp 2005, TranSafety Inc. 1997a & b, Danielson & Hubbard 1998, D’Angelo et al. 2004, Putman et al. 2004). Knapp et al. (2004) 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.

Studies testing the influence of reflectors on animal behavior found little or no evidence of avoidance (Zacks 1986, Waring et al. 1991, D’Angelo et al. 2006). 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 (D’Angelo et al. in 2006). Interestingly, data indicated that deer increased negative behavioral responses toward vehicles in the presence of reflectors (D’Angelo et al. 2006). Ramp and Croft (2002), however, found Swareflex reflectors produced a weak fleeing response in kangaroos. Ujvari et al. (1998) found that deer initially responded to reflectors with alarm and flight but then became habituated to the light reflection. D’Angelo et al. (2006) recommends that future development of deer-deterrent devices for WVC mitigation be based on empirical knowledge of deer senses and behavior.

**Case Studies and Contacts**

Chapter 6 Mitigation Methods that Seek to Influence Animal Behavior

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, Georgia 30602, (706)227-6867, gid4895@owl.forestry.uga.edu.

Direct Benefits

Roadside reflectors and mirrors are categorized as “tried” (AASHTO) and “used with conflicting safety analysis results” in a critical evaluation of DVC crash countermeasures (Knapp 2005).

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 (D’Angelo et al. 2006).

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 mile). The average life of reflectors is 12.5 years, so costs amount to $169 to $199 per km ($272 to $320 per mile) per year. Maintenance cost per mile per year is $500 ($300 per km per year) (Strieter-Lite, Strieter Corp., Rock Island, Illinois, http://www.strieter-lite.com/). In British Columbia, reflectors cost approximately $10,000 per km ($16,000 per mile) to install along both sides of a highway, and maintenance costs range in the order of $500 to $1,000 per km ($800 to $1600 per mile) annually (Sielecki 2004).

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)

response to the Shu Roo, a vehicle-mounted ultrasonic kangaroo deterrent, did not differ in the on or off position (Bender 2001).


A roadside wildlife warning system utilizing high frequency sounds has been developed (Bushman et al. 2001, International Road Dynamics, Inc., (IRD) Saskatoon, Saskatchewan, Canada, http://www.irdinc.com/ (accessed 26 January 2007)). 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 (Hunin 2005). The system is activated when trains approach (Hunin 2005). The effectiveness of this system has not been evaluated.

Another roadside wildlife warning system was developed by Firma Günter Josef Folda in Austria (Firma Günter Josef Folda 2007). 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 (Firma Günter Josef Folda 2007, ORF Tirol 2007, Edward Mulka, JAFA Technologies, Inc., personal communication). Unconfirmed data from Austria (between the cities of Nassereith and Imst in the Gurgltal on the Miemingerstraße road) indicate that the equipment may reduce wildlife-vehicle collisions by 85-93 percent (ORF Tirol 2007, Edward Mulka, JAFA Technologies, Inc., personal communication). 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 (ORF Tirol 2007, Edward Mulka, JAFA Technologies, Inc., personal communication).

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 (Ujvari et al. 2004).

In a comparison of whistle acoustic frequencies and intensities and deer hearing abilities, Scheifele et al. (2003) 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. Deer hearing sensitivity is estimated to be between 2 kHz and 6 kHz (Risenhoover et al. 1997, Scheifele et al. 2003). Taking into consideration the masking effect of road and car noise, however, deer are not likely to be able to hear the whistles (Romin & Dalton 1992, Scheifele et al. 2003). 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 (Bender 2001). Further, if whistles were audible in combination with vehicle and road noise, there is no evidence that they affect animal behavior (Muzzi & Bisset 1990, Romin & Dalton 1992, Bender 2001) and habituation to these sounds is possible (Scheifele et al. 2003, Ujvari et al. 2004).

Case Studies and Contacts

Contacts for some audio signal manufacturers are:

- 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, New Jersey 08054, Tel/Fax: (856) 802-9095, Cell: (856) 278-1597, Email: emulka@jafatech.com, http://www.jafatech.com/

Direct Benefits

Deer whistles are categorized as “tried” (AASHTO) and “used with conflicting safety analysis results” in a critical evaluation of DVC crash countermeasures (Knapp 2005).

The effectiveness of the IRD system is inconclusive. Maintenance staff anecdotally felt the system was effective, but the data was inconclusive, possibly since not enough data was collected. Currently the IRD system is not in use (Bushman 2006).

The effectiveness of the WIWASOL-II system may be 85-93 percent (ORF Tirol. 2007), but these results are currently unconfirmed.

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 road-side based audio signal system along a six km (3.7 mile) long road section, the costs were about €19,000 (ORF Tirol 2007).

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 (Kinley & Newhouse 2003) but have not been field tested (Knapp 2005). 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 (Castiov 1999). Other literature reviews that addressed effectiveness in terms of reducing WVCs have determined that olfactory repellents have not been adequately tested (Putman et al. 2004, Danielson & Hubbard 1998, Knapp 2005), show only limited effectiveness (Lutz 1994 in Putman 2004, Farrell et al. 2002, Trocmé et al. 2003) or are impractical because of the need to repeat applications, especially after precipitation events (Johnson 2001, Trocmé et al. 2003). Future development of olfactory repellent measures requires further study of wildlife behavioral responses (Baker et al. 2005) on a range of species (Ramp & Croft 2002) and of the potential for animal habituation (Knapp 2005).

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 1640 ft) yielded small and variable samples sizes for the number of collisions (Andreassen et al. 2005).

Captive trials of Wolfin® (Pro Cell Biotenik, Hornefors, Sweden), a synthetic scent repellent, showed no repellency of caribou or black-tailed deer (Brown et al. 2000b, Shipley 2001). 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 (Ramp & Croft 2002). 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 (Brown et al. 2000b).

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 (Kerzel and Kirchberger 1993 in Putman 1997). However, a more detailed assessment found DVCs rose in untreated sections (Lebersorger 1993 in Putman 2004). A roadside wildlife warning system utilizing scent repellents has been developed (Bushman et al. 2001, 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).

**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 (Trocmé et al. 2003). Repellents are categorized as “experimental” (AASHTO) and “not generally used and rarely studied for safety impacts” in a critical evaluation of DVC crash countermeasures (Knapp 2005).

**Indirect Benefits**

No indirect benefits were identified in the literature review.

**Undesirable Effects**

Kinley and Newhouse (2003) caution that unintended negative effects may arise from olfactory repellent application and recommend a cost-benefit analysis of associated safety, economic and ecological factors. 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.
Chapter 6 Mitigation Methods that Seek to Influence Animal Behavior

Costs

Costs should take into consideration maintenance requirements (Trocmé et al. 2003), time intervals for re-applications, the area to be treated and ecological impacts (Knapp 2005).

According to the literature, one liter of Plant Plus concentrate costs $30 (currency was not specified, but presumably Australian dollars) (Law 2005).

Guidelines

If olfactory repellents are used, it is important to ensure that the repellant 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 (Caro et al. 1995).

A single deer flagging model study was found (Graves & Bellis 1978). 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 (Graves & Bellis 1978). A number of confounding factors make it difficult to determine whether or not this mitigation alternative is viable (Knapp 2005). 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 (Knapp 2005).

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, Texas 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” (AASHTO) and “not generally used and rarely studied for safety impacts” in a critical evaluation of DVC crash countermeasures (Knapp 2005).
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 (DeNicola et al. 2000, Peterson 2003, Kloppers et al. 2005, VerCauteren et al. 2006).

Romin and Bissonette (1996) found 3 of 43 natural resource agency respondents used hazing as a method to reduce deer road mortality, one of which reported success. Hazing was not effective in moose vehicle collision mitigation efforts in Alaska (Thomas 1995). In British Columbia, Roosevelt elk (Cervus canadensis roosevelti) were relocated when hazing failed as a WVC mitigation measure (Sielecki 2004).

Green and blue lasers were found to be ineffective as frightening devices to disperse deer at night (VerCauteren et al. 2006). 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 (VerCauteren et al. 2006). Red lasers were not tested because deer cannot see in the red portion of spectrum (VerCauteren et al. 2006). Lasers have been proven to be effective on birds but not on deer (VerCauteren et al. 2006), probably a result of species-specific threat perception (i.e. animals may not associate the disturbance with danger) (DeNicola et al. 2000, VerCauteren et al 2006). Lights and water sprays have only limited effectiveness (DeNicola et al. 2000).
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 (DeNicola et al. 2000, Peterson 2003). In a study of Key deer capture techniques, hazing with helicopters or shooting out of vehicles in residential areas was not attempted (Peterson 2003).

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 (Kloppers et al. 2005). Natural wolf activity, however, appeared to reduce the efficacy of the aversive conditioning techniques (i.e. elk remained closer to town sites) (Kloppers et al. 2005). Aversive conditioning has shown some success in keeping grizzly bears off roadsides (Gibeau & Heuer 1996).

No scientific studies have been done to test the effectiveness of hazing on reducing WVCs (Danielson & Hubbard 1998), and hazing is not covered in other pertinent reviews on WVC mitigation measures (D’Angelo et al. 2004, Knapp 2005). DeNicola et al. (2000) addresses hazing in managing deer in suburban environments but not within the context of WVC reduction. Hazing can be difficult to implement in established conflict situations, because animal behavioral habits are difficult to change and habituation is possible (DeNicola et al. 2000).

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
Unknown. No scientific studies have been done to test the effectiveness of hazing on reducing WVCs (Danielson & Hubbard 1998).

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) (Kloppers et al. 2005).
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 (CMA) (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 (Danielson & Hubbard 1998, Brownlee et al. 2000, Knapp 2005), especially in areas without natural salt licks (Groot Bruinderink & Hazebroek 1996). 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 (Miller & Livaitis 1992). Implications associated with these roadside salt licks include increased moose vehicle collisions and increased brain worm infections in moose and white-tailed deer (Miller & Livaitis 1992). 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 (Feldhamer et al. 1986).

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 (Brown et al. 2000b). CaMg-acetate has been recommended as an alternative to deice roads in Finland instead of NaCl (Groot Bruinderink & Hazebroek 1996). Attempts at discouraging animals from road salt using the deicer calcium-chloride were unsuccessful in Jasper National Park, Canada (Bertwistle 1997).

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 (Fraser & Thomas 1982). About the same number of collisions happened more than 300 m (984 ft) from a roadside saltwater pool (Knapp 2005). Knapp (2005) questions the assumption of the study (i.e., all locations have an equal chance for a collision).

Road salt and deicing alternatives are addressed in literature reviews (Danielson & Hubbard 1998, Brownlee et al. 2000, Knapp 2005); however, whether the reduction or replacement of the road salt would reduce WVCs involving ungulates remains unknown (Knapp 2005).

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 (Knapp 2005). Deicing salt alternatives are categorized as “experimental” (AASHTO) and “used but not studied for safety impacts” in a critical evaluation of DVC crash countermeasures (Knapp 2005).

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 (D’Itri 1992; Brownlee et al. 2000). 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 (Miller & Litvaitis 1992); elimination of road salt may reduce this occurrence.

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 (Knapp 2005).

A 2-year control/treatment experiment tested the effectiveness of intercept feeding as a means to reduce DVCs by diverting mule deer from roadsides in Utah (Wood & Wolfe 1988). The researchers concluded that intercept feeding may have reduced DVCs by as much as 50 percent (Wood & Wolfe 1988). However, no information was provided on the number of DVCs before intercept feeding stations were operational (Knapp 2005).
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 (Andreassen et al. 2005). Attempts at discouraging animals from road salt using intercept mineral baiting were unsuccessful in Jasper National Park, Canada (Bertwistle 1997).


**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” (AASHTO) and “not generally used and rarely studied for safety impacts” in a critical evaluation of DVC crash countermeasures (Knapp 2005). Additional study which can refute or validate the effectiveness of intercept feeding in reducing DVCs would be appropriate (Knapp 2005).

**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 (Wood & Wolfe 1988).

**Costs**

Intercept feeding is labor intensive (Wood & Wolfe 1988, Farrell et al. 2002).
Chapter 6 Mitigation Methods that Seek to Influence Animal Behavior

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 (Case 1978, Cain et al. 2003). The practice of planting trees near roadways for landscaping reasons can attract ungulates to the right-of-way and increase the risk of WVCs (Putman 1997). 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) (Groot Bruinderink & Hazebroek 1996, Putman 1997, Hyman & Vary 1999 as cited in Evink 2000, Wells et al 1999, Rea 2003, Riley & Sudharsan 2006), while others focus on improving roadside habitat for wildlife (Varland & Schaefer 1998). Techniques employing forage repellents, unpalatable species and roadside brush removal have been used with limited effectiveness or are not cost-efficient when broadly applied (Rea 2003).

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 (Jaren et al. 1991). 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 mile) but that local evaluations are necessary to confirm that vegetation cover is the main contributor to collisions in specific sections (Jaren et al. 1991). It is possible, however, that the experimental design may have overstated the collision reduction potential of vegetation removal (Jaren et al. 1991, Knapp 2005).

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 (Rea 2003). 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 re-growth (Rea & Gillingham 2001, Rea 2003). Cutting in early-June results in browse with significantly less nutritional value for the first 2 years after cutting compared to plants cut later in the growing season and uncut controls (Rea & Gillingham 2001, Rea 2003). Rea (2003) 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.

No studies were found that specifically analyze the WVC safety impacts of roadside management policies or plantings (Knapp 2005), however, a 1999 report by the Arizona..
Department of Transportation describes a future 5-year monitoring plan to address the effectiveness of a number of mitigation measures (including those related to vegetation/habitat changes) on reducing WVCs (Brown et al. 1999). The need to properly study the safety impact of vegetation management along roadways remains (Knapp 2005).

Note: see also the section titled “Increase Visibility for 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” (AASHTO) and “used but rarely studied for safety impacts” in a critical evaluation of DVC crash countermeasures (Knapp 2005).

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 (Forman & Alexander 1998).

Costs

No costs were identified in the literature review.

Guidelines

Some guidance for implementing this mitigation measure is presented by Rea (2003).

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 (Knapp 2005, New York State Department
of Transportation 2006). 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 (Knapp 2005). Evaluation of the impact of roadside carcass removal on reducing WVCs has not been studied and rarely considered (Knapp 2005). 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 deer-vehicle collisions and the total number of wildlife-vehicle collisions. 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” (AASHTO) and “used but rarely studied for safety impacts” in a critical evaluation of DVC crash countermeasures (Knapp 2005).

**Indirect Benefits**

Carcass removal may reduce the frequency of secondary road kill 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) (Sielecki 2004). 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 (2006) found that it was unclear whether or not a vegetated median increased the ability of wildlife to cross the road safely.

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.
A comprehensive review by Knapp et al. (2004) and Putman et al. (2004) suggests that a reduction of the population size across a relatively wide area can be effective in reducing deer vehicle collisions (e.g., Danielson & Hubbard 1998, Craven et al. 2000, Doerr et al. 2001, Schwabe et al. 2002, Knapp et al. 2004, Iowa Department of Natural Resources 2005). Nonetheless, actual data on the effectiveness of population reduction programs on wildlife-vehicle collisions are few. For example, a field test showed that a deer population reduction program in Minnesota reduced winter deer densities by 46 percent and deer vehicle collisions by 30 percent (Doerr et al. 2001).

Deer population sizes, especially those of white-tailed deer, have grown substantially over the last century in the United States (Côté et al, 2004). This population growth is especially apparent since the 1960s (Porter & Underwood 1999, Côté et al. 2004). 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 (Porter & Underwood 1999, Brown et al. 2000a, Enck et al. 2000, Rooney 2001, Côté et al. 2004, Ditchkoff et al. 2006). Currently, white-tailed deer numbers are believed to be higher than they have ever been in the past several hundred years (Rooney 2001), causing or contributing to a series of problems, including deer vehicle collisions (Waller & Alverson 1997, Porter & Underwood 1999, Rooney 2001, Côté et al. 2004). 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 (Swihart et al. 1998). However, the fertility of first-year and yearling females is strongly density dependent, with very low fertility when population densities exceed 30 deer per km² (Swihart et al. 1998). 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 deer vehicle collisions seems intuitive, but is often complex and variable (e.g., Waring et al. 1991, Lehnert et al. 1998). Nonetheless, a comprehensive review by Knapp et al. (2004) and Putman et al. (2004) suggests that a reduction of the population size across a relatively wide area can be effective in reducing deer vehicle collisions (e.g., Danielson & Hubbard 1998, Craven et al. 2000, Doerr et al. 2001, Schwabe et al. 2002, Knapp et al. 2004, Iowa Department of Natural Resources 2005).
This chapter discusses the following measures to reduce wildlife population size along roads:

- Wildlife culling,
- Wildlife relocation,
- Anti-fertility treatment, and
- 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) (Brown et al. 2000a, Doerr et al. 2001, Riley et al. 2003, Nugent & Choquenot 2004).

A field test showed that a deer population reduction program in Minnesota reduced winter deer densities by 46 percent and deer vehicle collisions by 30 percent (Doerr et al. 2001). Sharp shooting 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 sharp shooting by professionals (Doerr et al. 2001).

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 (review in Côté et al. 2004). The does are less likely to migrate and establish new populations elsewhere.

A modeling project by Porter et al. (2004) 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). A further reduction of the annual survival to 42 percent would keep the population at 0.5 of the carrying capacity (Porter et al. 2004).

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 deer-vehicle collisions at 50 percent. Finally, wildlife culling can be met by 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, Minnesota, contact Michelle Doerr, 2887 Ulm Avenue, Stewart, Minnesota 55385, ewiggers@isle.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 deer vehicle collisions can be highly variable (see earlier discussion). Nonetheless, based on Doerr et al. (2001) and Knapp et al. (2004), a certain percentage in population size reduction may result in a similar percentage in deer vehicle collision reduction. However, reductions in population size of 50 percent or more may be hard to obtain (e.g., Doerr et al. 2001), perhaps capping the potential reduction in deer vehicle collisions at 50 percent or less.

**Indirect Benefits**

Indirect benefits of reducing wildlife population size include reduced negative impacts from “overpopulation” on agricultural crops, silviculture, and natural vegetation (Côté et al. 2004).

**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) (Porter & Underwood 1999, Fulton et al. 2004, Koval & Mertig 2004). 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 (Brown et al. 2000a, Côté et al. 2004). If refugia are present, more intensive effort will have to be undertaken at locations that are accessible to hunters or wildlife managers (Brown et al. 2000a).

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 (Côté et al. 2004). A change in regulations may be required to allow for greater quota, specifically for younger animals and does (Brown et al. 2000a, Van Deelen et al. 2006).

The number of hunters is declining (Enck et al. 2000, Riley et al. 2003), perhaps demanding a shift from recreational hunting to professional culling (Riley et al. 2003).

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 non-hunting public (review in Brown & Cooper 2006, Van Deelen et al. 2006).

**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 (Doerr et al. 2001). Others estimated these costs at $91-$310 per deer (DeNicola et al. 2000).

**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, South Carolina a deer relocation experiment was conducted (Cromwell et al. 1999). The relocated deer experienced relatively high mortality from capture-related causes, and 50 percent of the relocated deer dispersed from their release site (Cromwell et al. 1999).

**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, South Carolina, contact: Jennifer Cromwell, United States Department of
Direct Benefits

The relationship between deer population size and deer vehicle collisions can be highly variable (see earlier discussion). Nonetheless, based on Doerr et al. (2001) and Knapp et al. (2004), a certain percentage reduction in population size may result in a similar percentage reduction in deer vehicle collisions. However, reductions in population size of 50 percent or more may be hard to obtain (e.g., Doerr et al. 2001), perhaps capping a potential reduction in deer vehicle collisions at 50 percent or less. 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 (Cromwell et al. 1999).

Indirect Benefits

Benefits include reduced negative impacts from “overpopulation” on agricultural crops, silviculture, and natural vegetation (Côté et al. 2004).

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 (Cromwell et al. 1999). In one study, 50 percent of the relocated deer did not remain in their release area (Cromwell et al. 1999).

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 (Cromwell et al. 1999, Beringer et al. 2002). Relocation of deer can result in the spread of infectious diseases (Miller & Kaneene 2006). Wildlife relocation is, in general, not recommended (Craven et al. 1998).

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 (Côté et al. 2004).
Chapter 7 Mitigation Methods that Seek to Reduce Wildlife Population Size

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) (Porter & Underwood 1999).

Costs

The costs for relocation were estimated at $387 per relocated deer (Beringer et al. 2002). Others estimated these costs at $431 or $400-$2,931 per deer (review in DeNicola et al. 2000).

Guidelines

No guidelines were identified in the literature review.

ANTI-FERTILITY TREATMENT

Anti-fertility treatment can reduce reproduction of deer (Turner et al. 1992, Turner et al. 1996, McShea et al. 1997, Waddell et al. 2001, Naz et al. 2005). This measure is typically considered or applied where killing (through hunting) is illegal (private lands, legislation) or impractical ((sub) urban areas, public pressure), where re-colonization possibilities from elsewhere are limited (closed population), and where a relatively small deer population exists (e.g. less than or equal to 2000 breeding females) (Boone & Wiegert 1994, Seagle & Close 1996, Turner et al. 1996, Rudolph et al. 2000, Kirkpatrick & Rutberg 2001). Some drugs have shown to be effective for up to 1 or 2 years (Turner et al. 1996), 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) (Kirkpatrick et al. 1997).

Modeling efforts have shown that sterilization in combination with hunting can control the population size of deer (Boone & Wiegert 1994, Seagle & Close 1996). For the deer on Cumberland Island National Seashore, Georgia, (herd size 1500 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 (Boone & Wiegert 1994). 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 (1996) 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. 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 (Seagle & Close 1996). 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 (Merrill et al. 2003). Models developed by Porter et al. (2004) 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.

Results of a field test on a suburban white-tailed deer population in Irondequoit, New York 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) (Rudolph et al. 2000). Walter et al. (2002) captured and treated suburban female white-tailed deer in Connecticut with a contraceptive. 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 (Walter et al. 2002). A capture and sterilization program for a white-tailed deer population in Cayuga Heights, New York (Merrill et al. 2006) showed that capture efforts had to be relatively high because the traps were not sex or age specific. Furthermore, the efficacy of the sterilization program was dramatically reduced because it was not a closed population (Merrill et al. 2006).

Case Studies and Contacts

For information on a field test using immunocontraception in a suburban white-tailed deer in Irondequoit, New York, contact Brent Rudolph, Department of Fisheries and Wildlife, Michigan State University, East Lansing, Michigan 48824, (517)432-4943, rudolph13@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, Oklahoma, 74078, wdwalte@okstate.edu.

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

Direct Benefits

The relationship between deer population size and deer vehicle collisions can be highly variable (see earlier discussion). Nonetheless, based on Doerr et al. (2001) and Knapp et al. (2004), a certain percentage in reduction population size may result in a similar percentage reduction in deer vehicle collisions. However, reductions in population size of 50 percent or more may be hard to obtain (e.g., Rudolph et al. 2000), perhaps capping the potential reduction in deer vehicle collisions at 50 percent or less. The effectiveness is seriously diminished if it is an open population that allows the individuals from neighboring populations to fill the gaps (Merrill et al. 2006).
Indirect Benefits

Benefits include reduced negative impacts from “overpopulation” on agricultural crops, silviculture, and natural vegetation (Côté et al. 2004).

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 (Nettles 1997, Shea et al. 1997). However, health problems and effects on social behavior may not always occur, or they may be minimal (Kirkpatrick et al. 1997).

The efforts will have to be repeated constantly in a population (Boone & Wiegert 1994), and depending on the drug used, the same animals may have to be treated multiple times during their lives (Turner et al. 1996, Kirkpatrick et al. 1997, Baker et al. 2004).

The effort is less effective, or not effective, when re-colonization from elsewhere can occur (open population) (Seagle & Close 1996)

The method may only be feasible for relatively small populations (less than or equal to 200 females) (Rudolph et al. 2000).

Costs

Walter et al. (2002) 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).

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 (Porter & Underwood 1999, Brown et al. 2000, Enck et al. 2000, Rooney 2001, Côté et al. 2004, Ditchkoff et al. 2006). 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 (Pettorelli et al. 2005).

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 (Gill et al. 1996). 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 (Gill et al. 1996, Darimont et al. 2005).

Reducing the quality of the available food may only limit populations in relatively poor years (Pettorelli et al. 2005), and stimulating attractive browse to lure animals away from croplands may only work on a small scale, affect primarily females, and has to take into account the relative attractiveness of the foods available in the area (Cimino & Lovari 2003, Campbell et al. 2004).

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, Georgia 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 deer vehicle collisions can be highly variable (see earlier discussion). Nonetheless, based on Doerr et al. (2001) and Knapp et al. (2004), a certain percentage in population size reduction may result in a similar percentage in deer vehicle collision reduction. However, reductions in population size of 50 percent or more may be hard to obtain (e.g., Rudolph et al. 2000), perhaps capping the potential reduction in deer vehicle collisions at 50 percent or less. 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:

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

WILDLIFE FENCING

Fencing is one of the most commonly applied measures to separate wildlife from motorists (e.g., Romin & Bissonette 1996). Wildlife fences in North America typically consist of 2.0-2.4 m (6.5-8 ft) high wire mesh fence material (Figure 41). Several types of fence material are used, but page-wire or cyclone fence material is most common. The Utah DOT has painted wire mesh dark brown which effectively camouflages the wire mesh. Wooden or metal fence posts are typically used, the latter are particularly important when fencing over rock substrates.

Figure 41: Wildlife Fence Along Interstate 90 Near Bozeman, MT (Photo: Marcel Huijser, WTI).
Woods (1990) reported 94-97 percent reduction in ungulate-vehicle collisions along a fenced section of the Trans-Canada Highway. Along the same road, Clevenger et al. (2001b) showed that fences were effective in reducing vehicle collisions with ungulates by 80 percent. Clevenger et al (2001b) also identified that wildlife vehicle collisions (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. Dodd et al. (in prep.) found that wildlife fencing in combination with underpasses reduced elk-vehicle collisions by 86.8 percent. Reed et al. (1982) reported an average reduction of 78.5 percent for deer vehicle accidents in Colorado, and Ward (1982) reported a reduction of greater than 90 percent for mule deer in Wyoming. In Sweden, fencing reduced moose vehicle collisions by 80 percent (Lavsund & Sandegren 1991). Boarman and Sazaki (1996) found that new or properly maintained fences significantly reduced mortality for several wildlife species, including the desert tortoise. 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 (Sielecki 1999). In Pennsylvania, Feldhamer et al. (1986) 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. They suggested that fencing may be effective if properly maintained to fix holes that people cut into it, and 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 (2006), and their results could be applicable to preventing deer from accessing short segments of highway. 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 (2004) modeled population responses to a range of scenarios. 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, PO Box 174250, Bozeman, Montana 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, Arizona 85935, (928)368-5675, doddnbenda@cybertails.com.

For information about wildlife fencing along US 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, Ohio 44870, thomas.w.seamans@usda.gov.

Direct Benefits

Depending on the species concerned, the type of fencing, and whether safe crossing opportunities are provided for, wildlife fencing may reduce the number of wildlife vehicle collisions 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 keeps 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 animal vehicle collisions at fence ends (Clevenger et al. 2001b, Norris Dodd, Arizona Game and Fish Department, personal communication). Therefore, consideration should be given to measures that mitigate a potential concentration of wildlife vehicle collisions 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 (see later). In addition, wolves, bears and other predators have also occasionally been seen running prey species into the wildlife fences (Leeson 1996). Finally, birds may collide with fences and die (Baines & Summers 1997, Dobson 2001).
- 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 m (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 (2006) consisted of 5 rope strands at 25 cm (9.7 in) and cost $9 per m ($2.7 per ft) (Seamans & VerCauteren 2006). 1.2 m high (4-ft), 5-Braid™ ElectroBraid™ Deer Exclusion Fence is advertised at $4300 per km ($7,000 per mile) while 1.5 m (5 ft) high, 5-Braid™ ElectroBraid™ Moose Exclusion Fence is advertised at $4750 per km ($7,500 per mile) (ElectroBraid 2006).

Sielecki (1999) 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. Fencing in his study ranged from Can$40,000 to 80,000 per km.

The cost of wildlife fencing along US Highway 93 on the Flathead Reservation in Montana varied depending on the road section concerned: $26, $38, $41 per m ($7.9, $11.6, $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 (Griffin & Pletscher 2003, Boarman & Sazaki 1996, Aresco 2004). 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 (Jones & Longhurst 1958, Gloyne & Clevenger 2001). 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 (Grande et al. 2000, Terry McGuire, Parks Canada, personal communication). However, regular inspection for gaps and other problems is required (e.g. Clevenger et al. 2002b).

Regular fence maintenance is critical in order to keep it 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 with 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:

- 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, and
  - One-way gates;
- Mitigate WVCs at fence ends using,
  - Boulders between fence and roadway and
  - Animal detection systems;
- Improve landscape aesthetics of wildlife fencing;
- Reduce wildlife mortality risk of fencing; and
- Mitigate gaps in fencing at access roads using,
  - Gates, and
  - 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, Arizona, 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 (Lehnert & Bissonette 1997). 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 (Clevenger & Kociolek 2006). 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 (Clevenger & Kociolek 2006).

**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, Utah, 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 42.

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 43.
Figure 42: Gap in a Wildlife Fence Accompanied by Wildlife Warning Signs and Advisory Speed Limit Reduction, the Netherlands (Photo: Marcel Huijser).

Figure 43: Gap in a Wildlife Fence Combined with an Animal Detection System, Wildlife Warning Signs and Advisory Speed Limit Reduction, the Netherlands (Photo: Marcel Huijser).
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**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 road kill 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) (Lehnert & Bissonette 1997). Animal detection systems have been used at gaps in wildlife fences, but there are not data on the effectiveness of this measure in combination with a gap in a fence. As a stand-alone mitigation measure, however, animal detection systems may reduce collisions with ungulates by 82 percent on average (Huijser et al. 2006b).

**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 (Lehnert & Bissonette 1997).

The estimated cost of animal detection systems at a gap in the fence is $50,000 (including installation and fence) (Huijser et al. 2006b).

**Guidelines**

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 (Falk et al. 1978, Ludwig & Bremicker 1983, Feldhammer et al. 1986, Clevenger et al. 2002b) (Figures 44 to 46). 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 (Clevenger et al. 2002b). In some cases wildlife fencing is only installed over relatively short distances funneling wildlife towards a crossing structure (e.g. Dodd et al. 2003). 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 (Dodd et al. In prep.). 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 (Clevenger et al. 2002b). 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 44: Wildlife Underpass along US Highway 93 on the Flathead Indian Reservation, Montana (Photo: Marcel Huijser, WTI).

Figure 45: Wildlife Overpass in Banff National Park, Alberta, Canada (Photo: Marcel Huijser).

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) (Clevenger et al. 2002b). Furthermore, different species have different preferences.

![Image of underpass in Southern Florida](image)

Figure 46: Underpass in Southern Florida that Allows for Ecosystem Processes (Hydrology) as well as Wildlife Use, Including the Florida Panther (Photo: 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.

For more information on wildlife underpasses and one wildlife overpass along US 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, Arizona 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 wildlife vehicle collisions. 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 x 2.5 m (8.2 ft) wide) = $Can2,800 per m ($854 per ft) length; elliptical culverts (4 m (13 ft) high x 7 m (23 ft) wide) = $Can5,400 per m ($Can1646 per ft) length; open span bridge underpass (13 m (43 ft) wide x 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 (Kruidering et al. 2005).

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 (Kruidering et al. 2005).
Guidelines

Recommended minimum dimensions for underpasses and overpasses have been suggested for some ungulate species (see Foster & Humphrey 1995), but the needs of wide-ranging species are vague at best. The most comprehensive guidelines for designing wildlife crossing structures, including most below-grade crossing structures, can be found in Iuell (2003). 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 (2003), Foster and Humphrey (1995), Clevenger and Waltho (2000), Clevenger and Waltho (2005), and Kruidering et al. (2005). The last publication includes cost estimates for a range of types of crossing structures. Guidelines for wildlife crossings are being developed from NCHRP 25-27 and will 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 et al. (2002) 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.

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 (Reed et al. 1974a, Ludwig & Bremicker 1983, Feldhamer et al. 1986, Bissonette & Hammer 2000).

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 47). 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 backside of escape ramps is designed to preclude deer from gaining access to the right-of-way from the non-highway 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 big-horn sheep have also used these structures (Bruce Leeson, personal communication).
Bissonette and Hammer (2000) studied the effectiveness of earthen escape ramps (jump-outs) and one-way gates along a fenced section of US 91 and US 40 in northern Utah. 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 one 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 et al. (2002a) documented use of jump-outs by deer, elk and coyote on the Trans Canada Highway.

**Case Studies and Contacts**

For information on jump-outs along US 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
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Wildlife, College of Natural Resources, Utah State University, Logan, Utah 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, PO Box 174250, Bozeman, Montana 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 (Bissonette & Hammer 2000).

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 (Bissonette & Hammer 2000) and $6,250 (Pat Basting, Montana Department of Transportation, personal communication).

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 (2000).

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 48 and Figure 49) have been built for different species, including elk, deer and the Eurasian badger (Ludwig & Bremicker 1983, Bissonette & Hammer 2000, Kruidering et al. 2005). Reed et al. (1974a) found one-way gates relatively effective for deer, whereas Lehnert (1996) found that only 17 percent of the deer that approached the gates ended up using them. In general one-way gates are no longer recommended as wildlife can learn how to use them to get into the right-of-way (Clevenger et al 2002b), sometimes aided by hikers, fisherman, equestrians and bikers who propped and tied the gates open (Bruce Leeson, personal communication). 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 (Bissonnette & Hammer 2000).
Figure 48: One-way Elk Gate in British Columbia, Canada (Photo: Marcel Huijser).
Case Studies and Contacts

For more information on one-way gates for deer in Utah (Bissonette & Hammer 2000), contact John A. Bissonette, Utah Cooperative Fish Wildlife Research Unit, Utah State University, Logan, Utah, 84322-5290, (435)797-2511, john.bissonette@usu.edu.

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 (Bissonette & Hammer 2000).
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Guidelines

See Bissonnette and Hammer (2000).

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 50 (Clevenger et al. 2002a). 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 50). 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 20-60 cm (7.8-23.6 in) (about 75 percent are larger than 30 cm (11.8 in). The boulder apron, at a depth of about 40-50 cm (15.7-19.7 in), is installed on geofabric on sub-excavated smoothed ground. The boulders project about 20-30 cm (7.8-11.8 in) 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, PO Box 174250, Bozeman, Montana 59717-4250, (403)609-2127, Tony.Clevenger@pc.gc.ca.

Direct Benefits

Clevenger et al. (2002a) found that the combination of the boulder field and wildlife fencing were effective in reducing wildlife vehicle collisions. Six deer vehicle collisions occurred prior to fencing (and boulder field installation), while only two occurred after fencing. The boulders were believed to be an effective deterrent in keeping ungulates from wandering in between the fences (Clevenger et al. 2002a).
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 animal vehicle collisions. 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, Arizona 85935, (928)368-5675, doddnbenda@cybertails.com.

Direct Benefits

The benefits of using animal vehicle detection systems at fence ends are unknown, but as a stand alone mitigation measure, animal detection systems can reduce collisions with large ungulates by 82 percent (Huijser et al. 2006b). The application of animal detection systems at fence ends can be expected to result in a similar reduction in wildlife-vehicle collisions, 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 et al. (2006c) for general design considerations.

LANDSCAPE AESTHETICS OF WILDLIFE FENCING

Wildlife fencing can have a negative impact on landscape aesthetics; many people perceive tall wildlife fences as ugly. Potential solutions are 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 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.
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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 capercaille (*Tetrao urogallus*) (Dobson 2001).

**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 capercaille, 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 WVC, 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.
Chapter 8 Mitigation Methods that Seek to Physically Separate Animals from the Roadway

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 US Highway 93, Flathead Indian Reservation, Montana, 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 US Highway 93 on the Flathead Indian Reservation, Montana 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 51). However, standard cattle guards may be easily passable by Florida key deer and mule deer (Reed et al. 1974b), dangerous to pedestrians and cyclists (Peterson et al. 2003), and special designs may be needed (for example, those developed for the Florida Key deer (Peterson et al. 2003)). 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, Electrobraid Fence Ltd, personal communication).

Figure 51: Wildlife Guard along US Highway 93 on the Flathead Indian Reservation, Montana (Photo: 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 US Highway 93 on the Flathead Indian Reservation, Montana, contact Pat Basting, Montana Department of Transportation, (406)523-5872, pbasting@mt.gov.
Chapter 8 Mitigation Methods that Seek to Physically Separate Animals from the Roadway

Direct Benefits

Cattle or wildlife guards offer no additional benefits in reducing WVCs compared to undisturbed 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 (Peterson et al. 2003). 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 et al. (2003).
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 52) and swing-gates, with or without steps to accommodate for deep snow (Figure 53), 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 52: Angled Opening in Fence Allowing Access for People Along US Highway 93, Montana (Photo: Marcel Huijser, WTI).](image-url)
Case Studies and Contacts

For details on an opening in a fence along US 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.
Chapter 8 Mitigation Methods that Seek to Physically Separate Animals from the Roadway

Undesirable Effects

Some access designs (e.g. the opening in a fence along US 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, US Forest Service, personal communication, Norris Dodd, Arizona Game and Fish Department, personal communication) (Figure 54 and Figure 55). 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 54: Large boulders Placed in the Right-of-Way as a Barrier to Elk and Deer along State Route 260 in Arizona (Photo: Marcel Huijser).
Figure 55: 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 (Photo: 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, Arizona 85935, 928-367-5657, doddnbenda@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.
Chapter 8 Mitigation Methods that Seek to Physically Separate Animals from the Roadway

Costs

Costs for the Arizona case study were less than $197 per m (less than $60 per linear foot) (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 road kill, 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 56).
Case Studies and Contact

At one section of the US 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 a 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 57). The canal was never built, but the bridge allows wildlife to pass unharmed underneath.
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, Colorado 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, wildlife vehicle collisions 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 road-way (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) (Austin & Garland 2001). 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 wildlife vehicle collisions. 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

- Identifying and prioritizing WVC problem areas;
- Improved data collection and monitoring;
- Adjusting the road alignment by,
  - Considering the no-build option,
  - Considering alternative alignments, and
  - Road removal; and
- 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 wildlife vehicle collisions, one must also consider a broader context 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 wildlife vehicle collisions 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.
Chapter 9. Planning and Design Considerations

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 (2005) has been involved in a number of regional and statewide wildlife habitat linkage plans. In formulating such plans, he suggests using a variety of data including aerial photos, vegetation maps, topography maps, wildlife habitat and range maps, and road-kill 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 (2005), a prioritized linkage zone map was created for Arizona. The map was created during Arizona’s Missing Linkages Workshop in April 2004. The workshop included representatives from the Arizona Department of Transportation (ADOT), FHWA, US Fish and Wildlife Service (USFWS), Arizona Game and Fish Department (AZGFD), US Department of the Interior’s Bureau of Land Management (BLM), Tonto National Forest, and Northern Arizona University. This initial map was refined during six ecoregional workshops in November 2004. GIS databases were helpful in obtaining some of the data that was used in prioritizing the linkage zones.

The University of Alaska Anchorage produced a “toolbox” for the Alaska Department of Transportation & Public Facilities (ADOT&PF) to assess how Alaskan roads affect habitat quality and connectivity (DiBari et al. 2004). The project specifically addressed the use of Geographic Information Systems (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 exists on habitat features and that represent the diversity of ecosystems;
- Riparian corridors;
- Places where funding can be leveraged; and
- 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 (Smith 1999). 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 road kill 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 south east corner of the state (Geodata 2005). A number of models predict optimal crossing locations for specific species such as key deer in Big Pine Key, Florida (Grist et al. 1999) and grizzly bear in the area around Evaro Hill, Montana (Meitz 1994).

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 departments of transportation. 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 (STIP) 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.
Chapter 9. Planning and Design Considerations

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 Ch. 6 in National Research Council (2005), Ch. 3 in NCHRP Synthesis 305 by Evink (2002), Ch. 6-7 in Moore and Thorsnes (1994) and the following websites: Federal Highways Administration, www.fhwa.dot.gov/planning/, and American Planning Association, www.planning.org.

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 is 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 is 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 (Huijser et al., in prep.). A survey conducted as part of this report asked states if they collected WVC data (crashes or carcasses). Of the 30 state departments of transportation that responded to the survey: 19 collected crash data on WVCs, 13 collected carcass data, and eight collected neither. It should be noted that although the states reported they did not collect it, 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 (LARS) 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 Road Kill 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 LARS carcass data collection method, contact William Branch,
Maryland Department of Transportation, 410-545-8626, WBranch@sha.state.md.us.

For more information on hand held 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 wildlife vehicle collisions. 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 (1999) developed one such model for the Pennsylvania Department
of Transportation. 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.

Context sensitive design / context sensitive solutions (CSD/CSS) processes are used to
incorporate community values, aesthetics, 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
  (Neuman, T. et al. 2002);
• AASHTO Guide for Achieving Flexibility in Highway Design (AASHTO 2004b); and
• NCHRP Report 69; Performance Measures for Context Sensitive Solutions- A
  Guidebook for State DOTs. (Transtech et al. 2006). 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 road kills (Bethelsen 2003). The underpass (in combination
with fencing) now serves as a critical connection in a wildlife migration route (Bethelsen 2003).

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 turn around 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 et al. (2004) points out, the impact to wildlife has
not been monitored or researched. Switalski et al. (2004) suggests costs for road removal are as
follows:
• Gating the roadway ends and leaving the road intact: $1000-2800;
• 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 mile);
• Stream crossing restoration: $500-150,000 per crossing; and
• Full recontour of slopes: $3,000 – 200,000 per km ($4,850-322,000 per mile);
Figure 58 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 non-motorized multi-use pathway.

![Image of road removal](image)

**Figure 58:** Road Removal in Progress in Belgium (note that a path for pedestrians and bicyclists remains in place.) (Photo: 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.


**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:
• Side slopes: Steep side slopes can hide approaching animals from the driver’s view. The AASHTO (2004a) Green Book recommends slopes of one foot vertical to four feet horizontal or flatter. 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 (2006) found that “the general hypothesis is that concrete Jersey barriers may increase the risk of direct vehicle mortality [of wildlife].” 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).
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 wildlife vehicle collisions. 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 DOTs, federal agencies, and non-government organizations. The Technical Working Group members are listed in Table 9.

Table 9: Technical Working Group Members.

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
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<tbody>
<tr>
<td>Bill Branch</td>
<td>Maryland DOT</td>
</tr>
<tr>
<td>Michael Pawlovich*</td>
<td>Iowa DOT</td>
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<tr>
<td>Scott Jackson</td>
<td>US Fish and Wildlife Service</td>
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<tr>
<td>Susan Hagood</td>
<td>The Humane Society of the US</td>
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<td>Brent Haglund</td>
<td>Sand County Foundation</td>
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<td>Sandy Jacobson</td>
<td>Forest Service</td>
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<tr>
<td>Keith Knapp</td>
<td>Texas Transportation Institute</td>
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*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 (Neuman et al. 2003).

**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 (Neuman et al. 2003).

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 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 (Neuman et al. 2003).

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 there have not been found valid evaluations.
- **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 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 deer-vehicle collisions. The vote was not based on mitigation for other effects related to roads and traffic (e.g. barrier effect), nor for species other than deer (white-tailed and mule deer combined). Deer are involved with the majority of all reported wildlife-vehicle collisions (Chapter 2). If panel members had been asked to consider multiple species representing very different species groups, the procedure would have had to be 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.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Successful</th>
<th>Demonstrated</th>
<th>Attempted</th>
<th>Unknown</th>
<th>Failed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Information and Education</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Wildlife Warning Signs</td>
<td>2</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large, Non-Standard Wildlife Warning Signs</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seasonal Wildlife Warning Signs</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roadside Animal Detection Systems (RADS)</td>
<td>2</td>
<td>5</td>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>In-Vehicle Warnings: RADS to On-Board</td>
<td></td>
<td></td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-Veh. Warning: On-Board Animal Detectors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Increase Visibility: Roadway Lighting</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase Visibility: Vegetation Removal</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase Visibility: Wider Road Striping</td>
<td></td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reflective Collars (Buffalo)</td>
<td></td>
<td></td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduce Traffic Volume On Road Network</td>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Seasonal Closure</td>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Reduce Speed by Reducing Posted Speed Limit</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduce Speed By Traffic Calming</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wildlife Crossing Guards</td>
<td>4**</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mitigations that Attempt to Influence Driver Behavior

- 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 Attempt to Physically Separate Animals from the Roadway

- Wildlife Culling: 7
- Wildlife Relocation: 6, 1
- Anti-fertility treatment: 7
- Habitat Alteration: 4, 3

- 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.
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:

- Recommended for implementation;
- Recommended for further research; or
- 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.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Votes Received</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mitigations that Attempt to Influence Driver Behavior</strong></td>
<td></td>
</tr>
<tr>
<td>Public Information and Education</td>
<td>7</td>
</tr>
<tr>
<td>Standard Wildlife Warning Signs</td>
<td>2</td>
</tr>
<tr>
<td>Large, Non-Standard Wildlife Warning Signs</td>
<td>1 5</td>
</tr>
<tr>
<td>Seasonal Wildlife Warning Signs</td>
<td>7</td>
</tr>
<tr>
<td>Roadside Animal Detection Systems (RADS)</td>
<td>2 5</td>
</tr>
<tr>
<td>In-Vehicle Warnings: RADS to On-Board</td>
<td></td>
</tr>
<tr>
<td>In-Veh. Warning: On-Board Animal Detectors</td>
<td>7</td>
</tr>
<tr>
<td>Increase Visibility: Roadway Lighting</td>
<td>7</td>
</tr>
<tr>
<td>Increase Visibility: Vegetation Removal</td>
<td>7</td>
</tr>
<tr>
<td>Increase Visibility: Wider Road Striping</td>
<td></td>
</tr>
<tr>
<td>Reflective Collars (Buffalo)</td>
<td></td>
</tr>
<tr>
<td>Reduce Traffic Volume On Road Network</td>
<td></td>
</tr>
<tr>
<td>Seasonal Closure</td>
<td>6 1</td>
</tr>
<tr>
<td>Reduce Speed by Reducing Posted Speed Limit</td>
<td>6 1</td>
</tr>
<tr>
<td>Reduce Speed By Traffic Calming</td>
<td>1 5 1</td>
</tr>
<tr>
<td>Wildlife Crossing Guards</td>
<td>4 3</td>
</tr>
<tr>
<td><strong>Mitigations that Attempt to Influence Animal Behavior or Population Size</strong></td>
<td></td>
</tr>
<tr>
<td>Deer Reflectors and Mirrors</td>
<td>1 5</td>
</tr>
<tr>
<td>Audio Signals in Row or Deer Whistles</td>
<td>1 6</td>
</tr>
<tr>
<td>Olfactory Repellants</td>
<td>3 4</td>
</tr>
<tr>
<td>Deer Flagging Models</td>
<td>1 6</td>
</tr>
<tr>
<td>Hazing</td>
<td>2 5</td>
</tr>
<tr>
<td>Investigate deicing Alternatives</td>
<td>1 4 2</td>
</tr>
<tr>
<td>Intercept Feeding</td>
<td>2 5</td>
</tr>
<tr>
<td>Influence Species/ Nutritional Value in ROW</td>
<td>5 1</td>
</tr>
<tr>
<td>Expanded Median</td>
<td>4 2</td>
</tr>
<tr>
<td><strong>Mitigations that Seek to Reduce Wildlife Population Size</strong></td>
<td></td>
</tr>
<tr>
<td>Wildlife Culling</td>
<td>2 4 1</td>
</tr>
<tr>
<td>Wildlife Relocation</td>
<td>1 6</td>
</tr>
<tr>
<td>Anti-fertility treatment</td>
<td>3 4</td>
</tr>
<tr>
<td>Habitat Alteration</td>
<td>1 3 3</td>
</tr>
<tr>
<td><strong>Mitigations that Attempt to Physically Separate Animals from the Roadway</strong></td>
<td></td>
</tr>
<tr>
<td>Wildlife Fencing</td>
<td>6 1</td>
</tr>
<tr>
<td>Boulders Fence</td>
<td>2 5</td>
</tr>
<tr>
<td>Long Tunnels and Long Bridges</td>
<td>2 4 1</td>
</tr>
<tr>
<td>Underpasses and Overpasses</td>
<td>2 4 1</td>
</tr>
<tr>
<td>Underpasses / Overpasses and Fencing</td>
<td>4 1</td>
</tr>
</tbody>
</table>

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 (4 or more) was required to make a positive recommendation for implementation of the mitigation
measure. Also, a majority of votes (4 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 4 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 deer-vehicle collisions. 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; and
  - 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; and
  - Reflective collars placed on wildlife.

- Mitigations that may be promising, but require further investigation include:
  - 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, non-standard wildlife warning signs;
Chapter 10. Evaluation of Mitigation Methods by Technical Working Group

- 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; and
- 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 wildlife vehicle collisions and animal carcasses. The national databases, summarized in Chapter 2, all have some shortcomings in these regards. Most importantly, location data is 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 animal vehicle collisions 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 road kill data. Given the investment and life span of some of the mitigation measures, it is advisable, however, to project 50 to 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 and how these effects can be minimized and how the disrupted processes can be restored.

SUMMARY

To summarize, future research should focus on the following:

- Develop and implement guidelines and standards for collecting and reporting 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 research and development to improve existing mitigation measures.
- Develop and apply 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 wildlife vehicle collisions, specifically deer vehicle collisions. 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 km 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 deer vehicle collisions 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 mile) road section of a 4-lane road (2 lanes in each direction) that had five deer vehicle collisions 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 deer vehicle collision 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 km 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 km per year, and no cost-benefit calculations were conducted. However, this does not necessarily mean that these mitigation measures are not effective in reducing deer vehicle collisions or that they are not a wise investment. Instead it may only indicate that further research or analysis would be necessary to quantify their cost-benefit.
Chapter 12. Cost-Benefit Analyses

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.

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Cost ($ /km /yr)</th>
<th>% DVC Reduction</th>
<th>Benefit ($ /km /yr)</th>
<th>Balance ($ /km /yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard warning signs</td>
<td>$18</td>
<td>0%</td>
<td>$0</td>
<td>-$18</td>
</tr>
<tr>
<td>Enhanced wildlife warning signs</td>
<td>$249</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Seasonal wildlife warning signs</td>
<td>$27</td>
<td>26%</td>
<td>$10,904</td>
<td>$10,878</td>
</tr>
<tr>
<td>Animal detection systems (ADS)</td>
<td>$31,300</td>
<td>82%</td>
<td>$34,391</td>
<td>$3,091</td>
</tr>
<tr>
<td>ADS linked to on-board computer</td>
<td>?*</td>
<td>82%</td>
<td>$34,391</td>
<td>?</td>
</tr>
<tr>
<td>On-board animal detectors</td>
<td>$2,225*</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Vegetation removal</td>
<td>$500</td>
<td>38%</td>
<td>$15,937</td>
<td>$15,437</td>
</tr>
<tr>
<td>Deer reflectors and mirrors</td>
<td>$495</td>
<td>0%</td>
<td>$0</td>
<td>-$495</td>
</tr>
<tr>
<td>Deer whistles</td>
<td>$23.5*</td>
<td>0%</td>
<td>$0</td>
<td>?</td>
</tr>
<tr>
<td>Carcass removal</td>
<td>$250*</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Population culling</td>
<td>$2,508</td>
<td>50%</td>
<td>$20,970</td>
<td>$18,462</td>
</tr>
<tr>
<td>Relocation</td>
<td>$10,260</td>
<td>50%</td>
<td>$20,970</td>
<td>$10,710</td>
</tr>
<tr>
<td>Anti-fertility treatment</td>
<td>$61,702</td>
<td>50%</td>
<td>$20,970</td>
<td>-$40,732</td>
</tr>
<tr>
<td>Fence (incl. dig barrier)</td>
<td>$3,760</td>
<td>87%</td>
<td>$36,488</td>
<td>$32,728</td>
</tr>
<tr>
<td>Boulders in right-of-way</td>
<td>$2,461</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Long bridges</td>
<td>$781,250</td>
<td>100%</td>
<td>$41,940</td>
<td>-$739,310</td>
</tr>
<tr>
<td>Long tunnels or long bridges</td>
<td>$1,500,000</td>
<td>100%</td>
<td>$41,940</td>
<td>-$1,458,060</td>
</tr>
<tr>
<td>Fence with gap and warning signs</td>
<td>$3,772</td>
<td>0%</td>
<td>$0</td>
<td>-$3,772</td>
</tr>
<tr>
<td>Fence with gap and crosswalk</td>
<td>$5,585</td>
<td>40%</td>
<td>$16,776</td>
<td>$11,191</td>
</tr>
<tr>
<td>Fence with gap and ADS</td>
<td>$9,930</td>
<td>82%</td>
<td>$34,391</td>
<td>$24,461</td>
</tr>
<tr>
<td>Fence with underpasses</td>
<td>$5,860</td>
<td>87%</td>
<td>$36,488</td>
<td>$30,628</td>
</tr>
<tr>
<td>Fence with overpasses</td>
<td>$26,485</td>
<td>87%</td>
<td>$36,488</td>
<td>$10,003</td>
</tr>
<tr>
<td>Fence with under- and overpasses</td>
<td>$7,510</td>
<td>87%</td>
<td>$36,488</td>
<td>$28,978</td>
</tr>
</tbody>
</table>

Assumes one km with five DVCs per year
* costs not in $ per km / year, but in a different unit, see text
? unknown or uncertain

The costs and the potential reductions in wildlife vehicle collisions 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 cm x 76 cm (30 in x 30 in) sign (USA Traffic Signs 2007). The costs per km per year (2 signs per km, one sign for each travel direction, assumed life span of 7 years (USA Traffic Signs 2007), no maintenance) are $18, but since standard wildlife warning signs are considered ineffective in reducing wildlife vehicle collisions (i.e., $0 benefit), the final cost for this mitigation measure remains at $18 per km ($30 per mile) per year. The effectiveness of enhanced wildlife warning signs is largely unknown, causing them to be excluded from the analyses. Seasonal wildlife warning signs (2 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 deer vehicle collisions, and could end up saving $10,878 per km ($17,517 per mile) 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 wildlife vehicle collisions by 82 percent, they still result in a positive balance of $3,091 per km ($4977 per mile) 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 km of road length per year.

There are insufficient data available to evaluate the cost-benefit 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 mile) per year.

Assuming that deer reflectors and mirrors (life span 12.5 years, costs includes maintenance) are indeed not effective in reducing deer vehicle collisions, they have a negative balance of $495 per km ($797 per mile) per year. The costs for deer whistles are per vehicle rather than per km 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 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 km 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 km 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
Chapter 12. Cost-Benefit Analyses

(72x739) to 356 acres)) (Kilpatrick et al. 2000, Beringer et al. 2002, Grund et al. 2002). 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 mile) 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 to 91 individuals per km$^2$ (Porter & Underwood 1999, Kilpatrick et al. 2001). Assuming a population density of 70 individuals per km$^2$, there are 136.8 deer in 195.4 ha. The cost for culling, relocation and anti-fertility treatment was set at $110, $450, and $1128 (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, 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 (DeNicola et al. 2000). 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 (per mile $4,038 and $16,512) 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 (DeNicola et al. 2000, Rudolph et al. 2000). This results in an annual cost for anti-fertility treatment of $61,702 per km ($99,300 per mile). 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 miles) (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 (e.g. Dodd et al. in prep.). 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 (one 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 deer vehicle collisions per km per year), would be funneled through these gaps, and that the number of deer vehicle collisions 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 1 overpass every 25 km (15.5 miles). 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 59 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 59). 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 59) also have high effectiveness, but their positive financial balance is less strong.
CHAPTER 13 CONCLUSION

This report has summarized the considerable body of existing knowledge on the impacts and mitigations of wildlife vehicle collisions. 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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