WILDLIFE-VEHICLE COLLISION AND CROSSING MITIGATION MEASURES: *A TOOLBOX FOR THE MONTANA DEPARTMENT OF TRANSPORTATION*

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Wildlife-Vehicle Collision and Crossing Mitigation Measures: a Toolbox for the Montana Department of Transportation

by

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16. Abstract

This report reviews 39 mitigation measures that reduce animal-vehicle collisions and that provide habitat connectivity for wildlife across highways. The overview is restricted to mitigation measures aimed at large terrestrial mammals (deer size and larger). However, this report also includes information regarding how such measures may affect or benefit federally endangered or threatened species in Montana, regardless of their size. In addition to the detailed information for each mitigation measure, a summary table is provided that provides at-a-glance information on the costs and benefits of the individual mitigation measures for which such data were available. Furthermore, the report graphically illustrates which measures have the best monetary balance (the difference between benefits and costs) and which measures reduce animal-vehicle collisions and associated costs best. Based on the results, the authors of this report identified wildlife fencing, with or without wildlife underpasses or a combination of wildlife underpasses and overpasses, and animal detection systems with wildlife fencing, as the most cost-effective mitigation measures. Animal detection systems without wildlife fences or wildlife fences with a high density of wildlife overpasses are also cost-effective, but more data on system effectiveness are needed before these systems are recommended for implementation rather than further study. The final section of the report provides suggestions on the implementation or study for each of the 39 mitigation measures.

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EXECUTIVE SUMMARY

Animal-vehicle collisions affect human safety, property and wildlife. Furthermore, the number of collisions with large animals has increased in North America over the last decades. The negative effects of animal-vehicle collisions and the increase in collisions prompted the initiation of this project, which reviews 39 mitigation measures that reduce animal-vehicle collisions and that provide habitat connectivity for wildlife across highways. The overview is restricted to mitigation measures aimed at large terrestrial mammals (deer size and larger). However, this report also includes information regarding how such measures may affect or benefit federally endangered or threatened species in Montana, regardless of their size. The mitigation measures are organized in three broad-scale categories:

- Measures that aim to modify traffic and/or driver behavior (14 measures);
- Measures that aim to modify animal behavior or population size using minimal infrastructure (13 measures); and
- Measures that aim to physically separate or modify animal behavior using substantial infrastructure (12 measures).

For each mitigation measure, this report lists:

- A general description of the measure;
- Real world examples of the measure;
- The problem(s) that the measure aims to address (e.g., wildlife-vehicle collisions and/or the barrier effect of the transportation corridor);
- The effectiveness of the mitigation measure in terms of reducing animal-vehicle collisions and/or providing safe wildlife crossing opportunities, if applicable;
- A classification of the measure in one of the following categories:

  1) use with positive results,

  2) use with conflicting results,

  3) use with negative results,

  4) use but little/no study, and

  5) little/no use and little/no study;
- The range of costs for construction, installation and/or maintenance of the mitigation measure, if available;
- The pros and cons of the mitigation measure; and
- The potential benefit for threatened or endangered species in Montana with regard to direct mortality and the barrier effect of roads and traffic.

In addition to the detailed information for each mitigation measure, a summary table is provided that provides at-a-glance information on the costs and benefits of the individual mitigation measures for which such data were available. Furthermore, the report graphically illustrates which measures have the best monetary balance (the difference between benefits and costs) and which measures reduce animal-vehicle collisions and associated costs best. Based on the results, animal detection systems (with or without wildlife fencing) and wildlife fencing (with or without underpasses and/or overpasses) are estimated to be the most effective mitigation measures to reduce collisions with large wildlife species (e.g., deer) (>80% reduction). Of these mitigation measures, animal detection systems with wildlife fencing, wildlife fencing with underpasses, and wildlife fencing with a combination of underpasses and overpasses appear the most attractive from a monetary perspective. However, animal detection systems require further study (through implementation in combination with monitoring) as only limited data on system effectiveness are currently available. Long bridges and long tunnels (e.g., over a road length of at least several hundreds of meters) have a strongly negative monetary balance, and will therefore not often be constructed because of wildlife-vehicle collision concerns alone. Nonetheless, should they be required for other reasons (e.g., the nature of the terrain), wildlife-vehicle collisions may be eliminated and the barrier effect of the transportation corridor is likely to be greatly reduced.

Based on the suitability of wildlife underpasses and overpasses for large or threatened and endangered species in Montana, the implementation of wildlife fencing in combination with underpasses and overpasses has the preference over the implementation of wildlife fencing with only underpasses or wildlife fencing with only overpasses.

A number of mitigation measures were, under certain conditions, suggested for implementation: wildlife fencing, wildlife fencing in combination with under and/or overpasses, long bridges and long tunnels, public information and education, reducing road salt or using alternatives to road salt, aversion techniques or hazing, and changing the species composition or reducing the digestive quality of the vegetation in the right-of-way.

Other mitigation measures were suggested for (further) study: traffic volume and speed reduction, wildlife crossing guards, non-standard and seasonal wildlife warning signs, animal detection systems (with or without wildlife fencing), on-board animal detection systems, roadway lighting, vegetation removal, culling, reducing habitat quality, boulders in right-of-way, and fencing in combination with a signed gap in the fence or a crosswalk.

1. INTRODUCTION

Reducing animal-vehicle collisions and improving habitat connectivity for wildlife across roadways are important factors to consider in highway construction or improvement projects for human safety, economical, and ecological reasons. There are an estimated 725,000 to 1,500,000 collisions between motor vehicles and deer (*Odocoileus* sp.) in the United States alone each year (Conover et al. 1995), and animal-vehicle collisions result in more than 200 human fatalities, 29,000 human injuries, and over 1 billion dollars in property damage in the United States each year (Romin and Bissonette 1996). State Farm Insurance estimated there were approximately 1,000,000 insurance claims for wildlife-vehicle collisions per year between 2002 and 2006 (Miles 2006). Recent research suggests that while the total number of crashes per year in the United States has remained relatively stable, animal-vehicle collisions have steadily increased by about 50% between 1990 and 2004 (Huijser et al., in prep.).

Wildlife-vehicle collisions are a significant source of mortality to many species, with millions of individuals from a wide array of species killed each year (Evink 2002, Iuell et al. 2003, Forman et al. 2003, Seiler 2003). In addition, highways can be a movement barrier to many species, causing habitat fragmentation and, sometimes, reduced survival probability for the population concerned (Clevenger et al. 2002b, Forman et al. 2003, Mills and Conrey 2003, Foresman 2004).

Engineers and biologists have tested a variety of potential solutions to the safety, economical, and ecological conflicts between wildlife and highways. Many years of work have now resulted in substantial knowledge about the application and effectiveness of a wide array of mitigation measures that have been deployed worldwide to solve situation-specific wildlife collision and wildlife crossing concerns (e.g., Iuell et al. 2003, Knapp et al. 2004). However, knowing which mitigation measure addresses a particular problem and which would be suitable given local circumstances can be challenging.

The Montana Department of Transportation (MDT) asked the Western Transportation Institute at Montana State University (WTI) as part of the Montana Partnership for the Advancement of Research in Transportation (MPART) program to provide an overview of mitigation measures that reduce wildlife-vehicle collisions and allow animals to cross the road safely. MDT requested that the overview be restricted to mitigation measures aimed at large terrestrial mammals (deer size and larger). Furthermore, each mitigation measure should not only be described in general terms, but each measure should be evaluated for its pros and cons regarding its effectiveness in increasing safety and habitat connectivity, its appropriate use and restrictions, construction costs, and maintenance costs, if data are available.

2. METHODS

2.1. Project Scope and Structure of Report

This report provides an overview of mitigation measures that reduce animal-vehicle collisions and provide habitat connectivity for wildlife across highways. The overview is restricted to mitigation measures aimed at large terrestrial mammals (deer size and larger). However, this report includes information regarding how such measures may affect or benefit federally endangered or threatened species in Montana, regardless of their size. The mitigation measures are organized in three broad-scale categories:

- Measures that aim to modify traffic and/or driver behavior;
- Measures that aim to modify animal behavior or population size using minimal infrastructure; and
- Measures that aim to physically separate or modify animal behavior using substantial infrastructure.

For each mitigation measure, this report lists:

- A general description of the measure;
- Real world examples of the measure, including color pictures if available;
- The problem(s) that the measure aims to address: wildlife-vehicle collisions and/or the barrier effect of the transportation corridor (excluding direct road mortality);
- The effectiveness of the mitigation measure in terms of reducing animal-vehicle collisions and/or providing safe wildlife crossing opportunities, if applicable;
- A classification of the measure in one of the following categories:

  1) use with positive results,

  2) use with conflicting results,

  3) use with negative results,

  4) use but little/no study, and

  5) little/no use and little/no study;
- The range of costs for construction, installation and/or maintenance of the mitigation measure, if available;
- The pros and cons of the mitigation measure, including its limitations, effects on non-target species (positive or negative), how local circumstances can enhance or negate the effects of each measure; and
- The potential benefit for threatened or endangered species in Montana with regard to direct mortality and the barrier effect of roads and traffic.

In addition to the detailed information for each mitigation measure, a summary table is provided that allows for at-a-glance information about the cost and effectiveness of the individual mitigation measures. In addition, the balance between costs and benefits are calculated for a hypothetical road section allowing for a comparison of the cost effectiveness of the different measures.

2.2. Endangered and Threatened Species in Montana

There are twelve federally threatened or endangered animal species in Montana (U.S. Fish and Wildlife Service 2006). Their vulnerability to direct road mortality and the barrier effect of transportation infrastructure is indicated in Table 1.

Table 1. Vulnerability of ESA species to direct road mortality and the barrier effect of roads and traffic.

Species	Direct mortality	Barrier
Mammals		
Grizzly bear (*Ursus arctos horribilis*)	√	√
Canada lynx (*Lynx canadensis*)	√	√
Gray wolf (*Canis lupus*)	√	√
Black-footed ferret (*Mustela nigripes*)	-	-
Birds		
Whooping crane (*Grus americana*)	-	-
Eskimo curlew (*Numenius borealis*)	-	-
Piping plover (*Charadrius melodus*)	-	-
Bald eagle (*Haliaeetus leucocephalus*)	√	-
Least tern (*Sterna antillarum*)	-	-
Fish		
Pallid sturgeon (*Scaphirhynchus albus*)	-	(√)
White sturgeon (*Acipenser transmontanus*)	-	(√)
Bull trout (*Salvelinus confluentus*)	-	√
KEY √ = affected (√) = potentially affected - = not affected		

The grizzly bear, Canada lynx, gray wolf and bald eagle have all been recorded as road kill in Montana or elsewhere in the United States (Fuller 1989, Bryon and Herrero 2002, Huijser et al. 2006a, Shenk 2006). In addition, the grizzly bear and gray wolf are known to avoid paved roads and are likely severely impeded by relatively high volume roads (e.g., > 10,000 vehicles per month for wolves in Whittington et al. 2004; ~100 vehicles per hour for grizzly bears in Waller and Servheen 2005). Canada lynx is also thought to avoid high volume roads (Ruediger et al. 2000), but data are very sparse. Pallid and white sturgeon may be affected by roads if roads are combined with dams. However, large bridges are unlikely to form a barrier for sturgeon. Culverts can present a barrier for bull trout, depending on the characteristics of the stream and culvert (Burford 2005, Cahoon et al. 2005).

2.3. Sources

Literature sources reviewed include peer reviewed journal articles, proceedings, manuscripts, books and synthesis documents, such as: the NCHRP synthesis (Evink 2002), the COST 341 guide (Iuell et al. 2003), Foreman et al. (2003), the deer-vehicle crash toolbox (Knapp et al. 2004), and Donaldson (2006). Furthermore WTI-MSU consulted with individual experts.

2.4. Benefits

This overview of mitigation measures provides the Montana Department of Transportation with the information required for decisions that relate to the type of mitigation measures that best fit the objectives and local situation for current and future projects.

3. MITIGATION MEASURES TO MODIFY TRAFFIC AND/OR DRIVER BEHAVIOR

3.1. Reduce Traffic Volume on Road Network

General Description

There is a relationship between traffic volume, wildlife population distribution and abundance, and wildlife-vehicle collisions (Messmer and West 2000, Putman et al. 2004). The relationship between traffic volume and the number of recorded road-killed animals on a road is affected by changes in traffic volume, population dynamics and sampling intensity (Groot Bruinderink and Hazebroek 1996). This relationship between traffic volume, road mortality, animal density, and mobility warrants empirical study (Trocmé et al. 2003). Some modeling efforts suggest that traffic volume reduction may be a potential mitigation for reducing wildlife-vehicle collisions (Jaarsma and Willems 2002, Langevelde and Jaarsma 2004, Meyer and Ahmed 2004). However, the relationship between traffic volume and the number of road-killed animals is not necessarily linear (Seiler 2003), as higher traffic volumes are associated with wider roads and an increased barrier effect, reducing the number of events where animals attempt to cross the road (Figure 1) (Alexander et al. 2005). Furthermore, traffic volume typically varies considerably within a 24 h period, and, depending on the area, there may also be substantial seasonal fluctuations. Depending on the species concerned, traffic volume peaks may or may not coincide when most animals cross the road or would have crossed the road if they were not avoiding periods with high traffic volume all together (e.g., Waller & Servheen 2005, Dodd et al. 2006). Nonetheless, in the United States, most wildlife-vehicle collisions occur in October and November, between 5-8 am and 5-11 pm (Huijser et al., in prep.). Literature reviews by Danielson and 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.

Real-world Examples

- There are no known cases where actual traffic volume or road density reductions have been implemented to reduce wildlife-vehicle collisions.

Problem(s) Addressed

- Wildlife-vehicle collisions; and
- Barrier effect.

Effectiveness

Direct benefits in terms of reduced wildlife-vehicle collisions are unknown.

Classification

5) little/no use and little/no study

Knapp et al. (2004) does not address reducing traffic volume as a potential mitigation measure, but classifies "roadway maintenance, design and planning policies" as "use but not studied" and Donaldson (2006) classifies as "requires further research".

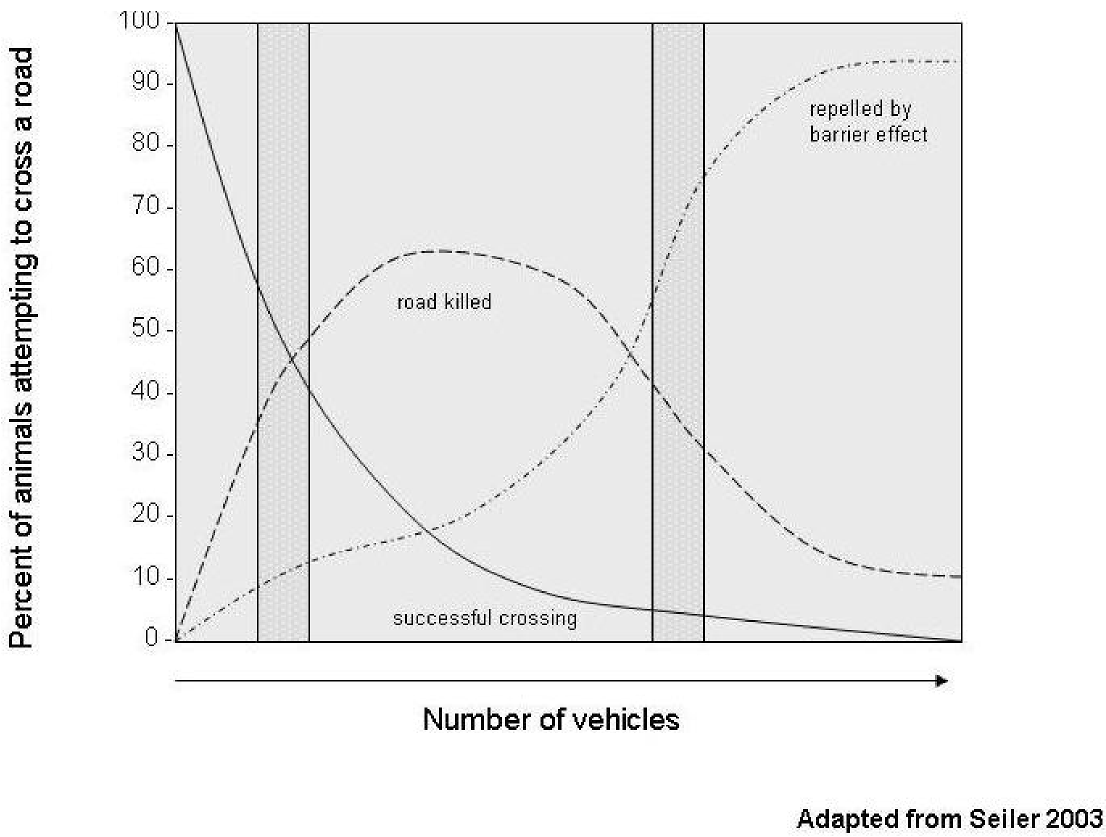

Figure 1. Conceptual relationship between traffic volume, road mortality and the barrier effect.

Costs

- Unknown.

Pros

- In the broad sense, reducing traffic volumes may reduce the overall number of collisions (not just wildlife-vehicle collisions); and
- In the broad sense, reducing traffic volume leads to reduced energy demands and lower pollution levels.

Cons

- In the broad sense, traffic volume cannot be simply reduced and is dependent on the human population size in an area, the housing and work situation, and recreational habits;
- In the broad sense, reducing traffic volume may have adverse economic impacts; and
- On specific high traffic roadways that act as barriers to wildlife attempting to cross, reducing traffic volume may encourage animals to cross more frequently and result in higher wildlife-vehicle collisions than currently exist.

Potential Benefit for Threatened or Endangered Species in Montana

Direct mortality: Reducing total traffic volume on the road network may reduce road kill for all non-aquatic species. However, this does not necessarily apply to roads that already have a relatively high traffic volume and for which traffic volume cannot be substantially reduced (see the non-linear relationship between traffic volume and number of road-killed animals in Figure 1).

Barrier Effect: Reducing total traffic volume on the road network may reduce the barrier effect of transportation infrastructure on species that are known to avoid higher volume roads, including grizzly bear, gray wolf, and Canada lynx.

3.2. Reduce Vehicle Speed

3.2.1. Posted Speed Limit

General Description

At relatively high speeds (e.g., ≥80 km/h (≥50 mi/h)), a speed reduction of even a few miles per hour can be beneficial as it leads to a disproportionate decrease in the risk of a severe collision (Kloeden et al. 2001). Kloeden et al. (2001) estimated that even a 5 km/h (3.1 mi/h) reduction in speed from 80 km/h (50 mi/h) on undivided roads could lower casualty crashes by 31-32%. In addition, lower vehicle speed leads to shorter stopping distances, which may not only reduce the severity of a crash, but may also help avoid a collision altogether. In Yellowstone National Park, a 55 mi/h (88.5 km/h) road with higher annual traffic levels had comparatively more road kill than lower speed and lower volume roads (Gunther et al. 1998). Designating or reducing speed limits by posting signs requires legislative (state, county, or city) approval prior to physically erecting signs. In addition, actual vehicle speed is related to the road configuration (e.g., lane width and curvature) and the characteristics of the area adjacent to the road (e.g., presence and abundance of pedestrians and other non-motorized traffic). Therefore, changes in road design in combination with lowering the posted speed limit may be more effective in reducing vehicle speed than lowering the posted speed limit alone.

Real-world Examples

- On the rural 2-lane Yellowhead Highway (3.7m (4.0 yard) lane widths, 3 m (3.3 yard) shoulders, and traffic volume of 1.2 million vehicles per year) in Jasper National Park in Alberta, Canada, posted vehicle speeds on three sections were reduced from 90 km/h (56 mi/h) to 70 km/h (43.5 mi/h) to mitigate wildlife-vehicle collisions. Additional signage was installed in advance of the reduced speed zones to inform motorists to "Slow Down for Wildlife". A speed study found that less than 20% of motorists obeyed the 70 km/h (43.5 mi/h) speed limit. It was inconclusive whether wildlife-vehicle collisions involving bighorn sheep (*Ovis canadensis*) and elk (*Cervus elaphus*) actually decreased in reduced speed zones (Bertwistle 1999).
- Near Jackson, Wyoming, on a 0.9 mile (1.45 km) stretch of highway with a reduced posted speed limit of 35 mi/h (56 km/h), motorists continued to have deer-vehicle collisions (Biota Research and Consulting, Inc. 2003).

Problem(s) Addressed

- Wildlife-vehicle collisions; and
- Potentially the barrier effect.

Effectiveness

Direct benefits in terms of reduced wildlife-vehicle collisions are unknown.

Classification

5) little/no use and little/no study

Knapp et al. (2004) classifies "speed limit reduction" as "use but rarely studied" and Donaldson (2006) classifies as "limited effectiveness or appears ineffective".

Costs

- Initial cost of installing or replacing speed limit signs, perhaps as little as $100 per sign (Pojar et al. 1975);
- Cost of regular enforcement;
- Increased travel time; and
- Potential increase in collision-related costs (other than wildlife-vehicle collisions) due to speed dispersion (vehicles traveling at vastly different speeds).

Pros

- Reduced speed may lessen the severity of collisions in terms of property damage, human injuries, and human fatalities;
- Reduced energy demands and fuel efficiency for a variety of vehicle types peaks at about 55 mi/h (88 km/h) (West et al. 1997);
- Potential reduction in all collisions due to increased reaction time; and
- Signs do not restrict animal movements.

Cons

- A substantial reduction in speed limits without changing the configuration of the road or the road environment can lead to speed dispersion and an increase in the overall number of crashes (Solomon 1964, Cerrelli 1981), especially on two-lane rural roads due to vehicles passing in unsafe situations;
- Reduced speed zones without associated changes to the road configuration or the adjacent landscape has limited effectiveness without consistent visible enforcement; and
- Posted maximum speed limits can only be adjusted by the Transportation Commission and/or the Legislature.

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Reduced vehicle speed and increased driver alertness may reduce road kill for all non-aquatic species.

Barrier Effect: Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all non-aquatic species. However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species.

3.2.2. Design Speed/Traffic Calming

General Description

If reducing vehicle speeds is the goal, then reducing the design speed of various geometric features of the road may have some effect on the running speeds of traffic. Sharper horizontal curves generally have the greatest effect on running speeds (Paul Ferry, Montana Department of Transportation, personal communication). Features such as reduced lane widths, narrow or no shoulders, and more narrow clear zones (i.e., obstructions such as trees closer to the roadway) are not strictly design speed dependent. Individually, these features have a minimal effect on running speeds (Paul Ferry, Montana Department of Transportation, personal communication). Cumulatively, these features still have a limited impact on running speeds, unless they occur on segments of roads with higher traffic volumes (Paul Ferry, Montana Department of Transportation, personal communication). In MDT's experience, the only potential practical application for reduced design speeds is to use an existing feature in place rather than reconstructing it to a higher design speed (Paul Ferry, Montana Department of Transportation, personal communication). This application would be on a case-by-case basis and would require an evaluation through the design exception process.

In neighborhoods or on highways approaching towns, traffic calming measures include speed bumps/humps, traffic circles, curb extensions, sidewalk extensions, raised medians, and full-lane rumble strips. In MDT's experience, these methods should not be used on high speed rural routes as they are impractical and potentially dangerous (Paul Ferry, Montana Department of Transportation, personal communication).

To date, such design speed and traffic calming measures have rarely been used to reduce wildlife-vehicle collisions.

Real-world Examples

- In Yellowstone National Park, USA, roads that were designed and reconstructed for higher speeds resulted in increased road kill. Although it was not implemented, extensive modeling on the potential impacts of design speed reductions led to recommendations for not upgrading design speed of roadways during planned reconstruction (Gunther et al. 1998).
- In Queensland, Australia, speed bumps have been installed to reduce vehicle speed to reduce Cassowary (*Casuarius casuarius*, a large bird) road kill (Figure 2).
- In Florida, rumble strip patches have been installed in a panther (*Puma concolor coryi*) crossing zone (Figure 3).
- In a national park in Tasmania, Australia, four 'slow points' were installed on a road to mitigate an increase in collisions with eastern quolls (*Dasyurus viverrinus*) and Tasmanian devils (*Sarcophilus laniarius*) after the road section was widened and sealed and vehicle speed had increased by 20 kph (12.4 mph) (Jones, 2000). The 'slow points' were concrete barriers with a 'Give Way' sign that forced vehicles into a single lane in

the center of the road. At the two slow points in the center, the curves and merging of traffic made vehicles reduce their speed by about 20 kph (17-35% reduction), while vehicle speed at the outer two slow points was only reduced by 1-7%. Nonetheless, road mortality became 'more sporadic'.

Problem(s) Addressed

- Wildlife-vehicle collisions; and
- Potentially the barrier effect.

Effectiveness

Direct benefits in terms of reduced wildlife-vehicle collisions are inconclusive.

Classification

5) little/no use and little/no study

Knapp et al. (2004) classifies "roadway maintenance, design and planning policies" as "use but not studied" and Donaldson (2006) classifies as "requires additional research".

Costs

Redesigning roads for lower speeds is likely relatively expensive unless they are done as part of a reconstruction project, but the authors were unable to locate documented costs.

Pros

- Lower speeds may improve the overall safety of the roadway; and
- Retaining slow design speeds on roads prone to wildlife-vehicle collisions would result in significant savings in potential reconstruction expenditures for higher speed roads.

Cons

- While roads with lower design speeds may encourage lower vehicle speeds, the narrower clear zones associated with such designs have been associated higher levels of wildlife-vehicle collisions and other types of collisions;
- Utilizing less than desirable geometric features (sharper horizontal curves, reduced lane widths, narrow or no shoulders, and more narrow clear zones) may reduce the overall safety of the roadway. The reduction in safety may be greater if these features violate driver expectancy.
- Depending on the road, its function, and traffic volume, traffic calming may lead to greater congestion and driver frustration;
- Some traffic calming designs may result in snow removal difficulties and maintenance issues; and
- Traffic calming options are not viable for most high speed state highways.

Potential Benefit for Threatened or Endangered Species in Montana

Direct mortality: Reduced vehicle speed may lead to reduced road kill for all non-aquatic species.

Figure 2. Prior to being vandalized, the top sign depicted a speed bump installed to reduce vehicle speed for Cassowaries. The speed bump is visible (marked with a yellow stripe) in the picture on the lower right. Photo by Marcel Huijser.

Barrier Effect: Reduced vehicle speed may increase the number of successful road crossing events for all non-aquatic species. However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species.

Figure 3. Patches of rumble strips accompany a panther warning sign in south Florida. Photo by Marcel Huijser.

3.2.3. Post Advisory Speed Limit

General Description

When a portion of a roadway has characteristics that result in a design speed that is lower than adjacent road sections, advisory speed limits may be useful. Advisory speeds are not enforceable, except by basic reasonable and prudent laws. Posted advisory speed limits have been used (or have the potential to be used) in conjunction with other mitigation measures, such as animal detection systems, in-vehicle technologies, and wildlife warning signs (Figures 4 and 5).

Real-world Examples

- In Saudi Arabia, enhanced camel (*Camelus dromedarius*) warning signs with reduced advisory speed limits resulted in relatively small, but statistically significant reductions of vehicle speed (3-7 km/h (1.9-4.4 mi/h reductions)); whereas standard camel warning signs did not. Enhanced signs were also larger than the standard warning signs, had diamond reflective material, had a yellow camel on a black background, and/or were accompanied by text message "camel-crossing" signs (Al-Ghamdi and AlGadhi 2004).
- In Montana, wildlife advisory messages posted on permanent and portable Dynamic Message Signs (DMS) reduced vehicle speeds. The greatest effect occurred during "dark" conditions, when the number of animal-vehicle collisions is higher (Hardy et al. 2006).
- In the Netherlands, advisory speed limit signs accompany gaps in exclusionary wildlife fencing.

Figure 4. Advisory speed limits accompany a deer warning sign near 't Harde, The Netherlands. Note: The LED part of the warning sign is linked to an animal detection system, but the advisory speed limit reduction sign is always visible in daylight, regardless of the presence and detection of large animals. Photo: Marcel Huijser.

-

Figure 5. The exact same sign as Figure 4 but when triggered at night. Photo by Marcel Huijser.

Problem(s) Addressed

- Wildlife-vehicle collisions; and
- Potentially the barrier effect.

Effectiveness

Evidence for whether advisory speed limits are effective at reducing wildlife-vehicle collisions remains sparse.

Classification

4) use but little/no study

Knapp et al. (2004) and Donaldson (2006) did not separately classify this mitigation measure.

Costs

Initial cost of signs themselves, perhaps as little as $100 per sign (Pojar et al. 1975).

Pros

- Advisory speed limits can be used with a variety of mitigation measures;
- Signs do not restrict animal movements; and
- Reduced speed may lessen the severity of collisions in terms of property damage, human injuries, and human fatalities.

Cons

Advisory speed limits are unenforceable.

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Reduced vehicle speed and increased driver alertness may reduce road kill for all non-aquatic species.

Barrier Effect: Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all non-aquatic species. However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species.

3.3. Wildlife Warning Signs

Wildlife warning signs comprise one of the most commonly applied mitigation measures (Forman et al. 2003, Sullivan and Messmer 2003). The placement of signs requires that a certain risk exists. The signs may result in: 1) increased alertness of drivers with regard to the potential presence of wildlife on or near the road, 2) reduced vehicle speed, or 3) a combination of both. Increased alertness can reduce reaction time. If drivers are warned, the time required to react to an unusual and unexpected event can be reduced from 1.5 seconds to 0.7 seconds (Green 2000). Assuming a constant vehicle speed of 55 mi/h (88 km/h) before and after posted warning signs, increased alertness could reduce the stopping distance of the vehicle by 68 ft (21 m).

Driver behavior is influenced by the type of warning sign (Pojar et al. 1975, Katz et al. 2003, Hammond and Wade 2004). Since driver response determines the effectiveness of warning signs, it is critical that signs are reliable (Figure 6). The definition of reliability depends on the type of sign (i.e., standard, non-standard (e.g., large or enhanced), or seasonal).

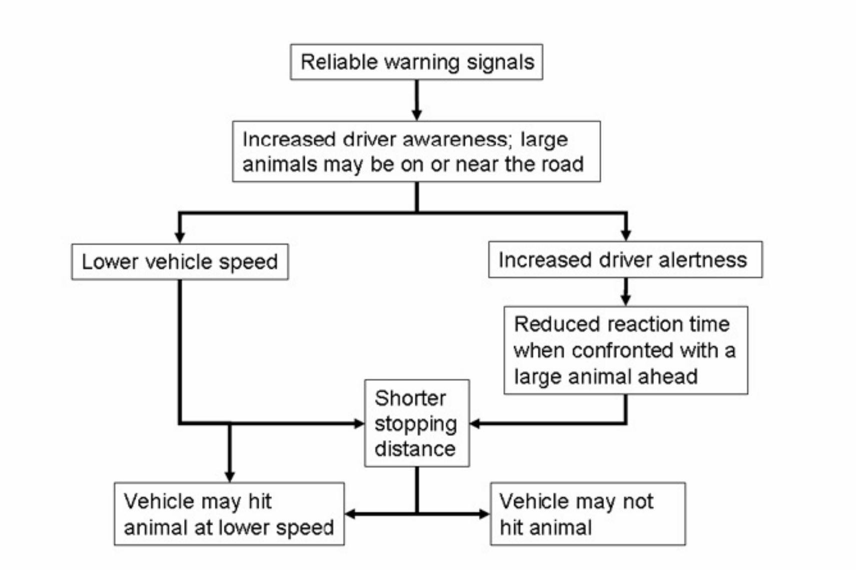

Figure 6. Flow chart of the effect of reliable warning signals.

3.3.1. Standard

General Description

In the United States, the standard deer warning sign is a diamond-shaped panel with a black deer symbol on a yellow background. These signs are intended to inform drivers that the upcoming road section has a history of a higher than average number of deer-vehicle collisions. Sometimes signs include text that informs drivers of the length of applicable road section (Figure 7).

Real-world Examples

- In Kansas, the effectiveness of standard deer warning signs was determined by comparing accident data before and after sign installation. Initially, it appeared as if accidents were reduced by 39%, but more robust analyses showed no evidence that the presence of the deer warning signs resulted in fewer deer-vehicle collisions (Meyer 2006).
- In Saudi Arabia, the installation of standard camel crossing signs did not result in reduced vehicle speed. Standard warning signs were triangular, with all sides measuring 110 cm (43.3 in), had a white interior with black camel silhouette and red border, and did not have diamond-shaped reflective material (Al-Ghamdi and AlGadhi 2004).
- The installation of deer warning signs did not reduce the number of deer-vehicle collisions in Michigan (Rogers 2004).

Figure 7. Standard deer warning sign on MT 83 in Montana accompanied by the length of the road section that the warning sign applies to. Photo by Marcel Huijser, WTI.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

Most authors question the effectiveness of standard warning signs on reducing wildlife-vehicle collisions (Williams 1964 cited in Pojar et al. 1975, Putman 1997, Sullivan and Messmer 2003, Putman et al. 2004) and the two studies that were found that actually evaluated effectiveness, confirmed existing doubts (Rogers 2004, Meyer 2006). Based on available data, standard deer warning signs are concluded to be ineffective in reducing wildlife-vehicle collisions.

Classification

3) use with negative results

Knapp et al. (2004) classifies “deer crossing signs and technologies” as “use but rarely studied”, and Donaldson (2006) classifies “passive deer crossing signs” as “limited effectiveness or appears ineffective”.

Costs

$94 per sign (not adjusted for inflation) (Pojar et al. 1975).

Pros

- Signs do not restrict animal movements; and
- Reduced speed may lessen the severity of collisions in terms of property damage, human injuries, and human fatalities.

Cons

- Signs may distract, or not be recognized by, drivers;
- Signs add to roadway clutter; and

- Signs require maintenance.

Potential Benefit for Threatened or Endangered Species in Montana

Because standard wildlife warning signs have been found to be ineffective in reducing wildlife-vehicle collisions, there are no expected benefits for endangered or threatened species.

3.3.2. Non-standard

General Description

Non-standard signs may be larger, more graphical, include flags, permanently flashing lights, light emitting diodes (LEDs), or messages displayed on Variable Message Signs (VMS) (Figures 8-10). Such signs are designed to attract the attention of the driver and to relay a stronger message than standard wildlife warning signs. However, uniformity across the country is desirable so that drivers learn and understand what different signs represent.

A driving simulator experiment exposed drivers to standard deer warning signs and enhanced deer warning signs (i.e., a standard deer warning sign with a flashing light on top). The average vehicle speed with standard deer warning signs was 61.87 (SD=5.16) mi/h (99.5 km/h). Similarly, the average vehicle speed with enhanced signs in which the lights were turned off was 61.80 (SD=4.80) mi/h (99.4 km/h). The average vehicle speed with enhanced signs with the lights turned on resulted in significantly lower vehicle speed of 59.55 (SD=4.66) mi/h (95.8 km/h) (Hammond and Wade 2004).

Real-world Examples

- In Saudi Arabia, enhanced camel warning signs resulted in significant vehicle speed reductions (3-7 km/h (1.9-4.4 mi/h)), while standard camel warning signs did not result in a significant reduction in speed. Enhanced signs were larger than standard warning signs, had a yellow camel on a black background, had diamond-shaped reflective material, and/or were accompanied by the text “camel-crossing” and a reduced advisory speed limit (Al-Ghamdi and AlGadhi 2004).
- Wildlife advisory messages posted on permanent and portable Dynamic Message Signs (DMS) reduced vehicle speeds and corresponding safe stopping sight distances by 1% – 9% (6–72 feet; 1.8–21.9 m); with the greatest effect occurring during “dark” conditions (Hardy et al. 2006).
- Animated deer crossing signs with lights turned on reduced vehicle speed by 3 mi/h (4.8 km/h) compared to the same signs when the lights were turned off. Speed reduction, however, was not accompanied by a reduction in deer-vehicle collisions (Pojar et al. 1975).

Figure 8. Enhanced standard deer warning sign on State Highway 75 in Idaho. Photo by Marcel Huijser, WTI.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

Observed reduction in vehicle speed suggests that large or enhanced wildlife warning signs may be somewhat effective, but the limited available data on wildlife-vehicle collisions indicate that such signs may not really be effective in reducing wildlife-vehicle collisions (Pojar et al. 1975).

Classification

4) use but little/no study

Knapp et al. (2004) classifies “deer crossing signs and technologies” as “use but rarely studied” and Donaldson (2006) classifies “passive deer crossing signs” as “limited effectiveness or appears ineffective”.

Figure 9. Non-standard elk warning sign on the TransCanada highway. Photo by Marcel Huijser, WTI.

Costs

- $2000 per sign (not adjusted for inflation) (Pojar et al. 1975); and
- A portable DMS (digital message system) is estimated to cost at least $15,000 and permanent designs cost much more.

Figure 10. A VMS updates motorists on moose casualties near Hoback Junction in Wyoming. Photo by Angela Kociolek.

Pros

- Signs do not restrict animal movements; and
- Reduced speed may lessen the severity of collisions in terms of property damage, human injuries, and human fatalities.

Cons

- Signs may distract drivers; and
- Signs require maintenance.

Potential Benefit for Threatened or Endangered Species in Montana

Unknown.

3.3.3. Seasonal

General Description

Seasonal wildlife warning signs are designed to deliver time-specific messages to drivers. They are displayed at certain times of the year during periods of higher risk during seasonal migration of ungulates, for example (Figures 11-13).

Figure 11. Seasonal warning signs for bison. WTI file photo.

Real-world Examples

- At mule deer (*Odocoileus hemionus*) seasonal migration crossing locations, temporary warning signs with reflective flags and permanently flashing amber lights reduced the percentage of speeders from 19% to 8%. The effect, however, was less pronounced in the second season, likely due to driver habituation. Still, the number of deer-vehicle collisions was reduced by 51% in individual test areas compared to control areas (Sullivan et al. 2004).

Figure 12. A permanent deer warning sign in Idaho has hinges for the option to be used seasonally. Photo by Marcel Huijser, WTI.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

Sullivan et al. (2004) showed that seasonal warning signs may reduce wildlife-vehicle collisions by as much as ~50% in the first season of use. However, driver habituation may have to be addressed in subsequent years

Rogers (2004) evaluated 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 1 October and 1 January (the peak of deer-vehicle collisions) for three consecutive years. The results indicated that there was no evidence that the seasonal signs reduced the number of deer-vehicle collisions.

Figure 13. Enhanced sheep warning sign on State Highway 75 in Idaho. Photo by Marcel Huijser, WTI.

Classification

4) use but little/no study

Knapp et al. (2004) classifies "deer crossing signs and technologies" as "use but rarely studied" and Donaldson (2006) classifies "passive deer crossing signs" as "limited effectiveness or appears ineffective".

Costs

$435 per mile (2 signs per mile, 1 for each travel direction) (Sullivan et al. 2004).

Pros

- Signs do not restrict animal movements; and
- Present opportunities to educate the public about landscape connectivity and migrating wildlife.

Cons

- This mitigation measure is site-, species-, and population-specific, with limited use otherwise; and
- Vandalism and theft of signs (Sullivan et al. 2004).

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Reduced vehicle speed and increased driver alertness may reduce road kill for all non-aquatic species. However, the location and time of road crossings by threatened and endangered species may not be the same as those for the target species.

Barrier Effect: Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all non-aquatic species. However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species. In addition, the location and time of road crossings by threatened and endangered species may not be the same as those for the target species.

3.4. Animal Detection Systems

3.4.1. Roadside

General Description

Roadside animal detection systems use sensors to detect large animals that approach the road. When a large animal is detected, the sensors send a message to a warning signal (usually lights mounted on signs) to inform motorists that a large animal is currently on or near the road. When a driver is aware that a large animal may be on or near the road ahead, the driver may become more alert, may reduce vehicle speed, or both. The two major types of animal detection systems are: 1) area-cover systems; and 2) break-the-beam systems.

Area-cover systems may be active or passive and can detect large animals within a certain range of a sensor. Active systems (i.e., microwave radar) constantly send a signal over an area and measure its reflection. Passive systems (i.e., video detection or passive infrared) detect animals by only receiving signals. These systems require algorithms that distinguish between different masses (e.g., moving vehicles with warm engines, moving pockets of hot air versus movements of large animals).

Break-the-beam systems have transmitters that send infrared, laser or microwave radio signals to a receiver. These receiving sensors detect large animals when their bodies physically block or reduce the signal.

Two other types of animal detection systems include: 1) radio-collared animals and receivers placed in the right-of-way and 2) seismic sensors to detect vibrations in the soil as large animals approach (Huijser et al. 2006b).

The effectiveness of animal detection systems has been evaluated with regard to a potential reduction in vehicle speed and a potential reduction in wildlife-vehicle collisions. Results from previous speed studies are variable: substantial decreases in vehicle speed (≥5 km/h (≥3.1 mi/h)) (Kistler 1998, Muurinen and Ristola 1999, Kinley et al. 2003); minor decreases in vehicle speed (<5 km/h (<3.1 mi/h)) (Kistler 1998, Muurinen and Ristola 1999, Gordon and Anderson 2002, Kinley et al. 2003, Gordon et al. 2004, Hammond and Wade 2004); and no decrease or even an increase in vehicle speed (Muurinen and Ristola 1999, Hammond and Wade 2004). Results are likely affected by the accompanying type of warning signal and signs. Whether warning signs include advisory or mandatory speed limit reductions, whether the driver is a local resident, and perhaps cultural differences may cause drivers to respond differently to warning signals in different regions (Huijser et al. 2006b). Road and weather conditions can also influence driver response (Huijser et al. 2006b).

Real-world Examples

- In Switzerland, seven area-cover infrared detection systems were installed to reduce collisions with roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*). The seven sites showed a reduction in collisions of 82% on average after an animal detection system was installed, (1-sided Wilcoxon matched-pairs signed-ranks test, P=0.008, n=7). Three of the sites have not had a single collision after 6-7 years post-installation. Collisions that occurred during the day when the systems were not active were excluded from the analyses (Kistler 1998, Romer and Mosler-Berger 2003, Mosler-Berger and Romer 2003, see also Huijser et al. 2006b).

- More than 30 locations in North America and Europe have had an animal detection system installed (Huijser et al. 2006b) (Figures 14 and 15). However, some of the systems were removed because the systems were not reliable enough. Other systems were removed because the landscape surrounding the road changed causing animals to reduce the crossing frequency at that location. While the limited data on system effectiveness are encouraging, animal detection systems should still be regarded as experimental rather than an established mitigation measure (Huijser et al. 2006b).

Figure 14. An animal detection system on US Highway 191 in Yellowstone National Park, Montana. Photo by Marcel Huijser, WTI.

Figure 15. An animal detection system in action in Kootenay National Park, British Columbia, Canada. Photo by Alan Dibb, Parks Canada.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

The only available data on the effectiveness of animal detection systems show an 82% reduction in collisions with large animals (review in Huijser et al. 2006b). However, this may change as more data become available. Most systems have or have had problems with the sensor reliability. However, some technologies are reliable or are improving their reliability (Huijser et al. 2006b).

Classification

4) use but little/no study

Knapp et al. (2004) classifies “deer crossing signs and technologies” as “use but rarely studied” and Donaldson (2006) classifies “technology-based deployments (active signs and technologies) as “requires additional research”.

Costs

$65,000-$154,000 per mile (per 1.6 km) (excluding installation costs) (Huijser, unpublished data). Costs for equipment increase if the road section has curves or slopes, or if the line of sight is blocked by objects.

Pros

- Animal detection systems do not restrict animal movements; and
- Despite substantial installation costs these systems are somewhat portable compared to wildlife underpasses or overpasses, and could be moved if/when animals select new crossing sites because of changes in the surrounding landscape.

Cons

- 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); and
- Small or medium sized animals are not detected.

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Reduced vehicle speed and increased driver alertness may reduce road kill for all large non-aquatic species (including grizzly bear). Medium sized mammal species such as Canada lynx and gray wolf may not or rarely be detected.

Barrier Effect: Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all large, non-aquatic species (including grizzly bear). However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species. Medium sized mammal species such as Canada lynx and gray wolf may rarely or never be detected.

3.4.2. On-board Detector

General Description

To date, in-vehicle or on-board animal detectors have typically used infrared technology. Vehicle-mounted sensors detect when a large animal (or human being) is within a certain range of the vehicle giving the driver time to slow down or stop.

Real-world examples

Several manufacturers have designed or produced on-board detectors but it is unclear whether they are still in production (e.g., Bendix 2002, General Motors 2003, Hirota et al. 2004, Honda 2004). Detection range may have been inadequate and false detections may have been a problem. See Hirota et al. (2004) for design concept.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

The effectiveness of this relatively new mitigation measure is unknown. However, benefits would be expected to be similar to animal detection systems; 82% reduction in collisions with large animals (review in Huijser et al. 2006b). This percentage may change as data become available.

Classification

5) little/no use and little/no study

Knapp et al. (2004) classifies "in-vehicle technologies (on roadways) as "use but not studied" and Donaldson (2006) classifies "in-vehicle technologies (infrared vision or sensors) as "requires additional research".

Costs

$2,250 per vehicle (review in Knapp et al. 2004).

Pros

- On-board detectors do not restrict animal movements;
- The system would not only detect large animals, but also humans (e.g., pedestrians, bicyclists); and
- Cost would be distributed amongst individual motorists.

Cons

- Vehicle-based systems only inform drivers in those vehicles equipped with such a detection system; drivers in other vehicles will not benefit; and
- It may take many years, (perhaps 10-20 years) before a substantial percentage of vehicles is equipped with on-board detectors.

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Reduced vehicle speed and increased driver alertness may reduce road kill for all large non-aquatic species (including grizzly bear). Canada lynx and gray wolf may rarely or not be detected. Note that a reduction in road kill depends on the number of vehicles equipped with on-board detectors.

Barrier Effect: Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for large non-aquatic species (including grizzly bear). It does not necessarily address potential road avoidance behavior displayed by certain individuals or species. Medium sized mammal species such as Canada lynx and gray wolf may rarely or not be detected at all. Note that the percentage of successful crossings depends on the number of vehicles equipped with on-board detectors.

3.4.3. On-board Computer Warning Linked to Roadside System

General Description

This technology has not been deployed yet and the only concept of an animal detection system that is linked to an on-board computer warning system is described in Huijser et al. (2006b) (Figure 16). See Huijser et al. (2006b) for considerations for planning and design.

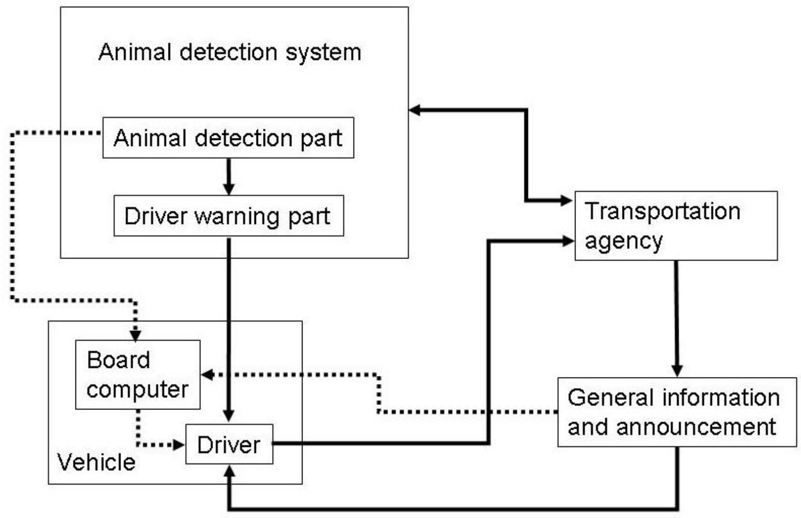

Figure 16. Conceptual operation on-board warning and roadside animal detection systems. The arrows indicate the direction of output and processes (solid lines = exist; dotted lines = future developments). The transportation agency would provide information (e.g., radio messages, warning signs, on-board computer messages) to the traveling public about the purpose of the upcoming animal detection system once they have traveled within a certain radius of the system. If a large animal has been detected on or near the road, the driver would see an activated warning signal when approaching the animal detection system area. Adapted from Huijser et al. 2006b.

Real-world examples

This mitigation measure has not yet been employed.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

Because this concept is still in the design phase, effectiveness cannot be quantified. However, benefits would be expected to be similar to animal detection systems; 82% reduction in collisions with large animals (review in Huijser et al. 2006b). However, this percentage may change as data become available.

Classification

5) little/no use and little/no study

Knapp et al. (2004) classifies “in-vehicle technologies (on roadways) as “use but not studied” and Donaldson (2006) classifies “in-vehicle technologies (infrared vision or sensors) as “requires additional research”.

Costs

$65,000-$154,000 per mile (per 1.6 km) (excluding installation costs) plus additional costs for on-board computer and communication systems (Huijser, unpublished data).

Pros

- Animal detection systems do not restrict animal movements;
- Despite substantial installation costs, these systems are somewhat portable compared to wildlife underpasses or overpasses and could be moved if/when animals select new crossing sites because of changes in the surrounding landscape; and
- The cost for on-board components would be distributed amongst individual motorists.

Cons

- 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);
- Vehicle-based systems only inform drivers in those vehicles equipped with such a detection system; drivers in other vehicles will not benefit;
- It may take many years, (perhaps 10-20 years) before a substantial percentage of vehicles is equipped with on-board systems; and
- Small or medium sized animals are not detected.

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Reduced vehicle speed and increased driver alertness may reduce road kill for all large non-aquatic species (including grizzly bear). Canada lynx and gray wolf may rarely or never be detected. Note that a reduction in road kill depends on the number of vehicles equipped with on-board systems.

Barrier Effect: Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all large, non-aquatic species (including grizzly bears). However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species. Medium sized mammal species such as Canada lynx and gray wolf may rarely or never be detected. Note that the percentage of successful crossings depends on the number of vehicles equipped with on-board systems.

3.5. Visibility for Drivers

3.5.1. Roadway Lighting

General Description

Given that most wildlife-vehicle collisions occur in non-daylight conditions (Schafer and Penland 1985, Lavsund and Sandegren 1991, Thomas 1995, Farrell and Morris 1996, Hughes et al. 1996, Putman 1997, Garrett and Conway 1999, Haikonen and Summala 2001, Gunson and Clevenger 2003, Rogers 2004) the installation of roadway lighting is hypothesized to help drivers see animals in time to avoid a collision.

Real-world Examples

- In Colorado, a five-year study involved alternately turning roadside lights on and off for one-week periods to evaluate 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 alter deer crossing behavior. However, there was some evidence that a greater proportion of deer crossed in areas with lights on than off compared to pre-study levels. Lighting did not affect vehicle speeds although motorists did significantly reduce speeds when a deer decoy was present. This practice was deemed unsafe because abrupt braking could endanger other motorists and was discontinued (Reed 1981).

- Near Anchorage, Alaska, the installation of roadway lighting, fencing, one-way gates, and bridge modifications along 11.5 km (7.1 mi) of the Glenn Highway resulted in a 70% decrease in moose (*Alces alces*)-vehicle collisions (McDonald 1991 as cited in Biota Research and Consulting Inc. 2003 and Wildlife Crossings Toolkit). The entire length was lighted and about 5.5 km (3.4 mi) of the road had fencing, one-way gates, and modified bridges. The lighted area with fences had a 95% reduction in moose-vehicle collisions. Lighted areas without fencing had a 65% reduction in moose-vehicle collisions. Whether the 65% reduction was the result of moose avoidance or increased visibility is unclear (McDonald 1991 as cited in Biota Research and Consulting Inc. 2003 and Wildlife Crossings Toolkit).

Problem(s) Addressed

- Wildlife-vehicle collisions.

Note: Roadway lighting appears to increase the barrier effect for many species.

Effectiveness

There is little and sometimes conflicting evidence on the effectiveness of roadway lighting in reducing wildlife-vehicle collisions. However, roadway lighting has been found to reduce property damage only (involving no human injury) collisions at night (Griffith 1994). Further study is required to understand the effect that lighting has on driver and animal behavior and wildlife-vehicle collisions.

Classification

2) use but little/no study

Knapp et al. (2004) classifies “roadway lighting” as “not generally used but rarely studied” and Donaldson (2006) classifies as “limited effectiveness or appears ineffective”.

Costs

In 2001, $1.3 million was spent to light three miles of the Glenn Highway to improve visibility of moose (Mode et al. 2005). Others concur that lighting is expensive (Miller 1985 as cited in L-P Tardiff and Associates 2003, Hedlund et al. 2003). In addition to installation costs, there are costs associated for the power and maintenance.

Pros

Unknown.

Cons

- Sensitive carnivore species such Canada lynx, mountain lions, bears, and wolves may avoid light, potentially adding to the existing effect of roads and traffic (Beier 1996); and
- Excessive lighting can affect landscape aesthetics.

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Increased visibility for drivers may reduce road kill for all large non-aquatic species.

Barrier Effect: Roadway lighting may increase the barrier effect for certain species, and as a result, can be harmful.

3.5.2. Vegetation Removal

General Description

White-tailed deer (*Odocoileus virginianus*)-vehicle collisions are associated with wooded areas with canopy vegetation and are negatively correlated with the distance between roadway and forest cover (Puglisi et al. 1974, Gleason and Jenks 1993, Finder et al. 1999). Removing roadside vegetation, especially shrubs and trees, may allow motorists to see wildlife approaching the road thereby avoiding collisions. In Sweden, predictive models showed moose-vehicle collisions were more common on roads that cross through clear-cuts and young forests (Seiler 2005). Collisions may be reduced by 15% where the distance between forest cover and the road is greater then 100 m (109.3 yard) (Seiler 2005).

Roadside vegetation management to reduce the attractiveness of roadside forage is addressed in section 4.3.

Real-world Examples

- In Sweden, clearing roadside vegetation resulted in a 20% reduction in moose-vehicle collisions (Lavsund and Sandegren 1991).
- In Norway, a study evaluating the effect of scent-marking, intercept feeding and forest clearing demonstrated that forest clearing resulted in a 49% reduction in moose-vehicle collisions (Andreassen et al. 2005).
- In Alaska, vegetation clearing (e.g., hydroaxing, hand clearing, steam clearing, spray inhibitors) is one of the most commonly applied measures to reduce moose-vehicle collisions (Thomas 1995).
- In Illinois, recommendations from a study included removing vegetation to provide clear width of at least 40 m (43.7 yard) on road sections where deer-vehicle collisions are particularly high (Finder et al. 1999).
- In Norway, clearing vegetation 20-30 m (21.9-32.8 yard) on each side of a railway reduced moose-train collisions by 56% (+/-16%) (Jaren et al. 1991).

Problem(s) Addressed

- Wildlife-vehicle collisions.

Note: Vegetation removal may increase the barrier effect for many species.

Effectiveness

There is evidence that vegetation removal is somewhat effective in reducing wildlife-vehicle collisions. The effects, however, are temporary and more study is needed.

Classification

4) use but little/no study

Knapp et al. (2004) classifies "roadside vegetation management" as "use but rarely studied" and Donaldson (2006) classifies "roadside vegetation management (plant choices and clearing)" as "requires additional research".

Costs

- Forest clearing for 18 km (11.2 mi) costs an estimated $500/km ($805/mi) or $9,000/year for a profit of $1,080 based on subtracting estimated expenses from income determined by income per moose times number of moose saved (Andreassen et al. 2005);
- Vegetation removal requires accounting for long-term maintenance costs; and
- Acquisition or purchase of right-of-way is required in order to manage vegetation as desired.

Pros

- May increase visibility of oncoming traffic to the animals themselves (Putman et al. 2004); and
- Removing large trees near roads may result in fewer collisions with fixed objects (Hedlund et al. 2003).

Cons

- Shrub and tree pruning can increase forage attractiveness near the roadside (Groot Bruinderink and Hazebroek 1996, Putman et al. 2004);
- Shrub and tree clearing may increase the barrier effect of the transportation corridor for species that avoid open areas; and
- Vegetation removal requires long-term maintenance.

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Increased visibility for drivers may reduce road kill for all large non-aquatic species.

Barrier Effect: Open areas may increase the barrier effect for certain species and, as a result, be harmful.

3.6. Public Information and Education

General Description

Public information and driver education seek to reduce death and serious injury by increasing motorist awareness of the causes of wildlife-vehicle collisions, high risk locations, and preventative measures. Videos, brochures, posters, bumper stickers, and general messages in the media have been used. Public information and driver education efforts usually work best when used in combination with other wildlife-vehicle collision reduction measures (Walker 2004, Hardy et al. 2006) (Figure 17).

Figure 17. Public education appears to have inspired this warning sign in Banff National Park, Canada. Photo by Marcel Huijser, WTI.

Many researchers have suggested driver education and public information campaigns as a means to help reduce wildlife-vehicle collisions (Evink 1996, Jacobs 2001, Biggs et al. 2004, Pynn and Pynn 2004, Rogers 2004, Knapp 2005) and several states have developed educational safety campaigns. Education and public information campaigns appear to result in increased driver awareness of the risks of wildlife-vehicle collisions and makes drivers aware of actions they can take to try to prevent severe collisions.

Recent research (Huijser et al., in prep.) suggests that drivers do not reduce the occurrence of wildlife-vehicle collisions as a result of driving experience. Apparently, drivers do not recognize the situation as "potentially dangerous" until it is too late; the occurrence of wildlife on or near the road seems too unpredictable to allow for a learning experience. However, instructions on how to respond when presented with a large animal on the road may reduce the severity of a crash.

Real-world Examples

- Since implementation of the "Don't Veer for Deer" campaign in Iowa, (Departments of Transportation, Public Safety, and Natural Resources, in conjunction with insurance agencies and local law enforcement), the number of fatalities resulting from deer-vehicle collisions dropped 60% in 2005; from 10 in 2003 to 4 in 2005. However, because of the variable nature of these data and the limited evaluation time, the results are inconclusive.
- In Jasper National Park, the Parks Canada "Drivers for Wildlife" program combines public education (bumper stickers and roadway billboards) with two digital signs that record speed and advise drivers to slow down in the high risk wildlife zone. Road-killed animals along park highways decreased by about 15% after the first 10 months of the public education and roadside sign program. However, the signs were credited for most of the reduction (Walker 2004).
- Maine (Department of Transportation Safety Office) also has a public information campaign to increase awareness of moose-vehicle and deer-vehicle collisions.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

There are no known studies proving the effectiveness of driver education or public information efforts in reducing the number or severity of wildlife-vehicle collisions (Knapp 2005). New campaigns can be designed with research objectives that are capable of identifying the effectiveness of public information and education efforts on the reduction of wildlife-vehicle collisions.

Classification

4) use but with little/no study

Knapp et al. (2004) classifies “public information and education” as “use but not studied” and Donaldson (2006) classifies as “requires additional research”.

Costs

For printed material and contract labor on statewide campaigns, costs range from $6,500 per 3 years (Duane Brunell, Maine Department of Transportation, personal communication) to $16,335 (time unknown) (Monique DiGiorgio, Southern Rockies Ecosystem Project, personal communication).

Pros

The wildlife-vehicle collision data maps used in educational campaigns can also be used to focus limited resources for mitigation efforts in the most problematic areas within a state, county, or metropolitan area.

Cons

None

Potential Benefit for Threatened or Endangered Species in Montana

Unknown.

3.7. Wildlife Crossing Guards

General Description

Trained individuals, paid or volunteer, physically control traffic on roads where animals are known to congregate on or near the road and motorists stop to view them. This measure has been used in places such as national parks where “animal jams” occur (Figure 18). Stationary motorists may keep animals from crossing the road or get dangerously close to wildlife, endangering both themselves and wildlife.

Real-World Examples

In Rocky Mountain National Park, Colorado, the volunteer group Bugle Corps manages vehicle traffic on park roads during elk breeding season (Cochran 2006).

Problem(s) Addressed

- Wildlife-vehicle collisions; and
- May reduce the barrier effect (no traffic) or increase the barrier effect (concentration of people and vehicles).

Figure 18. Bighorn sheep "jam" on Rock Creek Road, Montana. Photo by Marcel Huijser.

Effectiveness

Actual impact on wildlife-vehicle collision reduction remains unknown.

Classification

5) little/no use and little/no study

Costs

- Wages for paid crossing guards;
- Time spent in training and controlling traffic; and
- Orange vests and stop/yield paddles are inexpensive.

Pros

- Individual animals are afforded some protection when crossing or lingering on the road, but only when crossing guards are present;
- Crossing guards have the opportunity to communicate with drivers directly; and
- Provides opportunities for education and outreach.

Cons

- Time spent in training and active traffic control;
- Crossing guards are exposed to potential injury from motorists and wildlife;
- Wildlife may become habituated to human presence and traffic, potentially leading to undesirable or dangerous situations at a later time; and
- Crossing guards cannot be present everywhere all the time, limiting the potential effectiveness of this mitigation measure.

Potential Benefit for Threatened or Endangered Species in Montana

Road crossing events of threatened or endangered species typically are too unpredictable in time and space to benefit from wildlife crossing guards in terms of reduced road kill or safe crossing opportunities.

4. MITIGATION MEASURES TO MODIFY ANIMAL BEHAVIOR OR POPULATION SIZE USING MINIMAL INFRASTRUCTURE

4.1. Remove Carcasses

General Description

Carcass removal is typically applied for highway safety and aesthetics (Figure 19). Evaluation of the effect of carcass removal on reducing wildlife-vehicle collisions (e.g., scavengers) has not been studied and, to date, has rarely been considered (Knapp 2005). The presence of deer carcasses has been documented to have an effect on vehicle speed reduction (Pojar et al. 1975).

Figure 19. Road-killed mule deer on State Highway 75, Idaho. Photo by Marcel Huijser, WTI.

Real-world Examples

There are no known cases where carcass removal has been implemented to reduce wildlife-vehicle collisions or secondary road kill.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

Effectiveness of carcass removal in terms of wildlife-vehicle collision reduction has not been studied.

Classification

5) little/no use and little/no study

Costs

- In Canada, carcass removal and disposal were estimated at Can$100 (US$77) (deer), Can$350 (US$270) (elk), and Can$350 (US$270) (moose) (Sielecki 2004); and
- In Pennsylvania, the average for deer carcass removal and disposal in a certified facility was $30.50 per deer when removed by contractors and $52.46 per deer when removed by Pennsylvania Department of Transportation in 2003-2004 (Jon Fleming, Pennsylvania Department of Transportation, personal communication).

Pros

- May reduce the frequency of secondary road kills of scavengers that feed on carcasses (Knapp 2005);
- Carcass removal does not restrict animal movements;
- Systematic removal efforts allow for efficient data collection of road kills for wildlife-vehicle collision monitoring; and
- Subsequent composting of carcasses may yield economic and ecological benefits (Knapp 2005, NYSDOT 2006).

Cons

- In some areas, other species may depend on the availability of road kill as a food source;
- Handling and transporting carcasses may result in the spread of diseases, such as chronic wasting disease (Wisconsin DNR 2002); and
- Carcass disposal practices (e.g., solid waste landfill, composting) may have to be reevaluated if/when chronic wasting disease is found in wild ungulate populations in Montana (Montana Fish, Wildlife & Parks 2005).

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Carcass removal may benefit bald eagles, grizzly bears, and gray wolves which are vulnerable to collision when they scavenge road kill. On the other hand, road kill may be an important food source for these species, depending on the local conditions.

4.2. Reduce or Find Alternatives to Road Salt

General Description

Road salt used for winter maintenance may attract wildlife to the right-of-way and increase wildlife-vehicle collisions (Danielson and Hubbard 1998, Brownlee et al. 2000, Knapp 2005), especially when natural salt licks do not exist in the area (Groot Bruinderink and Hazebroek 1996). Reducing the amount of salt or using alternative deicers (without salt) may eliminate ungulate attractants on the right-of-way (Feldhamer et al. 1986) and recommendations are often made to this effect. For example, CaMg-acetate has been recommended as a NaCl alternative in Finland (Groot Bruinderink and Hazebroek 1996).

Real-world Examples

- In New Hampshire, a study of 11 radio-collared moose found that home ranges were associated with salt licks formed by road salt runoff. These roadside salt licks were thought to increase moose-vehicle collisions (Miller and Livaitis 1992).
- Forty-three percent of moose-vehicle collisions in one study occurred within 100m (109.3 yard) of a saltwater pool. These are higher than what would be expected (Fraser and Thomas 1982). However, Knapp (2005) concluded that the same amount of collisions happened more than 300m (328.1 yard) from a roadside saltwater pool.
- Lithium chloride, a gastrointestinal toxicant, effectively discouraged captive caribou (*Rangifer tarandus*) from eating treated food and its roadside application may prove useful in deterring ungulates from salt pools thereby reducing wildlife-vehicle collisions (Brown et al. 2000b).
- The use of salt alternative calcium-chloride did not discourage animals from the road in Jasper National Park, Canada (Bertwistle 1997).

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

Whether the reduction or elimination of the road salt reduces ungulate-vehicle collisions remains unknown (Knapp 2005).

Classification

4) use with little/no study

Knapp et al. (2004) classifies "deicing salt alternatives" as "use but not studied" and Donaldson (2006) classifies as "requires additional research".

Costs

Unknown.

Pros

- If ungulates concentrate around salt licks (including those formed by runoff) brain worm infection rates may increase (Miller and Litvaitis 1992); reduction or elimination of road salt may help reduce brain worm infection rates;
- Salt toxicity can be a direct cause of mortality in some bird species, especially in the family Fringillidae, subfamily Carduelinae (crossbills, grosbeaks, and siskins) and bird attraction to road salt may increase vulnerability to vehicle collisions (Brownlee et al. 2000). Reduction or elimination of, or alternatives to, road salt may benefit bird species; and
- Depending on the characteristics of the water body, road salt can negatively affect the water quality of water bodies alongside the road. Reduction or elimination of, or alternatives to, road salt may benefit aquatic systems.

Cons

- If alternatives to road salt are less effective in increasing road safety, road safety may be impacted. Before implementing alternatives to road salt one should be thoroughly familiar with the effectiveness and guidelines for use; and
- Reviewed alternatives cost substantially more than road salt.

Potential Benefit for Threatened or Endangered Species in Montana

Direct mortality: Bull trout, and white and pallid sturgeon may benefit from reduced use of fine-grained particles (e.g., sand) due to reduced sediment in streams, and they may also benefit from improved water quality.

4.3. Minimize Nutritional Value or Influence Species Composition of Right-of-Way Vegetation

General Description

Roadside vegetation and landscaping practices can serve as an attractant to wildlife and increase their vulnerability to wildlife-vehicle collisions (Case 1978, Putman 1997, Cain et al. 2003) (Figures 20 and 21). Several sources recommend planting unpalatable species, reducing forage quality, or applying noxious chemicals in the right-of-way as a means of eliminating wildlife attractants (Groot Bruinderink and Hazebroek 1996, Putman 1997, Wells et al 1999, Hyman and Vary 1999 as cited in Evink 2002, Rea 2003, Riley and Sudharsan 2006), while others call for improving roadside habitat for wildlife (Varland and Schaefer 1998).

Figure 20. Bighorn sheep foraging along roadside on US 93 in Montana. Photo by Marcel Huijser, WTI.

Rea (2003) conducted a detailed literature review on roadside vegetation management, plant response to tissue removal, and ungulate foraging behavior and recommended specific cutting regimes as a mitigation measure for reducing moose-vehicle collisions. Rea (2003) recommends cutting roadside brush soon after leaves develop in early spring to minimize nutritional value and palatability, but cautions that this mitigation measure may not be suitable for all management areas.

Figure 21. Deer foraging along roadside in the Salmon River Valley, Idaho. Photo by Marcel Huijser, WTI.

Real-world Examples

- Willows cut in mid-July were higher in digestible energy and protein compared to plants cut at other times of the year and uncut controls, suggesting that summer cutting regimes may unintentionally be attracting moose with nutritious re-growth (Rea and Gillingham 2001, Rea 2003).
- Arizona Department of Transportation planned a five-year monitoring study to address the effectiveness of vegetation/habitat changes (and other mitigation measures) on reducing wildlife-vehicle collisions (Brown et al. 1999). Results are not yet available.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

Implementing forage repellents, planting unpalatable species and removing roadside brush have limited effectiveness on reducing wildlife-vehicle collisions (Rea 2003). The need to properly study the effectiveness of roadside management policies or plantings on wildlife-vehicle collision reduction remains (Knapp 2005).

Classification

4) use with little/no study

Knapp et al. (2004) classifies “roadside vegetation management” as “use but rarely studied” and Donaldson (2006) classifies “roadside vegetation management (plant choices and clearing)” as “requires additional research”.

Costs

Unknown.

Pros

Unknown.

Cons

- Minimizing the nutritional vegetation may restrict or affect native vegetation;
- Reducing roadside habitat quality may increase the road effect zone (Forman and Alexander 1998);
- Implementing forage repellents, planting unpalatable species, and removing roadside brush may not be cost-efficient when broadly applied (Rea 2003); and
- There are operational challenges and limitations to roadside brush cutting regimes (i.e., ground moisture early in season, species-specific responses to same management regime, etc.) (Rea 2003).

Potential Benefit for Threatened or Endangered Species in Montana

Unknown.

4.4. Intercept Feeding

General Description

Intercept feeding involves strategically placing food sources away from roadways in an attempt to divert animals (Knapp 2005).

Real-world Examples

- In Utah, a two-year control/treatment experiment tested the effectiveness of intercept feeding as a means to reduce deer-vehicle collisions and found reductions of up to 50% (Wood and Wolfe 1988). However, no information was provided on the number of deer-vehicle collisions before intercept feeding began (Knapp 2005).
- In Norway, scent-marking, forest clearing, and supplemental feeding were determined to help reduce, but not eliminate moose-train collisions if applied over long distances (Andreassen et al. 2005).

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

The effectiveness of intercept feeding appears limited to short term reductions in areas of high deer concentrations (Wood and Wolfe 1988, Danielson and Hubbard 1998, Farrell et al. 2002) or in combination with other mitigation measures (Wood and Wolfe 1988, Knapp 2005). Further study is warranted.

Classification

5) little/no use and little/no study

Knapp et al. (2004) classifies “intercept feeding” as “not generally used but rarely studied” and Donaldson (2006) classifies as “limited effectiveness or appears ineffective”.

Costs

Unknown.

Pros

Unknown.

Cons

- Intercept feeding is labor intensive (Wood and Wolfe 1988, Farrell et al. 2002);
- May create a dependency on supplemental food and actually increase population size (Wood and Wolfe 1988); and
- Supplementary feeding of wild animals is unlawful in Montana.

Potential Benefit for Threatened or Endangered Species in Montana

Unknown.

4.5. Aversion Techniques or Hazing

General Description

Aversive conditioning or hazing attempts to disperse wildlife by frightening them with lights, lasers, water sprays, pyrotechnics, cannons, guns, helicopters, or predatory-resembling chases (DeNicola et al. 2002, Peterson 2003, Kloppers et al. 2005, VerCauteren et al. 2006).

Real-world Examples

- In Alaska, hazing was not effective in moose-vehicle collision mitigation efforts (Thomas 1995).
- In Canada, aversive conditioning showed some success in keeping grizzly bears off roadsides (Gibeau and Heuer 1996).
- Three of 43 natural resource agencies surveyed used hazing as a method to reduce deer-road mortality; one reported success (Romin and Bissonette 1996).
- In British Columbia, Roosevelt elk (*Cervus canadensis roosevelti*) were relocated when hazing failed as a wildlife-vehicle collision mitigation measure (Sielecki 2004).
- In Banff National Park, Canada, predatory chases by humans and dogs increased flight responses in twenty-four moderately habituated radio-collared elk (Kloppers et al. 2005).
- During treatment and control (observation with no laser) behavioral experiments, deer followed the laser light and acted more curious than frightened (VerCauteren et al. 2006).

Problem(s) Addressed

- Wildlife-vehicle collisions.

Note: Aversion techniques or hazing are likely to increase the barrier effect of the transportation corridor.

Effectiveness

No studies have tested the effectiveness of hazing on reducing wildlife-vehicle collisions (Danielson and Hubbard 1998). DeNicola et al. (2002) addressed hazing in managing deer in suburban environments, but not within the context of wildlife-vehicle collision reduction.

Lights and water sprays are only partially effective (DeNicola et al. 2002). Green and blue lasers are ineffective at dispersing deer at night (VerCauteren et al. 2006). Lasers are proven to be effective on birds, but not on deer (VerCauteren et al. 2006), probably because of species-specific threat perception (DeNicola et al. 2002, VerCauteren et al. 2006).

Classification

5) little/no use and little/no study

Costs

Aversive conditioning using humans was 15% less expensive than conditioning with dogs ($4,300 CAD) (Kloppers et al. 2005).

Pros

None.

Cons

- Hazing may cause excessive stress to animals;
- Noisy hazing methods disturb humans and non-target species populations;
- Hazing can be labor-intensive and difficult to implement because animal behavior is hard to change and habituation is possible (DeNicola et al. 2002);
- Other factors such as natural wolf activity can reduce the efficacy of the aversive conditioning techniques (i.e., elk remained closer to town sites) (Kloppers et al. 2005); and
- Aversion techniques or hazing should, in general, not be applied in habitat linkage zones where one wants to increase connectivity between habitat on both sides of the road.

Potential Benefit for Threatened or Endangered Species in Montana

Road crossing events of threatened or endangered species are typically too unpredictable in time and space to benefit from hazing or other aversion techniques in terms of reduced road kill or safe crossing opportunities.

4.6. Reflectors and Mirrors

General Description

Deer mirrors and reflectors are intended to visually repel wildlife from the roadway. Mirrors direct vehicle headlights off the roadway and into the surrounding right-of-way (Danielson and Hubbard 1998). Colored reflectors beam light from headlights into roadside habitat (Swareflex, D. Swarovski and Co., Wattens, Austria, www.swareflex.com) or onto the roadway itself (Strieter-Lite, Strieter Corp., Rock Island, Illinois, www.strieter-lite.com, D'Angelo et al., in press). The purpose and use of mirrors and reflectors is also discussed in several literature reviews and annotated bibliographies (Reeve and Anderson 1993, Knapp 2005, TransSafety 1997a and b, Danielson and Hubbard 1998, D'Angelo et al. 2004, Putman et al. 2004).

Real-world Examples

- A study of Strieter-Lite wildlife warning reflectors in four colors (red, white, blue-green and amber) were ineffective in altering white-tailed deer behavior and preventing deer vehicle-collisions (D'Angelo et al., in press). Interestingly, deer demonstrated an increase in potentially dangerous responses toward vehicles in the presence of reflectors (D'Angelo et al., in press).
- In Washington State, Swareflex reflectors significantly reduced wildlife-vehicle collisions (Schafer and Penland 1985).
- In Minnesota, reflectors reduced rural incidences of wildlife-vehicle collisions by 50-97%, but suburban metropolitan incidences increased (Pafko and Kovach 1996).
- Swareflex reflectors produced a weak fleeing response in kangaroos (Ramp and Croft 2002).
- Deer initially responded to reflectors with alarm and flight, but then became habituated to the light reflection (Ujvari et al. 1998).
- In Wyoming, 39% of Swareflex reflectors showed deterioration after three years (Reeve and Anderson 1993).
- The Strieter-Lite company posits that their reflectors work (Grenier 2002, unpublished) and that brightness or reflective illuminance is not a major factor because wild animals have acute night vision (Sielecki 2001). A spectrometric evaluation of Swareflex and Strieter-Lite wildlife warning reflectors yielded operational implications of low light reflection intensities (Sivic and Sielecki 2001).
- Utah DOT stopped using reflectors due to an increase in deer kills and high installation, maintenance and cleaning costs (Page 2006).

Problem(s) Addressed

- Wildlife-vehicle collisions.

Note: Wildlife mirrors and reflectors are designed to increase the barrier effect of the transportation corridor, at least when traffic is present.

Effectiveness

Most studies that tested mirrors and reflectors found no effect on wildlife-vehicle collisions (Waring et al. 1991, Ford and Villa 1993, Reeve and Anderson 1993, Thomas 1995, Cottrell 2003, Rogers 2004). Other studies had mixed results (Pafko and Kovach 1996, Barlow 1997), or inconclusive results (Gulen et al. 2000). Different experimental designs and the variety of models tested do not allow for comparison (D'Angelo et al. 2004). In a review of 10 studies, five concluded that roadside reflectors did not appear to impact deer-vehicle collisions, two concluded that they did, and three reached inconclusive or mixed results (Knapp et al. 2004).

Studies testing the influence of reflectors on animal behavior found little or no evidence of avoidance (Zacks 1985, Waring et al. 1991, D'Angelo et al., in press). Other possible reasons why reflectors and mirrors do not consistently decrease wildlife-vehicle collisions include improper installation and lack of maintenance. In the case of ineffective red-colored reflectors, perhaps the ineffectiveness is because deer cannot see in the red portion of spectrum (VerCauteren et al. 2006).

Situations in which mirrors and reflectors reduce wildlife-vehicle collisions might be a result of driver behavior (Zacks 1985), rural versus suburban landscapes (Pafko and Kovach 1996) or particular site characteristics (Barlow 1997). Future development of deer deterrents or deer-vehicle collision mitigation devices should be based on empirical knowledge of deer physical senses and behavior (D'Angelo et al., in press).

Classification

3) use with negative results

Knapp et al. (2004) classifies "roadside reflectors/mirrors" as "use with conflicting study results" and Donaldson (2006) classifies as "determined ineffective".

Costs

- Total cost of installation with reflectors, posts, equipment, and labor is $7,000–$10,000 per mile (1.6 km). Average reflector lifespan is 12.5 years, totaling $272 to $320 per mile ($169-199/km) per year. Maintenance cost per mile per year is $500 ($311/km) (Strieter-Lite, Strieter Corp., Rock Island, Illinois, www.strieter-lite.com); and
- In British Columbia, reflectors cost approximately $10,000/km ($16,000/mi) to install along both sides of a highway and maintenance costs range in the order of $500 to $1,000 per km ($800-$1600/mi) annually (Sielecki 2004).

Pros

Animal movements are not hindered when installed over long road sections and the measure allows animals to change crossing locations over time.

Cons

- Deer have been documented to move toward vehicles in the presence of reflectors (D'Angelo et al., in press);
- It is impractical to keep reflectors clean at all times (Sielecki 2001, Page 2006); and
- Reflectors are prone to theft and vandalism (Sielecki 2004).

Potential Benefit for Threatened or Endangered Species in Montana

None.

4.7. Audio Signals or Deer Whistles

General Description

Audio animal warning devices mounted on vehicles (e.g., deer whistles) or installed roadside are intended to alert wildlife of oncoming traffic.

Real-world Examples

- Sav-A-Life Deer Alert (Sav-A-Life Industries, New York, New York, www.sav-a-life.com) and Game Tracker's Game Saver are marketed as vehicle-mounted ultrasonic animal warning devices. These devices elicited no response in 150 groups of free-roaming mule deer in with/without trials (Romin and Dalton 1992).
- Acoustic road markings initially elicited behavioral responses in fallow deer (*Dama dama*), but deer became totally indifferent to the stimuli within 10 days (Ujvari et al. 2004).
- Shu-Roo, a vehicle-mounted ultrasonic kangaroo (*Macropodidae*) deterrent, did not cause behavioral differences in captive kangaroos in the on or off position. The Shu Roo signal was not detectable above the noise of four vehicles traveling at different speeds. Recordings yielded no difference whether or not the device was turned on (Bender 2001).
- A roadside wildlife warning system utilizing high frequency sounds was developed and tested in Saskatchewan (Bushman et al. 2001, International Road Dynamics, Inc., Saskatoon, Saskatchewan, Canada, www.irdinc.com). Results from the study were inconclusive and the system is no longer in service (Rob Bushman, IRD Inc., personal communication).
- A device using ultra-sound, infra-sounds, and seismological waves, called Eco Pillar, has or is being used in Slovenia and England to repel wild animals away from roads (Eurocontor, Slovenia, http://www.eurocontor-slo.si/eng/index.html). No independent information about its effectiveness was located.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Note: Audio signals in the right-of-way and deer whistles are designed to increase the barrier effect of the transportation corridor, at least when traffic is present.

Effectiveness

Deer hearing sensitivity is estimated to be between 2 to 6 kHz (Risenhoover et al. 1997, Scheifele et al. 2003). In one study, closed-end whistles produced frequencies of ~3.3 kHz with little variation and open-end whistles emitted frequencies of ~12 kHz with significant variation depending on air pressure (Scheifele et al. 2003). Given the masking effect of road and car noise, however, it is unlikely deer would be able to hear the whistles (Romin and Dalton 1992, Scheifele et al. 2003). In addition, there is no evidence that audio signals affect animal behavior

(Muzzi and Bisset 1990, Romin and Dalton 1992, Bender 2001) and habituation to sounds has been observed (Scheifele et al. 2003, Ujvari et al. 2004).

Literature reviews and annotated bibliographies deem audio repellants ineffective in terms of modifying animal behavior and reducing wildlife-vehicle collisions (Groot Bruinderink et al. 1996, Danielson and Hubbard 1998, Farrell et al. 2002, Gilsdorf 2002, Hedlund et al. 2004, Putman et al. 2004, Knapp 2005, D'Angelo et al. 2004).

Classification

3) use with negative results

Knapp et al. (2004) classifies "deer whistles" as "use with conflicting study results" and Donaldson (2006) classifies "determined ineffective".

Costs

Sav-A-Life Deer Alert individual vehicle-mounted device costs $23.50 each.

Pros

- For vehicle-mounted devices, expense is distributed amongst individual motorists; and
- Does not restrict animal movements.

Cons

- May afford motorists who use deer whistles a false sense of security against wildlife-vehicle collisions; and
- For those species that can hear the sounds, audio signals may alter behavior or drive animals away from suitable habitat and affect habitat connectivity.

Potential Benefit for Threatened or Endangered Species in Montana

None.

4.8. Olfactory or Chemical Repellants

General Description

Olfactory or chemical repellants are applied with the intention to deter wildlife from roadways.

Real-world Examples

- A proprietary 'chemical fence' (repellent chemicals encapsulated in slow release organic foam and applied to roadside posts or trees) showed some repellency and a reduction in the frequency of roe deer-vehicle collisions in one treated section (Kerzel and Kirchberger 1993 in Putman 1997). A subsequent detailed assessment found deer-vehicle collisions rose in untreated sections (Lebersorger 1993 in Putman 2004).
- Experimental applications of a mixture of brown bear (*Ursus arctos*), wolf, lynx (*Lynx lynx*), and human components, Duftzaun (HAGOPUR GmbH, Landsberg am Lech, Germany), showed an 85% reduction in moose-train collisions in Norway, but the 500 m (546.8 yard) treatment distances were short, resulting in small and accidental numbers of collisions with high variation (Andreassen et al. 2005).

- Captive trials of a putrescent whole egg repellant, Deer Away® Big Game Repellant (Intagra, Inc. Lakeville, Minnesota), initially altered caribou feeding behavior, but eventually time spent eating and amount eaten returned to pretreatment levels (Brown et al. 2000b).
- Captive trials of a synthetic scent repellant, Wolfin® (Pro Cell Biotenik, Hornefors, Sweden), showed no repellency of caribou or black-tailed deer (*Odocoileus hemionus*) (Brown et al. 2000b, Shipley 2001).
- A synthetic canine predator odor, Plant Plus (Roe Koh and Associates Pty. Ltd.), had aversive effects on one species of marsupial, but attracted another, indicating a need for more research (Ramp and Croft 2002).
- An experimental study and literature review found olfactory repellants were not suitable as area repellents for travel corridors (Castiov 1999).
- A roadside wildlife warning system utilizing scent repellants was developed (Bushman et al. 2001, International Road Dynamics, Inc., Saskatoon, Saskatchewan, Canada, www.irdinc.com), but findings were inconclusive and the system is no longer operational.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Note: Olfactory repellants are designed to increase the barrier effect of the transportation corridor.

Effectiveness

A literature review of olfactory and chemical repellants (capsaicinoids, synthesized animal odors, other animal products, garlic, particulates, soaps, thiram, bittering agents, natural predator excretions and putrescent egg, names natural predator excretions, and putrescent egg) as the repellants with the most potential to keep ungulates away from roadways (Kinley et al. 2003). Other literature reviews that addressed effectiveness in terms of wildlife-vehicle collision reduction determined that olfactory repellants are either not adequately tested (Danielson and Hubbard 1998, Putman 2004, Knapp 2005), appear to be only somewhat effective (Lutz 1994 in Putman 2004, Farrell et al. 2002, Trocmé et al. 2003), or are not practical because of the need to repeat applications (Johnson 2001, Trocmé et al. 2003). In terms of reducing wildlife-vehicle collisions, evidence for the effectiveness of olfactory repellants remains sparse (Trocmé et al. 2003) and this mitigation measure is considered experimental by AASHTO (Knapp 2005). Future development of olfactory repellants should consider wildlife behavioral responses on a range of species (Ramp and Croft 2002, Baker et al. 2005).

Classification

2) use with conflicting results

Knapp et al. (2004) classifies “repellants (on roadways)” as “not generally used but rarely studied” and Donaldson (2006) classifies “deer repellants” as “limited effectiveness or appears ineffective”.

Costs

- One liter of Plant Plus concentrate costs $30 (currency not specified, but presumably Australian dollars) (Law 2005); and
- A cost-benefit analysis should address safety, economic, and ecological factors and should account for maintenance requirements, re-applications, the size of the area to be treated and potential ecological impacts (Kinley and Newhouse 2003, Trocmé et al. 2003, Knapp 2005).

Pros

Olfactory repellant applications do not require permanent infrastructure.

Cons

- Unintended negative ecological effects may arise from olfactory repellant application (e.g., behavioral changes in target and non-target species, health risks from noxious products) (Kinley and Newhouse 2003);
- There is potential for animal habituation (Knapp 2005); and
- The treatment has to be repeated regularly.

Potential Benefit for Threatened or Endangered Species in Montana

Unlikely, especially for predators such as grizzly bear, Canada lynx, and gray wolf.

4.9. Deer Flagging Models

General Description

Deer flagging models are physical placards that illustrate the behavioral characteristic of fleeing white-tailed deer, i.e., raising their tails to expose the white underside. Tail flagging, however, has not been proven to act as a warning signal to conspecifics (Caro et al. 1995).

Real-world examples

One control/treatment experiment using wooden silhouette models of deer with painted or actual deer tails found the models to be ineffective for deterring deer from the roadway (Graves and Bellis 1978, D'Angelo et al. 2004).

Problem(s) Addressed

- Wildlife-vehicle collisions.

Note: Deer flagging models are designed to increase the barrier effect of the transportation corridor.

Effectiveness

Confounding factors in the Graves and Bellis (1978) study prevent firm conclusions (Knapp 2005). Future studies should consider pertinent variables of flagging, such as fluctuations in deer movements, and determine effects on deer-vehicle collisions (Knapp 2005).

Classification

5) little/no use and little/no study

Knapp et al. (2004) classifies “deer-flagging models” as “not generally used but rarely studied” and Donaldson (2006) classifies as “determined ineffective”.

Costs

Unknown, but probably minimal for spot treatments.

Pros

Unknown.

Cons

If deer flagging models indeed deter deer and other wildlife, the measure should, in general, not be applied in habitat linkage zones where one wants to increase connectivity between habitat on both sides of the road.

Potential Benefit for Threatened or Endangered Species in Montana

Unlikely.

4.10. Reduce Wildlife Population Size

4.10.1. Culling

General Description

Culling involves the killing of individual animals, typically deer (*Odocoileus* sp.), to reduce population size. Culling is done by increasing hunting quotas or employing professional sharpshooters if deer are finding refuge on private land or in (sub)urban areas (Brown et al. 2000a, Doerr et al. 2001, Riley et al. 2003, Nugent and Choquenot 2004).

Recreational hunters tend to focus on mature bucks (males) rather than does (females) or young, which is, unfortunately, the least effective way to reduce the population size (Côté et al. 2004). Killing does is more effective for reducing the population size than killing bucks because both the reproductive potential of the herd and the re-colonization potential is reduced (i.e., does tend to stay in the same place more than bucks) (review in Côté et al. 2004). Regulations that allow for greater quotas may specifically require targeting younger animals and does (Brown et al. 2000a, Van Deelen et al. 2006).

A modeling effort showed that if female dispersal was 8%, culling would have to reduce annual survival to 58% to maintain a population just under ecological carrying capacity and reduce survival to 42% to keep the population at 0.5 of the carrying capacity (Porter et al. 2004).

Real-world Examples

In Minnesota, a deer population reduction program reduced winter deer densities by 46% and deer-vehicle collisions by 30%. Sharp shooting by professionals using bait was deemed to be the most effective and adaptable culling method in an urban setting, as opposed to opportunistic sharp shooting or controlled hunting in parks and refuges (Doerr et al. 2001).

Problem(s) Addressed

- Wildlife-vehicle collisions.

Note: Culling and the associated disturbance are likely to increase the barrier effect of the transportation corridor, especially for the species that is being culled.

Effectiveness

Reducing population size by a certain percentage may result in a similar reduction in deer-vehicle collisions (Doerr et al. 2001, Knapp et al. 2004). However, population reductions of 50% or more can be hard to obtain (e.g., Doerr et al. 2001), perhaps limiting the potential reduction in deer-vehicle collisions to less than 50%. Culling may be ineffective in remote locations, on private lands, and in urban or suburban areas (Brown et al. 2000a, Côté et al. 2004).

Classification

2) use with conflicting results

Knapp et al. (2004) classifies “hunting or herd reduction” as “use but rarely studied” and Donaldson (2006) classifies “herd reduction” as “requires additional research”.

Costs

A controlled hunt was estimated to cost $117/deer killed. Professional sharpshooter cost varied, conservation officers - $108/deer killed; park rangers - $121/deer killed; and police officers - $194/deer killed (Doerr et al. 2001). DeNicola et al. (2000) estimated this cost to be $91-$310/ deer killed.

Pros

May help reduce negative impacts of deer overpopulation on agricultural crops and silviculture (Côté et al. 2004).

Cons

- The public may not favor or accept culling (Porter and Underwood 1999, Fulton et al. 2004, Koval and Mertig 2004);
- Repeated efforts are needed since deer populations will restore themselves to the same levels if habitat conditions remain similar; and
- Baiting deer increases efficacy of culling, but it is illegal in some areas and can lead to undesirable side effects (e.g., changes in feeding habits of deer can have effects on the ecosystem as a whole; population size may increase, resulting in starvation for some animals; deer crowding, fighting, injuries and spread of disease; deer domestication and habituation to unnatural foods and humans; decrease in hunter satisfaction (review in Brown and Cooper 2006, Van Deelen et al. 2006)).

Potential Benefit for Threatened or Endangered Species in Montana

None.

4.10.2. Relocation

General Description

Relocation involves the capture, transport, and release of animals (mostly deer, *Odocoileus* sp.) in another location in an effort to reduce the local population size.

Real-world Examples

A deer relocation effort on Head Island, South Carolina, resulted in relatively high mortality from capture-related causes and 50% of the relocated deer dispersed from their release site (Cromwell et al. 1999).

Problem(s) Addressed

- Wildlife-vehicle collisions.

  Note: Relocation and associated disturbance is likely to increase the barrier effect of the transportation corridor, especially for the species being relocated.

Effectiveness

Reducing population size by a certain percentage may result in a similar reduction in deer-vehicle collisions (Doerr et al. 2001, Knapp et al. 2004). However, population reductions of 50% or more can be hard to obtain (e.g., Doerr et al. 2001), perhaps limiting the potential reduction in deer-vehicle collisions to less than 50%. Effectiveness is compromised in populations that allow individuals from neighboring populations to fill the gaps or that allow relocated individuals to return (Cromwell et al. 1999).

Classification

5) little/no use and little/no study

Knapp et al. (2004) classifies "hunting or herd reduction" as "use but rarely studied" and Donaldson (2006) classifies "herd reduction" as "requires additional research".

Costs

Relocation cost estimates ranged from $387/relocated deer (Beringer et al. 2002) to as much as $2,931/relocated deer (DeNicola et al. 2000).

Pros

May help reduce negative impacts of deer overpopulation on agricultural crops and silviculture (Côté et al. 2004).

Cons

- The public may not favor or accept relocation, especially in areas that have a high degree of ecological integrity (Porter and Underwood 1999, Fulton et al. 2004, Koval and Mertig 2004);
- Repeated efforts are needed since deer populations will restore themselves to the same levels (e.g., growth, immigration, return of relocated individuals) if habitat conditions remain similar;

- Relocated individuals often suffer from a lower survival rate and possible mortality from the capturing effort (Cromwell et al. 1999, Beringer et al. 2002);
- Relocation of deer can aid in the spread of infectious diseases (Miller and Kaneene 2006); and
- Relocated individuals may compete with those at the release site or may contribute to the overpopulation at the release site (Côté et al. 2004).

Potential Benefit for Threatened or Endangered Species in Montana

None.

4.10.3. Anti-fertility Treatment

General Description

Anti-fertility treatment or sterilization is typically considered where hunting is illegal or impractical and when dealing with a relatively small closed deer population (e.g., ≤200 breeding females) (Boone and Wiegert 1994, Seagle and Close 1996, Turner et al. 1996, Rudolph et al. 2000). Some anti-fertility drugs are effective for up to 1 or 2 years (Turner et al. 1996). Modeling efforts have shown that sterilization in concert with hunting can reduce the population size of deer (Boone and Wiegert 1994, Seagle and Close 1996).

Real-world Examples

There are no known cases where anti-fertility treatment has been implemented to reduce wildlife-vehicle collisions.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

Reducing population size by a certain percentage may result in a similar reduction in deer-vehicle collisions (Doerr et al. 2001, Knapp et al. 2004). However, population reductions of 50% or more can be hard to obtain (e.g., Doerr et al. 2001), perhaps limiting the potential reduction in deer-vehicle collisions to less than 50%. Effectiveness is also seriously compromised if re-colonization from elsewhere can occur (Seagle and Close 1996, Merrill et al. 2006).

Classification

5) little/no use and little/no study

Knapp et al. (2004) classifies "hunting or herd reduction" as "use but rarely studied" and Donaldson (2006) classifies "herd reduction" as "requires additional research".

Costs

To treat 30 deer for 2 years was calculated to be $33,833 ($1,128/treated deer); labor was 64% of the total budget (Walter et al. 2002).

Pros

May help reduce negative impacts of deer overpopulation on agricultural crops and silviculture (Côté et al. 2004).

Cons

- Fertility control and some immunocontraceptives may disrupt normal reproductive behavior and functioning, and can cause abscesses, inflammations, weight gain, changes in general behavior, and changes in the herd sex ratio (Nettles 1997);
- Repeated efforts within a single population are necessary (Boone and Wiegert 1994) and, depending on the drug used, the same animals may have to be treated multiple times (Turner et al. 1996, Baker et al. 2004); and
- May only be feasible in relatively small populations (≤ 200 females) (Rudolph et al. 2000).

Potential Benefit for Threatened or Endangered Species in Montana

None.

4.10.4. Reduce Habitat Quality Away from Road

General Description

When there is a matrix of suitable cover and forage, deer population densities can be relatively high. Reducing the quality of available habitat can be done by certain mowing or cutting practices, allowing natural succession for more mature forests with different ground cover and shrub layers, or limiting or stopping irrigation and the use of fertilizers (Gill et al. 1996).

Real-world Examples

There are no known cases where habitat alteration away from road has been implemented to reduce wildlife-vehicle collisions.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Note: Reducing the habitat quality away from the road is likely to result in an increase of the barrier effect of the transportation corridor.

Effectiveness

Direct benefits in terms of reduced wildlife-vehicle collisions are unknown.

Classification

5) little/no use and little/no study

Knapp et al. (2004) and Donaldson (2006) did not separately classify this mitigation measure.

Costs

Unknown.

Pros

Reducing habitat quality away from roads may help minimize damage to agricultural crops, and gardens and lawns.

Cons

Altering habitat for ungulates may have unintentional effects on non-target species.

Potential Benefit for Threatened or Endangered Species in Montana

Unknown, but high levels of human impact on the landscape is likely to have a negative effect on grizzly bear, Canada lynx, and gray wolf.

5. MITIGATION MEASURES TO PHYSICALLY SEPARATE OR MODIFY ANIMAL BEHAVIOR USING SUBSTANTIAL INFRASTRUCTURE

5.1. Long Tunnels or Long Bridges

General Description

Not to be confused with wildlife overpasses or underpasses, long tunnels or long bridges can range from several hundreds of meters to many kilometers in road length. Long tunnels and landscape bridges are primarily constructed because of the nature of the terrain (e.g., mountainous topography, floodplain) and/or to avoid sensitive areas (Figure 22). Since these structures are not necessarily combined with wildlife fencing, they allow for natural animal movements under or over the road, as well as allow for other ecosystem processes, including those related to soil and hydrology.

Figure 22. A long bridge on State Route 260 in Arizona. Photo by Marcel Huijser.

Real-world Examples

- In Silver Creek Cliff, Minnesota is an example of the Australian Tunneling Method (Scott Bradley, Minnesota Department of Transportation, personal communication).
- In the United Kingdom, a cut and cover long tunnel was built from motorway A12 Hackney to the M11 link.
- Near Arrisoule, Neuchâtel, Switzerland is an example of a long tunnel on motorway A1.
- Over an important wetland surrounding the River Mino in Galicia, Spain is a long (landscape) bridge on motorway A9.
- Interstate I-70 in Colorado.

Problem(s) Addressed

- Wildlife-vehicle collisions; and
- Barrier effect.

Effectiveness

Depending on the local situation, long tunnels and long bridges may be among the most effective mitigation measures for reducing road kill and for allowing for unhindered animal movement. No data are available, but because vehicles are physically separated from animals on these structures, wildlife-vehicle collisions should theoretically be reduced by approximately 100%.

Classification

4) use but with little/no study

This measure was not discussed as a separate category in Knapp et al. (2004) or Donaldson (2006).

Costs

In Canada, a long tunnel is estimated to cost Can$24,000,000 (US$17,190,960) for a 200 m (218.7 yard) long section; a landscape bridge is estimated to cost Can$12,500,000 (US$8,953,625) for a 200 m (218.7 yard) long section (Anthony P. Clevenger, Western Transportation Institute – Montana State University, personal communication).

Pros

- Long tunnels and long bridges also allow for humans, forest products, crops, and livestock to move from one side of the road to the other because the public roads on top of the long tunnels or under the landscape bridges are left intact; and
- Long tunnels and landscape bridges allow for connectivity at the landscape level for a wide array of species, including abiotic ecosystem processes.

Cons

- Unknown.

Potential Benefit for Threatened or Endangered Species in Montana

Direct mortality: All species are likely to benefit because vehicles are physically separated from animal movements.

Barrier effect: All species have the potential to benefit because the vegetation, soil, and hydrology are left intact.

5.2. Boulders in Right-of-Way

General Description

As an alternative to wildlife fencing, large boulders may be placed in the right-of-way, outside of the clear zone. A substrate of large boulders is believed to discourage ungulates from walking across an area.

Real-world Examples

In Arizona, boulders have been used for this purpose along state route 260 (Terry Brennan, US Forest Service, personal communication).

Problem(s) Addressed

- Wildlife-vehicle collisions.

  Note: Boulders in the right-of-way are designed to increase the barrier effect of the transportation corridor.

Effectiveness

The effectiveness of large boulders as an alternative to wildlife fencing or as a measure to reduce wildlife-vehicle collisions is unknown.

Classification

5) little/no use and little/no study

Knapp et al. (2004) and Donaldson (2006) did not separately classify this mitigation measure.

Costs

Unknown.

Pros

In contrast to wildlife fencing, large boulders are natural and, depending on the landscape, can address the aesthetic concerns.

Cons

Depending on the right-of-way characteristics, terrain, and vegetation, boulders may pose a safety hazard, even if they are located outside of the clear zone.

Potential Benefit for Threatened or Endangered Species in Montana

Unknown, however, large boulders do not necessarily deter grizzly bear, Canada lynx or gray wolf.

5.3. Wildlife Fencing

General Description

In North America, standard wildlife fencing for ungulates is ~7.8 ft (2.4 m) tall and is one of the most commonly applied mitigation measures to separate vehicles from wildlife (Romin and Bissonette 1996). There are several different types of fencing: wire mesh, page-wire, cyclone, and electrified designs such as ElectroBraid™ (Electrobraid Fence, Nova Scotia, Canada http://www.electrobraid.com). Fence posts may be wooden or metal depending on the substrate (e.g., metal is useful for rocky surfaces). To keep other species from climbing over fences (e.g., cougars, bears), fences can be taller, mesh size can be smaller, and overhangs can be incorporated into the design (Jones and Longhurst 1958, Gloyne and Clevenger 2001).

Real-world Examples

- In Pennsylvania, deer permeated both ~7.2 ft (2.2 m) and ~8.8 ft (2.7 m) tall fences. Higher fencing ~8.8 ft (2.7 m) was more effective in excluding deer. Deer-vehicle collisions were not reduced, however. Suggestions to make fencing more effective included fixing gaps under and in the fence and decreasing the size of woven wire mesh (Feldhamer et al. 1986).
- In Sweden, fencing reduced moose-vehicle collisions by 80% (Lavsund and Sandegren 1991).
- In British Columbia, ~7.8 ft (2.4 m) high exclusion fencing was 97-99% effective in reducing large wildlife-vehicles collisions (Sielecki 1999).
- Woods (1990) reported 94-97% 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%. (Figure 23). Wildlife-vehicle collisions that still occurred were closer to fence ends than expected by chance, but were not significantly associated with gaps in the fence (Clevenger et al. 2001).
- Reed et al. (1982) reported an average reduction of 78.5% for deer vehicle accidents in Colorado.
- Ward (1982) reported a reduction of greater than 90% for mule deer in Wyoming.
- 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% fewer tortoise carcasses and 88% fewer vertebrate carcasses along a fenced section compared to an unfenced section of highway.
- Electric fencing (ElectroBraid™) was evaluated for keeping deer off runways at airports (and may also be suitable for short segments of roadway). Fencing as low as ~ 4.2 ft (1.3 m) tall was sufficient to exclude deer unless they were pressured to cross it. Fences were highly effective (90%) when turned on and maintained (Seamans and VerCauteren 2006).

Problem(s) Addressed

- Wildlife-vehicle collisions.

Note: Wildlife fencing is designed to increase the barrier effect of the transportation corridor.

Effectiveness

When installed and maintained correctly, wildlife fencing can form a nearly impermeable barrier to large mammals, eliminating or substantially reducing the number of wildlife-vehicle collisions. Most studies report an 80-95% reduction in wildlife-vehicle collisions. Since fencing creates an almost absolute barrier to wildlife movements, safe wildlife crossing opportunities must also be provided. Since some animals still breach fences and walk around fence ends, escape opportunities and fence end treatments must also be provided.

Figure 23. Wildlife fencing along the TransCanada Highway. Photo by Marcel Huijser, WTI.

Classification

1) use with positive results

Knapp et al. (2004) classifies "exclusionary fencing" as "use with generally positive study results" and Donaldson (2006) classifies as "determined effective".

Costs

- In 1997, ~7.8 ft (2.4 m) high wildlife fencing in Banff National Park, Alberta, cost Can$30/m (US$22/m or US$72/ft) (one side of highway) during the phase 3A Trans-Canada Highway expansion (Terry McGuire, Parks Canada, personal communication). The entire ~ 11 mile (18 km) section cost approximately Can$1,000,000 (US$722,540);
- Cost-benefit analyses of 16 cases revealed that benefits of the wildlife fencing outweigh potential costs in 12 of 16 cases. Fencing in these cases ranged from Can$40,000 (US$26,942/km) to Can$80,000/km (US$53,884/km) (Sielecki 1999);
- ElectroBraid™ fencing consisting of five ~9.8 in (25 cm) rope strands cost $9/m ($8.23/yard) (Seamans and VerCauteren 2006);

- 4 foot (1.2 m) high, 5-Braid™ ElectroBraid™ Deer Exclusion Fence is advertised at $7,000/mi; 5 ft (1.5 m) high, 5-Braid™ ElectroBraid™ Moose Exclusion Fence is advertised at $7,500/mi ($4,661/km) (Electrobraid 2006); and
- Along US Hwy 93 on the Flathead Reservation in Montana, the cost of wildlife fencing depended on the particular road section, ranging from $26 - $41/m ($23.8-37.5/yard). A finer mesh fence was added to the base for some fence sections at an additional cost of $12/m ($10.97/yard) (Pat Basting, Montana Department of Transportation, personal communication).

Pros

- Wildlife fencing in combination with wildlife overpasses or underpasses may reduce wildlife-vehicle collisions for large species (deer size and up) by 80-95%;
- 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);
- For those populations for which high road mortality and long-term viability is a concern, fencing could improve persistence. The authors however, do not recommend fencing for stable populations (Jaeger and Fahrig 2004); and
- Wildlife fencing also helps keep pedestrians away from traffic.

Cons

- Regular fence monitoring is critical to fix gaps between the ground and fence bottom or breaches created by humans or animals. Fence maintenance, however, is often neglected shortly after construction because priorities and budgets change over time;
- Fencing increases the barrier effect of the road, disrupting daily, seasonal, and dispersal movements, and potentially reducing survival probability of target and non-target species. This may be mitigated by providing for wildlife under- and/or overpasses (see paragraph 5.4);
- If safe crossing opportunities (e.g., wildlife crossing structures) are not provided or are too few in number, too small, or too far apart, animals are more likely to break through the wildlife fence, reducing the effectiveness of the fencing;
- Animals may breach fences (e.g., by climbing over, under, or through gaps) and become trapped in the right-of-way. This poses a highway safety risk and exposes the animals to road mortality, necessitating escape opportunities (e.g., jump-outs, ramps, one-way gates);
- Animals are known to cross roads where fences end and at intersections with access roads, in some cases, resulting in a new concentration of animal-vehicle collisions (Clevenger et al. 2001; Norris Dodd, Arizona Game and Fish Department, personal communication), necessitating fence end and access/gap treatments (e.g., wildlife/cattle guards);
- Large mammals may become tangled in or fatally wounded by fences;

- Predators may exploit fences when pursuing prey (e.g., along the Trans-Canada Highway, fencing cut off escape terrain for bighorn sheep enabling coyotes (*Canis latrans*) to stampede sheep into the fence). In addition, wolves, bears, and other predators have also been observed opportunistically running prey into wildlife fencing (Leeson 1996). Parks Canada installed a green 'curtain' on the wildlife fence along a section of the Trans Canada Highway to alert sheep to the fence (Terry McGuire, Parks Canada, personal communication);
- Birds may collide with fences and die (Baines and Summers 1997, Dobson 2001). Chestnut paling inserted in deer exclusion fences make them more visible to birds (Dobson 2001); and
- Wildlife fencing can have a negative impact on landscape aesthetics, but fencing can be made less visible by installing it behind trees or painting it brown or green to blend in with surroundings (Terry McGuire, Parks Canada, personal communication).

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Large species (e.g., grizzly bear, gray wolf) that cannot easily climb or otherwise cross wildlife fencing are likely to have fewer road killed individuals.

Barrier Effect: Large species (e.g., grizzly bear, gray wolf) that cannot easily climb or otherwise cross wildlife fencing are likely to be confronted with an increased barrier effect of the transportation corridor, unless sufficient safe crossing opportunities are provided for.

5.4. Wildlife Fencing with Crossing Opportunities

The very nature of wildlife fencing implies that it may act as an absolute barrier for certain species. While effective at separating animals from traffic and reducing road mortality, fencing can have unintended negative barrier effects as well. Wildlife fencing increases the barrier effect of a road, disrupting daily, seasonal, and dispersal movements, and potentially reducing survival probability of some populations for certain species. Therefore, whenever fencing or another absolute barrier is installed it should be in concert with safe crossing opportunities for wildlife.

One way of providing crossing opportunities is by leaving gaps in fences on both sides of the road so animals may cross at-grade. Gaps are generally accompanied by wildlife warning signs, wildlife crosswalks, animal detection systems, or combination thereof, and sometimes by mandatory or advisory speed limit reductions. Wildlife underpasses and overpasses offer safer crossing opportunities because the animals cross under or above the roadway.

5.4.1. Gaps with Wildlife Warning Signs and/or Crosswalks

General Description

Gaps in fencing allow animals to cross at-grade necessitating additional measures that inform and aid motorists.

Real-world Examples

- In northeastern Utah, a system of wildlife fences and gaps was installed to reduce vehicle collisions with mule deer along a two-lane and divided four-lane highway. Gaps had wildlife warning signs and painted crosswalks on the road surface to alert motorists. Road mortality was reduced by 42.3% (four-lane highway) and 36.8% (two-lane highway) compared to the expected road mortality (Lehnert and Bissonette 1997).

- In The Netherlands, advisory speed limit reduction signs were installed at gaps in a wildlife fence (one gap on each side of the road) (Figure 24).
- Animal crossings are limited to certain locations only.

Figure 24. Advisory speed limit reduction at a fence gap where large animals (red deer, wild boar, roe deer) may cross at grade in The Netherlands. Photo by Marcel Huijser.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Note: Wildlife fencing increases the barrier effect of the transportation corridor, but the gaps allow for at grade road crossing in restricted areas.

Effectiveness

Comparative data are not available for road kills occurring in gaps with or without warning signs, but a gap in wildlife fencing combined with wildlife warning signs and a crosswalk reduced the effectiveness of the wildlife fence from 80-95% to 42.3% (four-lane highway) and 36.8% (two-lane highway) (Lehnert and Bissonette 1997).

Classification

4) use but little/no study

Knapp et al. (2004) pooled all types of wildlife crossing structures and classified them as "used with generally positive results". Donaldson (2006) did not explicitly discuss this mitigation measure.

Costs

- A cross walk across a two-lane road (excluding wildlife fencing and escape from right-of-way measures) costs $15,000 (Lehnert and Bissonette 1997); and

- A cross walk across a four-lane divided highway (excluding wildlife fencing and escape from right-of-way measures) costs $28,000 (Lehnert and Bissonette 1997).

Pros

Gaps reduce the barrier effect of fencing and allow animals to cross at-grade.

Cons

- Since gaps encourage animals to cross at-grade, wildlife-vehicle collisions can occur, reducing the effectiveness of the wildlife fence;
- Animals may walk onto the road and wander parallel to the right-of-way, becoming trapped in between the wildlife fences and vulnerable to wildlife-vehicle collisions; and
- Animal crossings are limited to certain locations only.

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Large species (e.g., grizzly bear, gray wolf) that cannot easily climb or otherwise cross wildlife fencing are likely to have fewer road killed individuals, but direct mortality at fence gaps would still be a concern.

Barrier Effect: Large species (e.g., grizzly bear, gray wolf) that cannot easily climb or otherwise cross wildlife fencing are likely to be confronted with an increased barrier effect by the transportation corridor, unless sufficient safe crossing opportunities are provided for.

5.4.2. Gaps with Wildlife Warning Signs and Animal Detection Systems

General Description

Since gap locations are more likely to be wildlife crossing points on roads with wildlife fencing, these locations are natural choices for animal detection systems.

Real-world Examples

- The Netherlands has installed animal detection systems at gaps in wildlife fencing at two locations (‘t Harde and Ugchelen) (Huijser et al. 2006b).
- On State Route 260 in Arizona, elk-proof fencing funnels animals either to a crosswalk with animal detection system and warning signals or to underpasses (Arizona Game and Fish 2006).

Problem(s) Addressed

- Wildlife-vehicle collisions.

Note: Wildlife fencing increases the barrier effect of the transportation corridor, but the gaps with wildlife warning signs and animal detection systems allow for at grade road crossing in restricted areas.

Effectiveness

There are no data on the effectiveness of this measure in combination with a gap in a fence. However, as a stand alone mitigation measure, animal detection systems may reduce collisions with ungulates by 82% on average (Huijser et al. 2006b).

Classification

5) little/no use and little/no study

Knapp et al. (2004) and Donaldson (2006) did not explicitly discuss this combination of mitigation measures.

Costs

An animal detection system at a gap in wildlife fencing costs $50,000 (including installation and fence) (Huijser et al. 2006b).

Pros

Gaps reduce the barrier effect of fencing and allow animals to cross at-grade.

Cons

- Animals may walk onto the road and wander parallel to the right-of-way beyond the range of the animal detection system, becoming trapped in between the wildlife fences and vulnerable to wildlife-vehicle collisions;
- Small or medium sized animals are not detected;
- Animal crossings are limited to certain locations only; and
- See additional considerations in paragraph 3.4.

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Large species (e.g., grizzly bear, gray wolf) that cannot easily climb or otherwise cross wildlife fencing and that are detected are likely to have fewer road killed individuals, but mortality at fence gaps may still be too high.

Barrier Effect: Large species (e.g., grizzly bear, gray wolf) that cannot easily climb or otherwise cross wildlife fencing are likely to be confronted with an increased barrier effect of the transportation corridor because their movements across the road are restricted to certain locations only. However, the percentage of successful crossings may increase.

5.4.3. Wildlife Underpasses and Overpasses

General Description

There are a wide variety of wildlife underpasses and overpasses that offer safe crossing opportunities for wildlife. Examples of underpasses include culverts and open span bridges where animals cross under the road (Figures 25 and 26). Overpasses may consist of road tunnels dug into the earth or human-made, naturalistic bridges where animals cross over the road. The performance of these structures in reducing wildlife-vehicle collisions, however, is highly dependent on associated wildlife fencing that keeps animals off the roadway and funnels them towards the crossing structures (Clevenger et al. 2002b). Researchers have documented that wildlife underpasses and overpasses allow wildlife safe crossing and that a wide variety of species uses these techniques (Falk et al. 1978, Ludwig and Bremicker 1983, Feldhammer et al. 1986, Clevenger et al. 2002a).

Wildlife use of crossing structures depends on several parameters, including: location in the landscape, distance between structures, habitat surrounding the structures, dimensions, human use in the area, species-specific preferences, and time from installation since animals have a learning curve for finding the structures (Clevenger et al. 2002a). If target species are large, sensitive to human disturbance, or if multiple habitats have to be provided for on an overpass, a width of least 50-70 m (54.6-76.5 yard) is recommended. Wildlife use of crossing structures has been shown to increase with width until use levels out at ~ 50 m (54.6 yard) (Pfister et al. 2002).

Minimum dimensions have been suggested for some ungulate species (see Foster and Humphrey 1995), but specifications for wide-ranging species require further research. The most comprehensive guidelines for designing wildlife crossing structures to date are found in the European handbook (Iuell et al. 2003). Other guidelines specific to North American and European taxa also exist (Foster and Humphrey 1995, Clevenger and Waltho 2000, Clevenger and Waltho 2005, Kruidering et al. 2005). NCHRP 25-27 will include guidelines for wildlife crossing structures and will be available in 2008.

Real-world Examples

- In Banff National Park, Canada, grizzly bears, deer and elk tend to use overpasses (Figures 27 and 28) to a greater extent than underpasses, while black bears and mountain lions tend to use underpasses more than overpasses (Clevenger et al. 2002a).
- 24 underpasses along a 64 km (39.7 mi) long section of I-75 in southern Florida were installed to allow for water flow and animal movements, including the Florida panther (Foster and Humprey 1995).
- In Montana, wildlife underpasses and one wildlife overpass along US Hwy 93 on the Flathead Indian Reservation, and one wildlife overpass across MT Hwy 83 near Salmon Lake are planned, under construction or completed.

The Netherlands has large underpasses (7-10 m (7.7-10.9 yard) wide) and overpasses (typically about 50 m (54.6 yard) wide) (Kruidering et al. 2005).

Figure 25. A large wildlife crossing culvert. Photo by Tony Clevenger, WTI.

Figure 26. Bighorn sheep using an underpass in Canmore, Alberta, Canada. Photo by Tony Clevenger, WTI.

Figure 27. Red Earth Overpass on the TransCanada Highway. Photo by Tony Clevenger, WTI.

Problem(s) Addressed

- Wildlife-vehicle collisions; and
- Barrier effect.

Figure 28. Ten large mammal species have been documented to regularly use wildlife overpasses on the TransCanada Highway in Banff National Park; more than 84,000 crossings have occurred over a ten-year period. Clockwise from upper left: moose, grizzly bear (Threatened in Montana), gray wolf (Endangered in Montana), and elk. Photos by Tony Clevenger, WTI.

Effectiveness

Wildlife fencing in combination with underpasses or overpasses can reduce ungulate-vehicle collisions by 80% or more (Sielecki 1999, Clevenger et al. 2001). In addition, a wide variety of species has been shown to use wildlife underpasses and overpasses (Falk et al. 1978, Ludwig and Bremicker 1983, Feldhammer et al. 1986, Clevenger et al. 2002a).

Classification

1) use with positive results

Knapp et al. (2004) classify "wildlife crossings" as "use with generally positive study results" and Donaldson (2006) classifies as "determined effective".

Costs

- The cost of underpass structures varies widely:
  - Box culverts (3.0 m high x 2.5 m wide (3.3 x 2.7 yard)) = Can$2,800/m (Can$2,560/yard) (US$1,834/yard), total cost = Can$180,000 (US$128,932),
  - Elliptical culverts (4 m high x 7 m wide (4.4 x 7.7 yard)) = Can$5,400/m (Can$4,938/yard) (US$3,537/yard), total cost = Can$225,000-$250,000 (US$161,165-$179,073), and
  - Open span bridge underpass (13 m wide x 5 m high (14.2 x 5.5 yard)) = Can$55,000/m (Can$50,292/yard) (US$36,024)) (per meter estimates by Terry McGuire, Parks Canada, unpublished data; total cost estimates by Anthony P. Clevenger, Western Transportation Institute – Montana State University, personal communication);
- In The Netherlands large underpasses (7-10 m (7.7 x 10.9 yard) wide) are estimated to cost €30,000 - €50,000/m (€27,432-45,720/yard) (US$31,164-56,939/yard) (Kruidering et al. 2005);
- Tunneling and overpass structures can range from Can$33,650/m (US$24,103/m) for a 70-m long overpass to Can$119,300 (US$85,453) for a 27-m (29.5 yard) wide tunnel (Anthony P. Clevenger, Western Transportation Institute – Montana State University, personal communication). Total estimated cost of a 52m wide and 70 m long overpass = Can$1,750,000 (US$1,253,508) (Anthony P. Clevenger, Western Transportation Institute – Montana State University, personal communication);
- A proposed overpass across MT Hwy 83 near Salmon Lake (two-lane road) is estimated to cost $1,500,000 - $2,400,000;
- Three large wildlife underpasses (two that are 6.9 m wide, 4.8 m high, 21.9 m long (7.5 x 5.2 x 24.0 yard); one that is 7.7 m wide, 5.1 m high, 18.3 m long (8.4 x 5.6 x 20.0 yard) cost a total of $650,000 ($216,667 per structure on average), including wing walls; and
- Seven wildlife overpasses in The Netherlands ranged between €1,400,000 and €5,600,000 (US$1,735,546 and 6,974,184) (Kruidering et al. 2005).

Pros

Overpasses and underpasses provide crossing opportunities for a wide variety of wildlife species and at least partially address the barrier effect of wildlife fencing.

Cons

Unknown.

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Large species (e.g., grizzly bear, gray wolf) that cannot easily climb or otherwise cross wildlife fencing are likely to have substantially fewer road killed individuals.

Barrier Effect: Large species (e.g., grizzly bear, gray wolf) that cannot easily climb or otherwise cross wildlife fencing are likely to be confronted with an increased barrier effect of the transportation corridor because their movements across the road are restricted to certain locations only. However, the percentage of successful crossings is increased substantially. In addition, limited use of wildlife underpasses has been demonstrated for Canada lynx (Anthony P. Clevenger, Western Transportation Institute – Montana State University, personal communication). Underpasses are often combined with stream or river crossing, potentially reducing the barrier effect for pallid and white sturgeon, and bull trout.

5.5. Wildlife Fencing with Escape Opportunities

5.5.1. Jump-outs or Escape ramps

General Description

Jump-outs or "escape ramps" are sloped earthen mounds that lead up and away from the right-of-way, allowing animals to jump out from between roadway fences (Figure 29). In order to be safe and usable for the animal, standard 2.4 m (7.8 ft) wildlife fencing must be lower at the ramp site. The vertical nature of the non-highway side of the fence is designed to preclude animals from gaining access to the right-of-way.

Figure 29. A jump-out on US 93 in Montana. Photo by Marcel Huijser, WTI.

Real-world Examples

In northern Utah, 2.4 m (7.8 ft) wildlife fencing installed on US 91 and US 40 was not 100% effective because of human vandalism and gaps at the base of the fence. Earthen escape ramps (jump-outs) and one-way gates were added and tested for effectiveness in reducing deer mortality on roads. Deer-vehicle collisions declined after installation of jump-outs, and jump-outs were eight to eleven times more effective than one-way gates (Bissonette and Hammer 2000).

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

Based on Bissonette and Hammer (2000), jump-outs were effective in allowing deer to escape the right-of-way and in reducing deer-vehicle collisions. Installing jump-outs or "escape ramps" along two fenced road sections reduced deer-vehicle collisions by 28.6% on average (Bissonette and Hammer 2000). Jump-outs were eight to eleven times more effective than one-way gates (Bissonette and Hammer 2000).

Classification

1) use with positive results

Knapp et al. (2004) and Donaldson (2006) did not separately classify this mitigation measure.

Costs

Approximate costs for one jump-out ranged from $6,250 each (Pat Basting, Montana Department of Transportation, personal communication) to $11,000 (Bissonette and Hammer 2000).

Pros

- Jump-outs provide escape routes for non-target species; coyote, in addition to deer and elk, have been documented to use jump-outs on the TransCanada Highway (Clevenger et al. 2002a); and
- If earthen ramps offset 2% of deer mortality, they would be cost-effective within one to two years (Bissonette and Hammer 2000).

Cons

- If jump-outs are not built high enough, animals may jump into the right-of-way in between the fences; and
- If jump-outs are built too high, animals will not use them to escape from the right-of-way.

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Grizzly bear, gray wolf, and Canada lynx may avoid being trapped and road mortality may be reduced as a result of the presence of escape ramps.

5.5.2. One-way Gates

General Description

One-way gates are intended to allow animals to escape the right-of-way where wildlife fencing is installed.

Real-world Examples

- A variety of one-way gates have been built for different species, including elk, deer, and the Eurasian badger (*Meles meles*) (Ludwig and Bremicker 1983, Bissonette and Hammer 2000, Kruidering et al. 2005).
- One-way gates were believed to be relatively effective for deer (Reed et al. 1974a); however, in a later study, only 17% of deer that approached one-way gates actually used them (Lehnert 1996).

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

The effectiveness of wildlife fencing with one-way gates in reducing wildlife-vehicle collisions is unknown.

Classification

4) use with little/no study

Knapp et al. (2004) and Donaldson (2006) did not separately classify this mitigation measure.

Costs

One one-way gate cost $8,000 (Bissonette and Hammer 2000).

Pros

Unknown.

Cons

There is anecdotal information that individual animals have gotten stuck, wounded, or died in one-way gates.

Potential Benefit for Threatened or Endangered Species in Montana

Unknown.

5.6. Wildlife Fencing with End Treatments

Wildlife fencing eventually stops somewhere. To prevent animals from walking around fence ends onto the right-of-way in between the fences or onto the road, some form of end treatment may be required. Angled fencing away from the road may reduce the problem, but additional mitigation measures such as constructed boulder fields or animal detection systems may be required.

5.6.1. Boulders

General Description

Installing boulders the size of bowling balls to create a boulder field may discourage ungulates from walking around fence ends (Clevenger et al. 2002a).

Real-world Examples

In Banff National Park, Canada, deer-vehicle collisions on a particular road segment were reduced from six (prior to fencing and boulder field installation) to two (after fencing and boulder field installation). The boulders were credited as an effective deterrent in keeping ungulates from walking around the fence onto the right-of-way (Clevenger et al. 2002a). The boulder field begins at the fence end, sits on the margin of the paved edge of the highway, and is approximately 15 m wide and 20-25 m long (16.4 x 21.9-27.3 yard). Placing a guardrail between the road and boulder field provided for safety compliance in Alberta, Canada (and probably most states).

Another boulder field at a fence end was installed on both shoulders and in the median of the four lane, grass median separated highway at Dead Man's Flat's wildlife underpass along the Trans Canada Highway east of Canmore, Alberta (Bruce Leeson, personal communication). The field is 100 m (91.4 y) long with the width varying from about 8-20 m (7.3-18.3 y), 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. The median component, extending from pavement to pavement is 19 m (17.4 y) wide. The boulders are subangular, quarried rock, ranging in size from 20-60 cm (7.8-23.6 inch) (about 75% are larger than 30 cm (11.8 inch). The boulder apron, at a depth of about 40-50 cm (15.7-19.7 inch), is installed on geofabric on sub-excavated smoothed ground. The boulders project about 20-30 cm (7.8-11.8 inch) above local ground surface (Bruce Leeson, personal communication).

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

Clevenger et al. (2002a) found that the combination of boulder field and wildlife fencing was effective in reducing wildlife-vehicle collisions.

Classification

5) little/no use and little/no study

Knapp et al. (2004) and Donaldson (2006) did not separately classify this mitigation measure.

Costs

The material and labor for the installation of boulders at the fence end at Dead Man's Flat's wildlife underpass along the Trans Canada Highway east of Canmore, Alberta was estimated to cost Can$65,000 ($55,250) (installed in 2005, cost estimate for 2007) (Bruce Leeson, personal communication).

Pros

Boulders may be a relatively low-cost and aesthetically acceptable fence end treatment.

Cons

- Snow cover on boulder fields can allow ungulates to travel across, minimizing effectiveness as a fence end treatment; and
- Boulder fields near the roadway may be considered an obstruction and hazard in some states.

Potential Benefit for Threatened or Endangered Species in Montana

Unknown.

5.6.2. Animal Detection Systems

General Description

Installing animal detection systems (see section 3.4) at fence ends may reduce wildlife-vehicle collisions at these points.

Real-world Examples

In Arizona, an experiment currently underway involves an animal detection system at fence ends to mitigate a concentration of deer- and elk-vehicle collisions (Norris Dodd, Arizona Game and Fish Department, personal communication).

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

The effectiveness of wildlife fencing with animal detection systems in reducing wildlife-vehicle collisions is unknown.

Classification

5) little/no use and little/no study

Knapp et al. (2004) and Donaldson (2006) did not separately classify this mitigation measure.

Costs

Probably similar or less than stand-alone animal detection systems; $65,000-$154,000 per mile (1.6 km) (excluding installation costs) (Huijser, unpublished data). Equipment costs increase if the road section has curves or slopes, or if the line of sight is blocked by objects.

Pros

Unknown in combination with a fence end, but as a stand alone mitigation measure, animal detection systems can reduce collisions with large ungulates by 82% (Huijser et al. 2006b).

Cons

Unknown.

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Large species (e.g., grizzly bear, gray wolf) that cannot easily climb or otherwise cross wildlife fencing and that are detected are likely to have fewer road killed individuals at fence ends, but mortality at fence gaps may still be too high.

Barrier Effect: Large species (e.g., grizzly bear, gray wolf) that cannot easily climb or otherwise cross wildlife fencing are likely to be confronted with an increased barrier effect by the transportation corridor because their movements across the road are restricted to certain locations only. However, the percentage of successful crossings may increase.

5.7. Wildlife Fencing Intersecting with Access Roads

Access roads that intersect with the main road disrupt wildlife fencing, resulting in a gap where animals can walk around a fence end and enter the right-of-way.

5.7.1. Access Roads with Gates

General Description

Access gates in wildlife fencing are generally only installed at very low traffic volume access roads. Gates must be opened and closed when entering or leaving the main road.

Real-world Examples

Access road gates are used for the US 93 reconstruction project in Montana to retain the integrity of wildlife fencing.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

No studies have addressed this mitigation measure, but no significant reduction in collisions is expected compared to an undisrupted wildlife fence.

Classification

5) little/no use and little/no study

Knapp et al. (2004) and Donaldson (2006) did not separately classify this mitigation measure.

Costs

$300-360 for a single panel gate and $350-$550 for a double panel gate along US Hwy 93 on the Flathead Indian Reservation, MT, USA (Pat Basting, Montana Department of Transportation, personal communication).

Pros

Unknown.

Cons

- Gates are an inconvenience to motorists who must stop and get out of the car to open/close the gates; and

- If gates are left open, the effectiveness of the fencing is compromised.

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Unknown, but for species that cannot cross a wildlife fence or gate, direct mortality is likely to decrease.

Barrier Effect: Unknown, however, the barrier effect of the transportation corridor is likely to increase.

5.7.2. Wildlife Guards

General Description

Wildlife guards are specially designed cattle guards to discourage wildlife, especially ungulates, from walking through a gap in a fence.

Real-world Examples

- Standard cattle guards do not deter Florida key deer (*Odocoileus virginianus clavium*) and mule deer (Reed et al. 1974b).
- Standard cattle guards are hazards to pedestrians and cyclists (Peterson et al. 2003).
- In Banff National Park, Canada, some wildlife guards are electrified to discourage bears from walking across.
- In Montana, wildlife guards are installed along US 93 to retain the integrity of wildlife fencing.

Problem(s) Addressed

- Wildlife-vehicle collisions.

Effectiveness

No studies have addressed this mitigation measure, but no significant reduction in collisions is expected compared to an undisrupted wildlife fence.

Classification

4) use with little/no study

Knapp et al. (2004) and Donaldson (2006) did not separately classify this mitigation measure.

Costs

$30,000 for a specially designed wildlife guard (Pat Basting, Montana Department of Transportation, personal communication).

Pros

- Wildlife guards are convenient for motorists since they do not require them to stop or get out of their vehicle; and
- In contrast to a gate, a wildlife guard cannot accidentally be left open.

Cons

- Depending on the design and target species, some cattle or wildlife guards may be ineffective at discouraging certain species, or they may be only partly effective (e.g., 75-99% for Florida Key deer) (Peterson et al. 2003); and
- Wildlife guards may pose hazards to pedestrians and cyclists and be unpleasant to motorists.

Potential Benefit for Threatened or Endangered Species in Montana

Direct Mortality: Unknown, but for species that cannot cross a wildlife fence or wildlife guard, direct mortality is likely to decrease.

Barrier Effect: Unknown, however, the barrier effect of the transportation corridor is likely to increase.

6. COST-BENEFIT ANALYSES

6.1. Costs of Wildlife-Vehicle Collisions

There are substantial costs associated with wildlife-vehicle collisions. Recent research (Huijser et al., in prep.) estimated the average costs for each deer, elk, and moose collision at $8,015, $17,475 and $28,600 respectively. The estimates include costs associated with vehicle repair, human injuries, human fatalities, towing, accident attendance and investigation, hunting and recreational value of the animal concerned, and carcass removal and disposal.

6.2. Costs and Benefits of Mitigation Measures

Table 2 summarizes the costs of the mitigation measures identified in this report and their effectiveness in reducing wildlife-vehicle collisions, specifically deer-vehicle collisions. The costs are presented (where possible) as cost per km of road length per year. The same method was used for quantifying the potential benefits as a result of reducing deer-vehicle collisions. For this analysis, researchers used a hypothetical 1 km (0.62 mi) road section of a 2-lane road (1 lane in each direction) that had 5 deer-vehicle collisions per year. The cost associated with one deer-vehicle collision was estimated at $8,015 (previous paragraph). Finally, the balance (dollar amount saved per km road length per year) was calculated (benefits – costs). 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 or received by different groups in society.

It should be noted that the costs and benefits in Table 2 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 are measured inconsistently in the literature. Furthermore, costs and benefits can vary widely for different sites and situations (e.g., geographic locations, effectiveness, frequency of wildlife-vehicle collisions, surrounding terrain).

In some cases the costs could not be translated to costs per km per year, and no further cost-benefit calculations were conducted for these mitigation measures. 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 the potential benefits.

The calculations presented here do not include inflation indexes and discounting was not applied. Table 2 provides the best guess about costs, effectiveness, and benefits, based on the information currently available. Nonetheless, the calculations provide an initial insight into the balance between the costs and benefits of different mitigation measures and how this balances compares between measures.

The remainder of this chapter discusses the values in Table 2 for each mitigation measure for which sufficient data were available.

Table 2: Summary cost/benefit of mitigation measures

Mitigation measure	Costs ($ /km /yr)	% WVC reduction	Benefits ($ /km /yr)	Balance ($ /km /yr)
Reduce traffic volume	?	?	?	?
Reduce traffic speed	?	?	?	?
Wildlife crossing guards	?	?	?	?
Standard wildlife warning signs	$12	0%	$0	-$12
Non-standard wildlife warning signs	$249	?	?	?
Seasonal wildlife warning signs	$27	26%	$10,420	$10,393
Animal detection systems (ADS)	$31,300	82%	$32,862	$1,562
ADS linked to on-board computer	?*	82%	$32,862	?
On-board animal detectors	$2,225*	?	?	?
Roadway lighting	?	?	?	?
Vegetation removal	$500	38%	$15,229	$14,729
Public information and education		?	?	?
Deer reflectors and mirrors	$495	0%	$0	-$495
Deer whistles	$23.5*	0%	$0	?
Audio and visual signals in ROW	?	?	?	?
Olfactory or chemical repellants	?	?	?	?
Deer flagging	?	?	?	?
Aversion techniques or hazing	?	?	?	?
Reduce or find alternatives to road salt	?	?	?	?
Intercept feeding	?	?	?	?
ROW vegetation (species, quality)	?	?	?	?
Carcass removal	$250*	?	?	?
Culling	$2,508	50%	$20,038	$17,530

Mitigation measure	Costs ($ /km /yr)	% WVC reduction	Benefits ($ /km /yr)	Balance ($ /km /yr)
Relocation	$10,260	50%	$20,038	$9,778
Anti-fertility treatment	$61,702	50%	$20,038	-$41,665
Reduce habitat quality	?	?	?	?
Fence (incl. dig barrier)	$3,760	87%	$34,865	$31,105
Boulders in right-of-way	?	?	?	?
Long bridges	$781,250	100%	$40,085	-$741,165
Long tunnels	$1,500,000	100%	$40,085	-$1,459,915
Fence with gap and warning signs	$4,303	0%	$0	-$4,303
Fence with gap and crosswalk	$5,041	40%	$16,030	$10,989
Fence with gap and ADS	$10,036	82%	$32,862	$22,826
Fence with underpasses	$5,754	87%	$34,865	$29,111
Fence with overpasses	$26,378	87%	$34,865	$8,487
Fence with under- and overpasses	$7,403	87%	$34,865	$27,462

KEY:

The Table assumes one km with five DVCs per year

* costs not in $ per km / year, but in a different unit, see respective 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: $94 per sign. The costs per km per year (2 signs per km, one sign for each travel direction, assumed life span of 10 years, no maintenance) are $12, 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 $12 per km 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% reduction of deer-vehicle collisions, and could end up saving $10,393 per km per year. Bear in mind, however, 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 still result in a positive balance of $1,562 per km per year because of their effectiveness in reducing wildlife-vehicle collisions by 82%.

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 for either roadway lighting measures, or public information and education programs. Vegetation removal, however, demonstrates more potential and may result in a positive balance of $14,729 per km 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 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 for audio and visual warning signals in the right-of-way, olfactory repellants, 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, but here WTI Researchers translated these costs to dollars per km road length 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 (43-50-86-144 ha) (Kilpatrick and Spohr 2000, Beringer et al. 2002, Grund et al. 2002). For a home range of 75 ha the diameter is 978 m (1,069.5 yard), the width of the zone. For a 1 km (.62 mi) long road section, this zone is 97.7 ha for one road side and 195.4 ha for both road sides. Population densities of (suburban) white-tailed deer that are considered a “problem” have been estimated at 50-88-91 individuals per km^2 (Porter and 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% before the culling, relocation, or anti-fertility treatment efforts become 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). 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 road length of $2,508, $10,260 for culling and relocation. For the anti-fertility treatment, it was assumed that 80% of the females (80% 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. 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 that the effectiveness for the culling, relocation, and anti-fertility treatment efforts will be much reduced or potentially eliminated.

Cost for a reduction in habitat quality are highly variable and depend on local conditions. Therefore, this mitigation measure was not included in the analyses.

Wildlife fences (life span 20 years or more, not including maintenance) can reduce collisions with ungulates by at least 80% and have a positive balance of $34,712 per km per year. There are insufficient data available for boulders in right-of-way (as an alternative to wildlife fences). The costs for long bridges and long tunnels were set at $781,250 and $1,500,000 per km per year respectively (80 year life span). Both long bridges and tunnels result in a strongly negative balance.

To accommodate for 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 (1.24 mi) (0.5 crossing opportunity/km). In addition, gaps were set at a width of 100 m (109.3 yard), and the number of escape ramps between gaps was set at 2.5 per roadside per km (one every 317 m (346.6 yard) between gaps). In addition, the animals could "escape" through the gaps. The number of escape ramps between crossing structures was set at 3.5 per roadside per km (two immediately next to a crossing structure (50 on either side from center), and 5 in between at 317 m (346.6 yard) 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 mi). The cost for an underpass (a wide culvert, ±7 m wide, ±5 m high) was set at $200,000, while the cost for an overpass (50 m wide) was set at $3,500,000. The cost for an escape ramp was set at $8,500 (life span 80 years). Wildlife fences with gaps that are mitigated by warning signals ($12/km/yr, 10 yr life span) or a crosswalk ($750/km/yr, 10 yr life span) have a negative balance while wildlife fences in combination with animal detection systems, 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, in general, not recommended to reduce deer-vehicle collisions, at least not from a strictly monetary perspective. However, if alternatives are not suitable given the local conditions, or if other factors besides deer-vehicle collision reduction play a role, these measures may be considered after all. All other mitigation measures for which the cost-benefit analyses could be conducted had a positive or only a slightly negative balance. However, it is also important to evaluate mitigation measures on the portion of the problem that may not have been solved. None of the mitigation measures are 100% 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 30 shows the individual mitigation measures (excluding long tunnels, long bridges, and ant-fertility treatment) in relation to their balance and the costs associated with the deer-vehicle collisions that have remained. Based on the results, the authors of this report identified wildlife fencing, with or without wildlife underpasses or a combination of wildlife underpasses and overpasses, and animal detection systems with wildlife fencing, as the most cost-effective mitigation measures (measures identified by solid oval). These mitigation measures have a strongly positive balance with relatively few remaining deer-vehicle collisions and associated costs. Animal detection systems without wildlife fences or wildlife fences with a high density of wildlife overpasses (measure identified by dashed oval) are also cost-effective, but their positive balance is less strong than for wildlife fencing, with or without wildlife underpasses or a combination of wildlife underpasses and overpasses, and wildlife overpasses, and animal detection systems with wildlife fencing. It is important to note though that these mitigation measures offer different levels of habitat connectivity and that this non-monetary value was not included in the analyses. Furthermore, the balance between costs and benefits of all the mitigation measures may change as new or better estimates become available or as prices change over time. Nonetheless, based on the assumptions and estimates, the mitigation measures listed above are among the most attractive, at least from a monetary perspective.

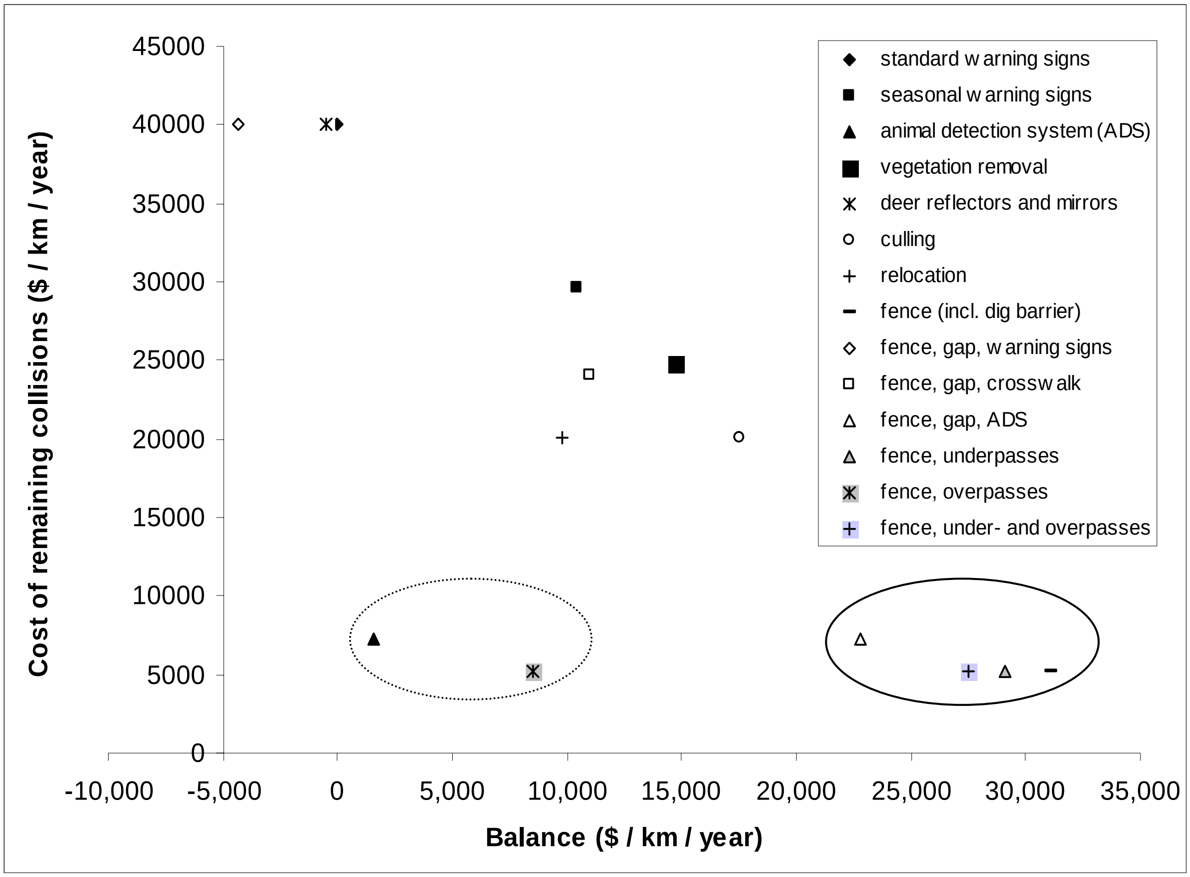

Figure 30: Balance and remaining costs for the different mitigation measures (further explanation in text).

7. PROBLEMS ADDRESSED AND TARGET SPECIES

7.1. Species-Specific Performance of Mitigation Measures

The cost-benefit analysis (see previous chapter) suggested that animal detection systems (with or without wildlife fencing) and wildlife fencing (with or without underpasses and/or overpasses) are the most cost-effective mitigation measures to reduce collisions with large wildlife species, at least from a monetary perspective. However, these mitigation measures offer different levels of habitat connectivity, a parameter that was not included in the analyses. This chapter provides insight in the degree of habitat connectivity provided by the mitigation measures that performed best in the cost-benefit analyses.

Table 3 lists large mammal species, threatened and endangered (T&E) species in Montana, and other species groups, and classifies the performance of the different mitigation measures with regard to collision reduction and safe crossing opportunities for each species or species group. The classification is partially based on Clevenger et al. (2002b), and Clevenger and Waltho (2005).

Animal detection systems and wildlife fencing reduce collision with ungulates in similar percentages, 82% and at least 80% (see earlier in this report). However, the degree of collision reduction for these mitigation measures depends on different factors; animal detection systems must detect the species involved and wildlife fencing must be impenetrable to the species involved. Small and medium sized animals (e.g., mountain lion, Canada lynx, gray wolf) are rarely or never detected by animal detection systems while species that can climb relatively well (e.g., black bear, mountain lion, Canada lynx) can climb the most common types of wildlife fencing. The effectiveness of wildlife fencing as a barrier can be improved though, by reducing the mesh size, the use of overhangs on top of the fence, and metal posts which are harder to climb than wooden posts.

A fundamental difference between animal detection systems and wildlife fencing is that animal detection systems, at least when deployed over long road sections, do not necessarily increase the barrier effect of the road. Therefore, animal detection systems were classified to provide "optimal" safe crossing opportunities for wildlife, even though the mitigation measure does not address the barrier effect of the road and traffic itself. Wildlife fencing, however, increases the barrier effect of the road and traffic to an absolute or near absolute barrier for most terrestrial species. For this reason, wildlife fencing should not be used as a stand alone mitigation measure, but it should be used in combination with other mitigation measures (e.g., an animal detection system at gaps in the fence, wildlife underpasses, wildlife overpasses, or a combination of wildlife underpasses and overpasses).

The classification of the performance of wildlife underpasses, wildlife overpasses, and a combination of wildlife underpasses and wildlife overpasses is based on the available knowledge about the relative species specific preferences based on Clevenger et al. (2002b), and Clevenger and Waltho (2005). For the purpose of this chapter we considered an underpass to be a wide culvert (±7 m wide, ±5 m high (7.7 x 5.5 yard)) and an overpass to be ±50 m (54.6 yard) wide. Large bridges were excluded from this discussion, as their properties may result in a safe crossing opportunity performance that is similar to that of wildlife overpasses. Furthermore, the primary reason for the construction of large bridges is often the nature of the terrain (e.g., gullies, canyons, streams, rivers) rather than habitat connectivity concerns for terrestrial species alone.

The use of crossing structures by ungulates, grizzly bears, and gray wolves is positively correlated with "open" structures that are wide, high, and short (underpass) or wide and short (overpass). Therefore, underpasses were classified as U (= usable) and overpasses and a combination of underpasses and overpasses were classified as O (= optimal) for these species. The use of crossing structures by black bears and mountain lions is negatively correlated with "open" structures; they show greater use of "confined" crossing structures. Therefore, overpasses were classified as U (= usable), and underpasses or a combination of underpasses and overpasses were classified as O (= optimal) for these species.

Information on pronghorns, bighorn sheep, mountain goats, and Canada lynx with regard to the use of wildlife underpasses and overpasses is limited; hence the question marks (= unknown) in Table 3. However, pronghorns, bighorn sheep, mountain goats, and Canada lynx have been observed using underpasses, and Canada lynx has been observed using overpasses (Singer & Doherty 1985; Clevenger et al. 2002b; Plumb et al. 2003; Anthony P. Clevenger, Western Transportation Institute – Montana State University, personal communication).

None of the mitigation measures discussed in this chapter addresses collision reduction for birds, including bald eagles. Animal detection systems, and wildlife underpasses and overpasses do not typically provide effective safe passage opportunities for this species group. Collisions with bull trout do not occur, except perhaps on roads that lack a bridge or culvert over a stream or river. However, if underpasses are combined with a stream crossing, underpasses can improve habitat connectivity for fish, including bull trout.

If wildlife fences have fine mesh sizes for the fence bottom, or if fences are specifically constructed for these species groups (e.g., short fences with fine mesh, concrete, or plastic barriers), the number of road-killed amphibians, reptiles, and small-medium sized mammals can be substantially reduced. Wildlife underpasses and overpasses can provide these species groups with safe crossing opportunities. However, this may require additional measures specifically targeted at these species groups, such as ensuring soil and air humidity that is similar to the surroundings, natural substrate, and cover (e.g., line of tree stumps) (Kruidering et al. 2005).

For the purpose of comparing the mitigation measures, points were assigned for different classifications for each species or species group: optimal = 2 points, usable = 1 point, rest = 0 points. The bottom line of Table 3 shows the total points for each mitigation measure. Wildlife fencing, wildlife fencing with underpasses, wildlife fencing with overpasses, and wildlife fencing with under- and overpasses rank best with regard to collision reduction. Animal detection systems, with or without wildlife fencing, and wildlife fencing with under- and overpasses rank best with regard to safe crossing opportunities for wildlife. When the points for collisions and crossings are combined, animal detection systems, with or without wildlife fencing, and wildlife fencing with a combination of underpasses and overpasses rank best.

7.2. Factors Affecting the Performance of Mitigation Measures

The overall effectiveness of the mitigation measures is dependent on many factors, including:

- The location in the landscape with regard to the habitat and movements of the species concerned, and road or right-of-way characteristics that may influence the probability of a wildlife-vehicle collision. The road and landscape parameters differ between species. For wildlife crossing structures, proximity to cover is negatively correlated with deer, elk, and grizzly bear use and positively correlated with mountain lion use (Clevenger and Waltho 2005);

- The dimensions of under- and overpasses. Some species have higher use of large and open crossing structures, while others have higher use of more confined crossing structures (Clevenger and Waltho 2005); and
- Human caused disturbance, including: traffic noise, proximity of towns, and human use of crossing structures negatively affects the use of crossing structures by wildlife, especially carnivores (Clevenger and Waltho 2000, 2005).

A diversity of crossing structures of mixed size classes is recommended as a general strategy to improve the permeability of roads to wildlife.

7.3. Animal Detection Systems versus Wildlife Crossing Structures

The pros and cons of animal detection systems versus wildlife crossing structures (i.e., under- or overpasses) in combination with wildlife fencing are summarized below (adapted from Huijser et al. 2006b). Note that this paragraph is based on a reliable and effective animal detection system, that up to date only a couple of animal detection systems have been evaluated with regard to their reliability and effectiveness, and that new data, especially with regard to system effectiveness may substantially change the estimated reduction in wildlife-vehicle collisions (82%).

Pros for Animal Detection System*s*

- Animal detection systems have the potential to provide wildlife with safe crossing opportunities anywhere along the mitigated roadway, but wildlife crossing structures are usually limited in number and they are rarely wider than about 50 m (54.6 yard);
- Animal detection systems are less restrictive to wildlife movement than fencing or crossing structures. They allow animals to continue to use existing paths to the road or to change them over time;
- Animal detection systems can be installed without major road construction or traffic control for long periods; and
- Animal detection systems have the potential to become less expensive than wildlife crossing structures, especially once they are mass produced.

Cons for Animal Detection Systems

- Although the available data on the effectiveness of animal detection systems with regard to collision reduction are encouraging, animal detection systems presently are not as “tried and proven” as wildlife crossing structures;
- Currently, animal detection systems only detect large animals (e.g., deer, elk, and/or moose). Relatively small animals are not detected, and drivers are not warned about their presence on or near the road;
- Wildlife crossing structures have the potential to provide cover (e.g., vegetation, including living trees, tree stumps) and natural substrate (e.g., sand, water) allowing better continuity of habitat;
- Some types of animal detection systems are only active in the dark and animals that cross during the daylight may not be protected;
- Animal detection systems usually require the presence of poles and equipment in the right of way, sometimes even in the clear zone, presenting a safety hazard of their own;

- Animal detection systems may substantially reduce the number of animal-vehicle collisions, but since they allow large animals to cross the road at grade, they will never completely eliminate animal-vehicle collisions;
- Animal detection systems can be aesthetically displeasing; and
- Wildlife crossing structures are likely to have greater longevity and lower maintenance and monitoring costs.

The choice between animal detection systems (with or without wildlife fencing and wildlife crossing structures in combination with wildlife fencing) currently depends on whether the success of the project is defined as: 1) Accomplishing a certain minimum result in terms of wildlife-vehicle collision reduction and/or safe crossing opportunities for wildlife or 2) Conducting research that helps to further evaluate the effectiveness of different mitigation measures. The choice also depends on the problem at hand (wildlife-vehicle collisions and/or lack of safe crossing opportunities for wildlife) and the species or species groups concerned, as well as the local situation, including road, right-of-way, and landscape characteristics. For additional considerations see Huijser et al. (2006b).

Table 3. The suitability of different mitigation measures to reduce collisions and to provide safe crossing opportunities for different species and species groups.

Species	Animal detection system (ADS)		Fence (incl. dig barrier)		Fence with gap and ADS		Fence with under-passes		Fence with over-passes		Fence with under- and over-passes	
	Collisions	Crossings	Collisions	Crossings	Collisions	Crossings	Collisions	Crossings	Collisions	Crossings	Collisions	Crossings
L or T&E species												
White-tailed deer	O	O	O	N	O	O	O	U	O	O	O	O
Mule deer	O	O	O	N	O	O	O	U	O	O	O	O
Elk	O	O	O	N	O	O	O	U	O	O	O	O
Moose	O	O	O	N	O	O	O	U	O	O	O	O
Pronghorn	O	O	O	N	O	O	O	U	O	?	O	U
Bighorn sheep	O	O	O	N	O	O	O	U	O	?	O	U
Mountain goat	O	O	O	N	O	O	O	U	O	?	O	U
Black bear	O	O	U	N	O	O	U	O	U	U	U	O
Grizzly bear	O	O	O	N	O	O	O	U	O	O	O	O
Mountain lion	U	O	U	N	U	O	U	O	U	U	U	O
Canada lynx	U	O	U	N	U	O	U	?	?	?	?	?
Gray wolf	U	O	O	N	U	O	O	U	O	O	O	O
Bald eagle	N	n/a	N	n/a	N	n/a	N	n/a	N	n/a	N	n/a
Bull trout	n/a	n/a	n/a	n/a	n/a	n/a	n/a	U	n/a	n/a	n/a	U
Species groups												
Amphibians	N	N	U	N	N	N	U	U	U	U	U	U
Reptiles	N	N	U	N	N	N	U	U	U	U	U	U
Birds	N	n/a	N	n/a	N	n/a	N	n/a	N	n/a	N	n/a

Species	Animal detection system (ADS)		Fence (incl. dig barrier)		Fence with gap and ADS		Fence with under-passes		Fence with over-passes		Fence with under- and over-passes	
	Collisions	Crossings	Collisions	Crossings	Collisions	Crossings	Collisions	Crossings	Collisions	Crossings	Collisions	Crossings
SM-M mammals	N	N	U	N	N	N	U	U	U	U	U	U
Points	21	24	24	0	21	24	24	17	23	17	23	23
Points combined	45		24		45		41		40		46	

KEY

L or T&E species: Large or Threatened and Endangered species in Montana.

SM-M mammals: Small-Medium sized mammals

O = optimal, U = usable, potentially with adaptations, N = not suitable, ? = unknown, n/a = not applicable

Points: O = 2 points, U = 1 point, rest = 0 points

8. CONCLUSION

The mitigation measures reviewed in this report are summarized in Table 4. Each measure is classified with regard to its effectiveness in reducing wildlife-vehicle collisions (specifically deer-vehicle collisions), whether the estimate is stable, whether the measure addresses wildlife-vehicle collisions and/or the barrier effect of the transportation corridor, and the monetary balance (benefits minus costs). In addition, the table lists the mitigation measures for which the authors of this report recommend implementation and/or further study.

Animal detection systems (with or without wildlife fencing) and wildlife fencing (with or without underpasses and/or overpasses) are estimated to be the most effective mitigation measures to reduce collisions with large wildlife species (e.g., deer) (>80% reduction) (Table 4). Of these mitigation measures, animal detection systems with wildlife fencing, wildlife fencing with underpasses, and wildlife fencing with a combination of underpasses and overpasses appear the most attractive from a monetary perspective (Table 4). Long bridges and long tunnels (e.g., over a road length of at least several hundreds of meters) have a strongly negative monetary balance, and will therefore not often be constructed because of wildlife-vehicle collision concerns alone. Nonetheless, should they be required for other reasons (e.g., the nature of the terrain), wildlife-vehicle collisions may be eliminated and the barrier effect of the transportation corridor is likely to be greatly reduced.

While animal detection systems do not necessarily reduce the barrier effect of the transportation corridor (except for direct mortality), wildlife fencing with underpasses, or underpasses, and overpasses, physically separate the animals from traffic and provide natural substrate (e.g., sand) and cover. This is likely to reduce the barrier effect of the transportation corridor for species that may avoid open areas, unnatural substrate (e.g., asphalt) and the disturbance associated with the road and traffic. On the other hand, the wildlife fencing increases the barrier effect of the transportation corridor, and not all species or individuals may be funneled towards the crossing structures, especially if they are relatively far apart. Nonetheless, wildlife fencing with underpasses or a combination of underpasses and overpasses may reduce the barrier effect of the transportation corridor for at least some species (Table 4). In addition, animal detection systems are a relatively new mitigation measure and only limited, though encouraging, data are available on their effectiveness. If wildlife-vehicle collisions must be substantially reduced, e.g., by 80% or more, then fencing and wildlife crossings structures are more appropriate than the use of animal detection systems as the effectiveness estimate for animal detection systems may change if more data become available.

Based on the suitability of wildlife underpasses and overpasses for large, or threatened and endangered species in Montana (Chapter 7), the implementation of wildlife fencing in combination with underpasses and overpasses has the preference over the implementation of wildlife fencing with only underpasses or wildlife fencing with only overpasses.

Data on effectiveness of several other mitigation measures are lacking or insufficient to justify a wildlife-vehicle reduction estimate. Nonetheless, the authors of this report suggest implementing some of these measures, at least under certain conditions (Table 4). For example, public education may not reduce wildlife-vehicle collisions, or at least not substantially, but the public may appreciate being informed about the extent of the wildlife-vehicle collision problem and the efforts that are undertaken to reduce the problem at specific locations. However, public education as a stand alone mitigation measure is unlikely to result in a substantial reduction of wildlife-vehicle collisions. Similarly, reducing road salt or using alternatives to road salt may not substantially reduce wildlife-vehicle collisions, but implementation is likely to benefit aquatic habitat. Aversion techniques or hazing may be the only option on certain locations if no alternatives are available. However, in general it should be regarded as a temporary measure rather than a structural measure. Changing the species composition or reducing the digestive quality of the vegetation in the right-of-way may not substantially reduce animal-vehicle collisions either, but it may reduce the time grazers, especially deer, spent in the right-of-way, and therefore their exposure to traffic.

Some other measures appear promising and worthy of (further) study because of intuitive potential benefit, available data appear encouraging, or because the measure may only be applicable for specific situations (Table 4). These measures, however, lack a wildlife-vehicle collision reduction estimate at this time. Measures that fall into this category are traffic volume and speed reduction, wildlife crossing guards, non-standard and seasonal wildlife warning signs, animal detection systems (with or without wildlife fencing), on-board animal detection systems, roadway lighting, vegetation removal, culling, reducing habitat quality, boulders in right-of-way, and fencing in combination with a signed gap in the fence or a crosswalk.

Table 4: Summary evaluation of mitigation measures

Mitigation measure	% DVC reduction	% DVC Stability	Addresses C	Addresses B	Balance ($)	Suggestion
Reduce traffic volume	?	n/a	+	+	?	Study
Reduce traffic speed	?	n/a	+	0/+	?	Study
Wildlife crossing guards	?	n/a	+	–/+	?	Study[1]
Standard wildlife warning signs	0%	Stable	+	0	–	X
Non-standard wildlife warning signs	?	n/a	+	0	?	Study
Seasonal wildlife warning signs	26%	Instable	+	0	++	Study[2]
Animal detection systems (ADS)	82%	Instable	+	0	+	Study
ADS linked to on-board computer	82%	Instable	+	0	?	Study
On-board animal detectors	?	n/a	+	0	?	Study
Roadway lighting	?	n/a	+	–	?	Study[3]
Vegetation removal	38%	Instable	+	–	++	Study
Public information and education	?	n/a	+	0	?	Implement[4]
Deer reflectors and mirrors	0%	Instable	+	–	–	X
Deer whistles	0%	Instable	+	–	?	X
Audio and visual signals in ROW	?	n/a	+	–	?	X
Olfactory or chemical repellants	?	n/a	+	–	?	X
Deer flagging	?	n/a	+	–	?	X
Aversion techniques or hazing	?	n/a	+	–	?	Implement[5]
Reduce /alternatives to road salt	?	n/a	+	0	?	Implement[6]
Intercept feeding	?	n/a	+	0	?	X
ROW vegetation (species, quality)	?	n/a	+	0	?	Implement[7]
Carcass removal	?	n/a	+	0	?	Implement[8]
Culling	50%	Instable	+	–	++	Study[9]

Mitigation measure	% DVC reduction	% DVC Stability	Addresses C	Addresses B	Balance ($)	Suggestion
Relocation	50%	Instable	+	–	+	X
Anti-fertility treatment	50%	Instable	+	0	– – –	X
Reduce habitat quality	?	n/a	+	–	?	Study
Fence (incl. dig barrier)	87%	Stable	+	–	+++	Implement[10]
Boulders in right-of-way	?	n/a	+	–	?	Study
Long bridges	100%	Stable	+	+	– – –	Implement[11]
Long tunnels	100%	Stable	+	+	– – –	Implement[11]
Fence with gap and warning signs	0%	Instable	+	–	–	Study
Fence with gap and crosswalk	40%	Instable	+	–	++	Study
Fence with gap and ADS	82%	Instable	+	–	+++	Study
Fence with underpasses	87%	Stable	+	–/+	+++	Implement
Fence with overpasses	87%	Stable	+	–/+	+	Implement
Fence with under- and overpasses	87%	Stable	+	–/+	+++	Implement

KEY: DVC reduction: Deer-Vehicle Collision reduction. DVC stability: The stability of the DVC reduction percentage.

Addresses: C = DVCs, B = Barrier effect of transportation corridor. + = reduces the problem, 0 = does not address the problem, – = increases the problem

Balance: The financial balance, based on the assumptions and estimates, for the mitigation measure on a road section with 5 DVCs per km per year: + = (0 – 10,000), ++ = (10,000 – 20,000), +++ = (>20,000), – = (-10,000 – 0), – – = (-20,000 – -10,000), – – – = (< -20,000)

Suggestion: X = implementation or study not currently recommended. [1] Only suitable where wildlife and traffic are both abundant and where staff and/or volunteers are available (e.g., National Parks). [2] Only suitable where seasonal migration occurs (e.g., mule deer or pronghorn). [3] Only suitable for spot treatments in areas where increased disturbance from lighting is not an issue. [4] Only implement in combination with other mitigation measures that are known to reduce wildlife-vehicle collisions substantially. [5] Only implement at specific locations, e.g., at fence ends, if no alternatives are available. [6] Alternatives may reduce road mortality of some species, but a substantial reduction may only be obtained in combination with other measures. [7] Implement when the right-of-way vegetation has to be sown or re-sown. [8] Carcass removal may reduce road mortality of scavengers, but not ungulates. [9] Only in selected areas (e.g., urban, suburban setting) where no alternatives may be available. [10] Only in selected areas (e.g., suburban or urban setting) where habitat connectivity may not be an issue. [11] Only if installed for other reasons (e.g., because of the nature of the terrain).

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