Literature Review Highway Wildlife Mitigation for Wisconsin, USA

Final Report

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16. Abstract

This literature review relates to the effectiveness of mitigation measures along highways in Wisconsin that are aimed at: 1. Improving human safety through reducing collisions with common large wild mammal species and species that are of conservation concern, and 2. Reducing the barrier effect of roads and traffic for common large wild mammal species and for species that are of conservation concern. We summarized the effectiveness of measures aimed at influencing driver behavior, influencing animal behavior or population size, and measures that aim to physically separate animals from roads and vehicles. We also distinguished between measures that are targeted at large wild mammals versus small animal species including amphibians, reptiles, and small mammals. If the objectives include both reducing collisions with large wild mammals and maintaining or improving connectivity for large wild mammals, and if ethics regarding associated impacts are considered, then there is only one approach that is highly effective: wildlife barriers (fences) in combination with wildlife crossing structures (underpasses and overpasses). For small animal species, fences in combination with wildlife crossing structures are similarly effective. However, temporary or permanent road closure and road removal are also sometimes implemented for small animal species. Since these measures limit the routes people can drive, these measures are usually very local and they mostly relate to short road sections that have, or had, very low traffic volume. Local measures are unlikely to benefit large mammal species that have large home ranges and that have populations that tend to occur over large areas. But small animal species may have very specialized habitat (e.g. a wetland) and small home ranges. Therefore, the small spatial scale of temporary or permanent road closure and road removal can be meaningful to small animal species. Nonetheless, the barrier effect of a road with open habitat and a non-natural substrate remains with temporary or permanent road closure. Only when road removal is combined with habitat restoration can the barrier effect disappear. Assisted road crossings for small animal species are somewhat comparable to wildlife crossing personnel for large mammals. This can reduce direct road mortality, but the barrier effect may or may not be addressed.

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1 Introduction

1.1 Scope of this literature review

The scope of this literature review is limited to mitigation measures aimed at:

- Improving human safety through reducing collisions with large wild mammal species that are common in Wisconsin.
- Improving biological conservation through reducing direct road mortality of Species of Greatest Conservation Need (SGCN) in Wisconsin.
- Reducing the barrier effect of roads and traffic for large mammal species that are common in Wisconsin and for Species of Greatest Conservation Need (SGCN) in Wisconsin.

The measures are evaluated for two parameters:

- Effectiveness in reducing collisions or direct road mortality
- Effectiveness in reducing the barrier effect of roads and traffic.

2 Large wild mammals

2.1 Introduction

This chapter focuses on measures to reduce collisions with large wild mammals (larger than a coyote (*Canis latrans*)) in Wisconsin. The most frequently recorded large mammal species in the crash data is white-tailed deer (*Odocoileus virginianus*) (96.09% of all reported crashes with an animal), followed by American black bear (*Ursus americanus*) (0.76%) (Huijser & Bell, 2025). Therefore, the selected measures for this review will mostly focus on these two species.

The mitigation measures were grouped into measures that seek to influence driver behavior, those that seek to influence animal presence or behavior around roads, and those that seek to physically separate animals from vehicles. The authors summarized the effectiveness of the measures in reducing collisions with large wild mammal species and evaluated whether these measures maintain or improve habitat connectivity for large wild mammals or have negative side effects on large wild mammals. While a reduction in collisions would mean that more animals reach the other side of the road successfully, the authors of this report did not consider this to reduce the barrier effect of the transportation corridor. To reduce the barrier effect, the measure needs to "make it more attractive or easier for animals to successfully cross to the other side of the road". Lastly, when available, costs or relative costs of implementing the measure were documented.

Note that the identification and prioritization process for road sections that may qualify for mitigation measures influence the outcome. For example, road sections that have a high number of collisions with large and common wild mammals (e.g. white-tailed deer, elk (*Cervus canadensis*), American black bear) may be different from road sections where habitat connectivity is critical to the long-term presence of rare species in the landscape which may not have a body size that is large enough to be a threat to human safety (e.g. threatened or endangered amphibians, reptiles, or small mammals).

In Wisconsin, most of the large wild mammal-vehicle collisions occur especially in the fall (October-November) (Huijser & Bell, 2025). White-tailed deer crashes had two distinct peaks, one in May-June, and another in October-November. The latter peak is associated with the rut. Black bear crashes were most frequent between April and November when they are most active. Large wild mammal-vehicle collisions predominantly occur in the dark, especially around dawn (4 am - 7 am) and in the evening hours (5 pm - 10 pm). White-tailed deer crashes follow a nearly identical pattern as animal crashes whereas black bear crashes were most frequent in the evening (7 pm - 11 pm). Interestingly, a peak in black bear crashes around dawn was absent.

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2.2 Mitigation measures aimed at influencing driver behavior

In this section we summarize mitigation measures that aim to reduce collisions with large wild mammals through influencing driver behavior.

2.2.1 Public information

Summary
The effectiveness of education and public information campaigns in reducing large wild mammal-vehicle collisions is not known and could potentially be zero. Public knowledge and education efforts do not reduce the barrier effect of roads and traffic on wildlife as the measures do not make it any easier for animals to cross the road.

Descriptive narrative
Public information and education campaigns aim to increase the driving public's awareness of animal-vehicle collisions and inform motorists how to avoid them or reduce their severity. Common methods to distribute information to the public are through media such as newspapers, mailed brochures, flyers, billboards, roadside kiosks, magazines; the internet, TV, and radio (e.g. Wildlife Collision Prevention Program, 2019). Measuring or estimating the number of motorists who receive the information and then, as a result, change their behavior based on the new information is difficult to quantify. However, some stress that it is important to target the right demographic, and it is essential to provide concrete suggestions, in this case safe driving tactics that can reduce the risk of a collision (Kioko et al., 2015; Rea et al., 2018; Riley & Marcoux, 2006). However, strong beliefs and desires are not easily changed via education, and as a result many people do not want to receive further education (Kioko et al., 2015; Ramp et al., 2016; Urbanek et al., 2015). Furthermore, the accumulation of knowledge does not always translate into changing habits; motorists do not always make the correct maneuver even when they know what to do and what not to do (Vanlaar et al., 2019). Other more direct methods are information given during license and registration renewal, or driver education classes. However, in contrast to all other crashes combined, crashes with wildlife are not higher for relatively young drivers (Huijser et al., 2008; Huijser & Bell, 2025). Apparently, gaining more experience in driving and becoming more mature as a driver does not reduce the likelihood of crashes with large wild mammals. This suggests that public information campaigns may not be effective either. This is likely because design speed, posted speed limit, and operating speed on most rural highways are too high for drivers, educated and experienced or not, to be able to avoid a collision in the dark (Huijser et al., 2017; Riginos et al., 2022).

Driving simulators allow researchers to implement a comparative study between different groups; a control group and one exposed to education programs aimed at avoiding hazards (Antonson et al., 2015). Teenagers who used a computer-based education tool scored higher on both a driver’s behavior scale and rural safety scale (Kumfer et al., 2017). They demonstrated better knowledge and awareness while driving and were quicker at identifying hazards and quicker to react. Hazard perception training may result in drivers recognizing hazards earlier, identifying the risk, and braking earlier (Beanland et al., 2013; Riley & Marcoux, 2006). Simulations were used to document the effectiveness of radio warning messages for collisions with wildlife. These messages caused the highest reduction in speed and were enhanced when coupled with wildlife warning signs (Jägerbrand & Antonson, 2016).

One method to identify if educational efforts are beneficial is through the distribution of surveys regarding animal-vehicle collisions and their causal factors. These surveys indicate that the general public's knowledge of the important factors association with collisions with deer is low (Riley & Marcoux, 2006). Most drivers involved in collisions with deer believe their collision could not have been prevented (Kioko et al., 2015; Riley & Marcoux, 2006). However, people that have had more exposure are more likely to think animal-vehicle collisions are not a serious issue (Ramp et al., 2016).

Potential undesirable side effects

There are no apparent undesirable side effects of public information or education campaigns or programs regarding animal-vehicle collisions.

Costs of the measure

- Radio ads $200 to $5,000 a week.
- TV ads $200 to $1500 locally for 30 seconds. $123,000 average for national broadcasts.
- 1000 mailed flyers about $236, at $0.05 a print and $0.186 postage rates (2018 USPS postage rates).
- Social media : free, or a relatively low fee.

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2.2.2 Standard, enhanced and seasonal warning signs

Summary

Standard and enhanced wildlife warning signs are generally not effective in reducing wildlife-vehicle collisions, unless they are time and location specific. Seasonal wildlife warning signs can reduce collisions with large wild mammals (9-50%), but data are sparse and variable. Warning signs do not reduce the barrier effect of roads and traffic.

Descriptive narrative

Standard wildlife warning signs are typically manufactured in the same style as other traffic warning signs, which is country dependent (Tryjanowskia et al., 2021). Most signs depict a symbol of a large mammal species that is common, widespread and large enough to be a safety concern for motorists (e.g. white-tailed deer in the United States). Enhanced wildlife warning signs tend to be larger than standard signs, they may have flashing lights or bright flags attached to them, and they may also include eye-catching or perhaps even disturbing illustrations, images of certain species that the warning relates to, collision statistics or other customized text (Huijser et al., 2015). These characteristics aim to capture the attention of motorists and educate them about the safety and the conservation impact of wildlife-vehicle collisions. Enhanced warning signs are more frequently observed and recalled by drivers than standard warning signs (Summala & Hietamaki, 1984). They are normally installed at road sections that have a relatively high number of collisions, or in areas where a species of conservation concern occurs. Temporal wildlife warning signs warn drivers of wildlife presence during specific times of the year or day. These signs tend to be species specific and may only be visible to drivers during the most hazardous time of the year or day (e.g. signs that fold in half and are removed in the off season, or variable message signs that are activated at certain times of the year or day (i.e., electronic signs with programmable text or symbols). Seasonal warning signs may be placed where roads intersect migration corridors (e.g. mule deer migration routes in the western United States) or where species are attracted to the highway during specific times of the year (e.g. bighorn sheep licking road salt in specific areas in the Rocky Mountains). If the warning relates to certain hours of the day, the signs may be permanent, but their message may be enhanced during the time of the day with peak wildlife activity (e.g. flashing lights around dusk and dawn) or the message may only be visible during the most hazardous hours of the day.

Standard and enhanced wildlife warning signs are typically considered effective if they result in a reduction in the number of collisions with large wild mammals. Other parameters may also be used to measure effectiveness, such as a reduction in vehicle speed or other driver responses such as touching the brakes or being more alert. While drivers may reduce vehicle speed in response to standard and enhanced signs (Pojar et al., 1975; Al-Ghamdi & AlGadhi, 2004; Rogers 2004; Sullivan et al., 2004; Poot & Clevenger, 2018), the majority of studies of the effectiveness of these sign types in reducing collisions concluded that they were not effective (e.g. Pojar et al., 1975; Coulson, 1982; Rogers, 2004; Meyer, 2006; Bullock et al., 2011; Shima et al., 2018). However, some have found standard warning signs to be effective (34% reduction in collisions) immediately after installation at recently identified hot spots (Found & Boyce, 2011), or in conjunction with a fake animal (a snake) on the road (Collinson et al., 2019). Data on the effectiveness of temporal signs suggests that they can be effective in reducing collisions. Temporal warning signs can reduce collisions, although effectiveness varies substantially (9–50%) (Sullivan et al., 2004; Colorado Department of Transportation, 2014). These patterns of when seasonal, enhanced or temporal signs are or can be effective seem to be associated with the signs being more precise in location and time. However, most standard or enhanced wildlife warning signs are applied over long road sections and are not necessarily only applied at the times with the highest risk (review in Huijser et al., 2015). Implementing standard or enhanced wildlife warning signs may still be required or desirable to limit liability concerns. However, because such warning signs are unlikely to be effective in reducing collisions, their implementation should also not reduce liability. Furthermore, while standard and enhanced signs have some educational value, one could also argue that drivers may wrongfully think that these signs reduce collisions, and therefore the public may not support effective mitigation measures that are more expensive.

The primary goal of wildlife warning signs is to improve human safety by reducing the rate and severity of wildlife-vehicle collisions. The concern is not explicitly nor primarily with providing safe and effective crossing opportunities for wildlife because:

- Wildlife warning signs do not make it any more attractive for wildlife to approach and cross the road; 2. Warning signs do not change the fact that roads are linear open areas without cover with an unnatural substrate (usually asphalt or concrete) and traffic;
- Wildlife warning signs do not reduce the traffic volume and animals still have to avoid vehicles while crossing the road; and
- Wildlife warning signs should be located at wildlife-vehicle collision hotspots, not where wildlife crosses the road successfully or locations that need improved connectivity to enhance population viability.

Depending on the type of sign, drivers may be more attentive and may (slightly) reduce their speed. This may increase the rate of successful road crossings for some wildlife. However, in some situations, drivers feel that evasive maneuvers would be too dangerous to them or other humans, and they may choose to hit the animal. Other drivers aim to hit and kill certain species, especially species that are small in body size and that are unlikely to result in vehicle damage (e.g. most reptile species including snakes), and they may use the information provided by the warning signs to be more alert and try and hit the animals (Ashley et al., 2007). In conclusion, wildlife warning signs do not reduce the barrier effect of a transportation corridor.

Potential undesirable side effects

Signs can cause distraction and this can lead to other crashes as drivers pay less attention to the road and other vehicles (Wolfe et al., 2019; Hinton et al, 2024). This is especially true for enhanced wildlife warning signs that are designed to attract attention of the drivers, and this may be a reason to avoid implementing signs that are designed to attract more attention from drivers than “standard” wildlife warning signs. Signs that are relatively unique depicting unusual species are also frequently stolen (Gunson & Schueler, 2012). Furthermore, warning signs for certain species may also make poachers more aware of where they should target their efforts.

Costs of the measure

The purchase costs for seasonal wildlife warning signs were estimated at US$ 400 for a large sign, and US$ 80 for two flashing lights (Sullivan et al., 2004).

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2.2.3 Roadside animal detection systems

Summary
Animal detection systems use electronic sensors installed along the roadside to detect large animals (i.e., typically deer size and larger) that approach the road or that are on the road. Once an animal has been detected, signs are activated to warn drivers of the presence of the animal. These signs are very specific in time and place. Animal detection systems can reduce wildlife-vehicle collisions with large mammals by 33-97% provided that the sensors detect the target species reliably. However, animal detection systems should still be considered experimental, and implementation should be regarded as a high-risk project as many projects fail because of technological, management, financial, or maintenance issues. Most animal detection systems are more difficult to develop for small or medium sized animal species because they are more challenging to detect reliably. Similar to standard, enhanced and seasonal warning signs, animal detection systems do not address the barrier effect of a highway and associated traffic.

Descriptive narrative
Animal detection systems use electronic sensors installed along the roadside to detect large animals (i.e., typically deer size and larger) that approach the road or that are on the road. Once an animal has been detected, signs are activated to warn drivers of the presence of the animal (Huijser et al., 2015). These signs are very specific in time and place. However, animal detection systems are more difficult to develop for small or medium sized animal species because they are more challenging to detect reliably. The effectiveness of animal detection systems is variable, but they can reduce wildlife-vehicle collisions with large mammals by 33-97% provided that the sensors detect the target species reliably (Mosler-Berger & Romer, 2003; Huijser et al., 2006; Dai et al., 2009; Gagnon et al., 2010; 2019; Strein, 2010; Minnesota Department of Transportation, 2011; Sharafsaleh et al., 2012; Meena & Loganathan 2020; Bhardwaj et al., 2022). Note that animal detection systems can be implemented as a stand-alone measure or in combination with wildlife fences (at a fence gap or a fence-end) (Huijser & McGowen, 2003; Gagnon et al., 2010; 2019; Huijser et al., 2015; Bhardwaj et al., 2022). Since the risk of severe crashes increases exponentially with increasing vehicle speed (Kloeden et al., 1997), it is useful to also evaluate the potential effect of activated warning signs associated with animal detection systems on vehicle speed. Drivers tend to reduce their speed somewhat (<5 km/h) (Kistler, 1998; Muurinen & Ristola, 1999; Hammond & Wade, 2004; Huijser et al., 2006; Huijser et al., 2017; Grace et al., 2017) or more substantially (≥5-22 km/h) in response to activated signs of animal detection systems (Kistler, 1998; Kinley et al., 2003; Gordon et al., 2004; Gagnon et al., 2010; 2019; Sharafsaleh et al., 2012; Huijser et al., 2017). The greatest reductions in vehicle speed seem to occur when the signs are associated with advisory or mandatory speed limit reductions or if road conditions and visibility for drivers are poor (Kistler, 1998; Muurinen & Ristola, 1999; Huijser et al., 2017). Finally, the design of the warning signs influences the effectiveness of the system in reducing collisions with wildlife (Grace et al., 2015).

Actual and perceived reliability can differ as drivers may rarely see animals on or along the road when the warning signs are activated (Sharafsaleh et al., 2012), or they may see animals in the proximity of the road with the warning signs turned off as the animals are beyond the range of the sensors. Regardless, to inform the driver adequately, it is important that the warning signs are relatively close together. A driver should not pass a warning sign without being able to see and interpret the next warning sign should it be activated. This may require a modification of the guidelines for sign placement which tend to be based on static signs rather than signs that display no message at all unless a danger has been detected. Some animal detection systems have a portion of the warning signs visible all the time with an additional flashing light that is activated after a detection has occurred. However, it is best if no message is displayed at all, unless an animal has been detected to minimize the likelihood that drivers ignore activated signs and to avoid oversaturating the roadside with signs. Additional standard warning signs spaced at relatively great distances can then still address potential liability issues in case of false negatives (i.e., an animal is present, but it was not detected). Finally, the Animal detection systems should still be considered experimental, and implementation should be regarded as a high-risk project as many projects fail because of technological, management, financial, or maintenance issues (Huijser & McGowen, 2003; Huijser et al., 2006; 2009a; 2009b; 2017; Sharafsaleh et al., 2012, Huijser et al., 2017). Detection systems are experimental regarding the level of certainty that a system will be operating as desired by a particular date - especially in detecting the target species with sufficient reliability - and a relatively wide and variable range of effectiveness in reducing wildlife-vehicle collisions. The latter is probably associated with the different types of detection technologies and the great variability in the signs presented to drivers. Note that animal detection systems do not address the barrier effect of a highway and associated traffic.

Potential undesirable side effects

Since many animal detection system projects suffer from technological, management, financial, or maintenance issues, and because there can be a disconnect between perceived and actual reliability of the system by the public, animal detection systems are often viewed negatively by the public. Further, there are potential issues with liability if a system fails to detect a large mammal, or if sudden braking in response to an activated warning sign results in a rear-end collision. The latter means that the application of animal detection systems is perhaps not suited for high-volume roads (Huijser et al., 2015). In addition, activated warning signs may also make poachers more aware of where and when they should target their efforts.

Costs of the measure

Highly variable (e.g. $65,000-$333,000 per mile road length), depending on the technology topography, curvature, and access roads (Huijser et al., 2009c; Pers. comm. Deb Wambach, Montana Department of Transportation).

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2.2.4 On-board vehicle animal detection and warning systems

Summary
The effectiveness of on-board animal detection and warning systems in reducing large wild mammal-vehicle collisions is unknown. Similar to roadside animal detection systems, on-board animal detection systems do not address the barrier effect of a highway and associated traffic.

Descriptive narrative
Driver assistance hardware and software and autonomous vehicles are rapidly being developed, introduced, and improved (Hecht, 2018; Abdel-Aty & Ding, 2024). This technology aims to reduce the probability of crashes with large animal species by detecting a large mammal in or near the path of a vehicle, with or without a human operating the vehicle (i.e., both traditional cars with the driver operating the vehicle and (partially) automated vehicles with automatic emergency braking). These sensors have already been incorporated into commercially produced vehicles, and they can also be used as an after-market product for older vehicles. In addition to sensors integrated into vehicles, high-risk road sections and high-risk times-of-day may also be identified through crash and carcass data collected by road maintenance personnel, law enforcement personnel, or the public through a citizen science program. Such information may be based on historical data (e.g., accumulated in recent years), but it can also be based on real-time observations using mobile devices and Global Positioning Systems (GPS) coordinates for observations of dead or alive animals on or near the road. Such route planners can also suggest alternative routes that have lower risk for collisions with large mammals.

Regardless of the level of human control of the vehicle, sensors and driver warning systems in vehicles are developed and implemented to address a wide range of potential collision situations e.g., rear-end crashes, crashes with pedestrians and bicyclists. Some of the sensors and driver warning systems are also aimed at reducing collisions with large mammals. There are five types of sensors used by the auto industry: long-range radar, short/medium-range radar, ultrasound, optical cameras and lidar (Hecht, 2018). Lidar is used to identify moving wildlife and pedestrians. Different types of sensor technology have different uses and varying capabilities under different environmental conditions (Xique et al., 2018). Thus, having multiple sensor types and redundant warning systems can increase reliability under varying environmental and traffic conditions (Dennis et al., 2018).

There are several driver assistance systems available commercially for vehicles in the United States that focus on large animals. A Swedish company has developed Autoliv which is a vehicle mounted night vision animal detection system used by several car manufacturers, including Audi, BMW, Mercedes and Daimler (Foslund & Bjarkefur, 2014). The infrared-based system is designed to identify animals, partially obscured or not, at all angles. It has a very low level of false positives - one such event per year (Foslund & Bjarkefur, 2014). Volvo has developed a radar-based system to detect large animals, so that it can operate effectively both day and night (Adams, 2017).

Another type of vehicle-based driver warning system uses crowd-sourced data sent to a driver's mobile device in a vehicle. Waze, the app for mobile devices allows users to report dead or live animals along the road. Based on thousands of these reports, Waze creates a map of the most dangerous road segments for collisions with large mammals (Cohen, 2017). Other applications that use crowd sourcing include Google Maps and Apple Maps. Such route planners can also suggest alternative routes that have lower risk for collisions with large mammals.

Commercial applications for on-board driver warning systems for large mammals continue to be developed and improved, increasing the reliability of these systems in detecting large animals on or near roads. Most of the scientific journal articles and white papers on this topic are restricted to evaluating the technological capabilities and the reliability of the sensors and warning systems. Unfortunately, studies that evaluate the effectiveness in reducing collisions with large mammals are lacking.

Potential undesirable side effects

The public may feel that collision reduction with large mammals through vehicle-based detection systems protects them against crashes with large mammals. However, topography, tall vegetation in the right-of-way, and curves can all reduce the effective range of the sensors. In addition, not all animals are on or immediately adjacent to the road already when vehicles approach. Animals can also approach the road quickly and are not necessarily detected at the far end of the range of the sensors that typically can only cover the road ahead and a narrow strip adjacent to the pavement. Narrow rights-of-way, topography, curvature, and vegetation can severely limit the range of the sensors off to the side of vehicles. The limited detection range to the side of a road can suppress the effectiveness of on-board vehicle detection systems and lead to an erosion of confidence in the reliability and effectiveness of these systems. Collision avoidance systems in general allow vehicles to have smaller gaps between them. This increases the capacity of a road. Reduced gap times between vehicles and increased traffic volume can further increase the barrier effect of a road for wildlife.

Costs of the measure

The price of vehicle-based animal detection systems is unknown as they have been incorporated into the overall cost of the vehicle. The initiative for this measure and the scale of implementation lies with car manufacturers and consumers, and the cost is for the purchaser of the vehicle. The cost for crowd sourcing applications for mobile devices, such as Waze, Google Map and Apple Map is usually zero. The normal cost of the mobile device, such as cellular phone or computer tablet, that uses the crowd sourcing application can vary from a couple hundred to over a thousand dollars per unit.

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2.2.5 Increase visibility: Roadway lighting

Summary
Roadway lighting may reduce collisions with large wild mammals by 57-68%, but these reductions can not only result from of increased visibility of the animals to drivers but also because animals avoid the roadway lighting. Highway lighting can increase the barrier effect of roads and traffic for light-repelled species and cause disorientation to migrating birds.

Descriptive narrative
Roadway lighting is the installation of lights, typically on poles, along the road network to increase visibility for motorists. During the dark hours, the lights allow drivers to identify hazards at greater distance, giving them more time to avoid a crash. The amount of illumination provided by each lighting unit is a function of the strength of the bulb, the light reflector, and the height of the pole. The type of light source (e.g., LED lights vs high pressure sodium lights), the color (e.g. amber, white, green, or red), and the area that is lighted all influence visibility for drivers and have a wide variety of effects on different species groups. Lighting can be considered in high-risk areas to reduce collisions with large animal species, but the lights can also increase the barrier effect of the road and traffic for some animal species and therefore increase habitat fragmentation (e.g., Frank et al., 2023). In addition, other species may be attracted to the lights and experience higher risk of collisions. In general, lights should not be installed at or near wildlife crossing structures (i.e., underpasses or overpasses) or in areas where wildlife connectivity is an objective. Lighting at-grade crossing opportunities at a gap in a wildlife fence can be considered, but such at-grade crossing opportunities do not reduce the barrier effect of roads and traffic to begin with; they are mostly intended to reduce wildlife-vehicle collisions while still allowing, at least in theory, wildlife to cross at a select few locations where a gap in the fence is provided.

Roadway lighting may reduce collisions with large wild mammals by 57-68% (McDonald, 1991; Riley & Marcoux, 2006; Wanvik 2009), but the reductions in large mammal-vehicle collisions along lighted roadways cannot only be associated with increased visibility of the animals to drivers but also with animals avoiding the roadway lighting (Frank et al., 2023). In one study, vehicle speed did not change with lighting, but when deer decoys were present, drivers significantly decreased their speed (Reed & Woodard, 1981). Highway lighting increases a motorist's sight distance on the road and along the roadside, allowing them to better identify hazards, respond to them in time, and avoid a collision. Limited forward vision and associated time to respond to animals on or near the road results in elevated risk of animal-vehicle collisions (Sullivan, 2009). Many vehicle headlights do not allow drivers to see large mammals on the road in the dark early enough to be able to stop before hitting the animal when traveling at highway speeds (Mastro et al., 2010; Huijser et al., 2017). In addition to this, not all animals are already on the roadway travel lanes when the vehicle approaches. The animals may still be off the pavement adjacent to the road and they may run towards the road when the vehicle is already very close to the animal. Highway lighting only increases the distance at which drivers can detect hazards on or near the roadway, not off to the sides of a road. If installed, lighting should be placed appropriately along highways (AASHTO, 2018; Fors & Carlson, 2015).

One experimental study found that the installation of highway lighting did not change the locations where deer cross the road (Reed & Woodard, 1981), but it is unclear if reductions in large mammal-vehicle collisions along lighted roadways are related to increased visibility of the animals to drivers or to animals avoiding the roadway lighting (McDonald, 1991; Riley & Marcoux, 2006). Highway lighting may increase the barrier effect of roads and traffic for light-repelled species (Gaston et al., 2014; Langen et al., 2015;

Spoelstra et al., 2015; Frank et al., 2023)). The placement of lighting can be considered at at-grade crossings (e.g. gaps in a wildlife fence) and does not reduce the barrier effect of the road and traffic. On the contrary, lighting may increase the barrier effect of the road corridor for some species. While the purpose of roadway lighting is to reduce collisions, not to maintain or increase habitat connectivity, increasing the barrier effect of the road corridor is something that should generally be avoided. Only lighting the highway or an at-grade crossing opportunity when vehicles approach can reduce the negative impacts of lights on wildlife, especially when traffic volume is low. Restricting the lighted areas to those that need to be lit for the drivers to see the animals also reduces the impact of light on wildlife. For example, only the road and the area immediately adjacent to the pavement may need to be lit; the lights can be directed to not light the areas further away from the road or the sky.

Potential undesirable side effects

The physical effects of lighting are light spill, sky glow, and glare, and can impact the natural environment and motorists both on and off the roadway (Lutkevich et al., 2012). Artificial lighting can have a variety of effects on invertebrates, amphibians, birds, small terrestrial mammals, and bats, but the effect can depend on the light color (Rotics et al., 2011; Berthinussen & Altringham, 2012; Langen et al., 2015; Spoelstra et al., 2015; 2017; van Grunsven et al., 2017; van Langevelde et al., 2017). In addition, some species may be attracted to lights and experience higher risk of collisions with vehicles. Highway lighting can attract insects which can cause direct mortality. Alive and dead insects along the roadway can attract other scavengers which also may die from getting hit by vehicles (Langen et al., 2015; Muñoz et al., 2015). Streetlights have recently been shown to change the community composition of ground-dwelling invertebrates such as ants and beetles, which can in turn influence food web dynamics (Davies et al., 2012). These adverse effects can create hazardous conditions. Light-distracted species may suffer mortality due to distractions from normal behavior such as feeding or foraging (Gaston & Bennie, 2014). Since artificial lighting of roadways can negatively affect animal physiology, behavior and predation rates, the use of artificial lighting to reduce collisions with large wild mammals may require its own set of mitigation measures to reduce its negative effects on wildlife (Blackwell et al., 2015).

Costs of the measure

The cost of highway lighting is not only a function of pole size, reflectors and bulbs, but also influenced by the location and the proximity of the electric grid. Rural roads may have poor access to utilities which increases the cost of construction. The average cost of a streetlight pole including installation is about $4,000 per light (MKLights, 2025). The price increases rapidly when the length of the road being lit increases and with the need for associated utility, installation and maintenance costs.

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2.2.6 Increase visibility: Vegetation management

Summary
Shrubs, trees, and unmown grasses and herbs along highways may be associated with higher numbers of large mammal-vehicle collisions as the animals are less visible to drivers. Clearing brush and other vegetation may reduce these collisions to 50%. However, other studies found that vegetation management was not effective at all or that it could even attract ungulates to the right-of-way vegetation because of regrowth. Vegetation mowing and clearing can both positively and negatively affect the habitat for various species in the right-of-way. It can also increase the barrier effect of roads and traffic, especially for species that depend on cover.

Descriptive narrative
Management of roadside vegetation by clearing shrubs and mowing grasses and forbs can increase the visibility of animals along highways, allowing drivers more time to react to their presence. Shrubs, trees, and unmown grass along highways can result in more collisions with large wild mammals as the animals are less visible to drivers. Clearing brush and other vegetation may reduce these types of collisions up to 50% (Hegland & Hamre, 2018), but it may also not be effective at all (Lindstrøm, 2016). The area immediately adjacent to the pavement, the "clear zone", must remain clear of obstacles including trees and shrubs. This allows drivers that have run off the pavement with their vehicle to regain control before hitting a large object. However, much of the vegetation beyond the clear zone to the edge of the right-of-way, is not cut or mown on a regular basis. This area can be the focus of active vegetation management with the aim of improving visibility of large mammals and reducing collisions with large wild mammals. However, there are mixed results on the effectiveness of this measure in reducing collisions with large wild mammals, and it may also increase the barrier effect of the road and traffic to wildlife. Vegetation mowing and clearing can both positively and negatively affect the habitat for various species in the right-of-way (Huijser & Clevenger, 2006; Silva et al., 2019). It can also increase the barrier effect of roads and traffic for species that depend on cover (Donald & Cassady St Clair, 2004; Huijser & Clevenger, 2006; Lewis et al., 2011; Ascensão et al., 2016; Kite et al., 2016).

Research on the effectiveness of vegetation clearing has shown varying results. In one study in Norway, roadside vegetation reduction had no effect on moose or roe deer collisions (Lindstrøm 2016). Other studies found that roadside vegetation clearance decreased large wild mammal-vehicle collisions. Collisions with red deer (*Cervus elaphus*, closely related to elk), were reduced by 53% (Meisingset et al., 2014), but only in winter. Roadside clearing reduced collisions with moose (Lavsund & Sandegren, 1991; Seiler, 2005). When open land on road verges increased from 60 percent to 100 percent, collisions with red deer were 50% lower in Norway (Hegland & Hamre, 2018). Decreasing the mowing rates or vegetation clearing in highway rights-of-way in Maryland and New York did not result in a detectable increase in collisions with deer (Barnum & Alt, 2013). Similarly, there was no increase in collisions with wildlife after planting 950,000 wildlife friendly shrubs and trees along 4-lane highways in Indiana (Roach & Kilpatrick, 1985). In addition, cover or vegetation clearing adjacent to the road did not affect the probability of collisions with moose (Rea et al., 2018). It appears changes in the landscape beyond the right-of-way, and the timing and frequency of mowing or cutting and potential regrowth contribute to varying effectiveness in collision reduction (Guyton et al., 2014; Rea et al., 2010; Rea et al., 2014; Canal et al., 2019). In addition, increasing grass-herb vegetation in a forested environment could also attract large herbivores to the right-of-way rather than reduce their numbers and presence along the transportation corridor (review in Huijser & Clevenger, 2006). The use of less palatable species (e.g., avoid clover) when seeding or planting in the right-of-way can also help reduce the attraction of the right-of-way vegetation to herbivores (Rea, 2003; Guyton et al., 2014).

Potential undesirable side effects

Cutting and mowing may increase the nutritional value of vegetation for foraging by ungulates. The regrowth and new sprouts of the vegetation after cutting can be an attractant to ungulates, although it depends on the timing of the cutting (Rea, 2003; Guyton et al., 2014). However, in Newfoundland, vegetation cutting reduced the attractiveness of the vegetation to moose (Tanner & Leroux, 2015). Reducing cover can also increase the barrier effect of roads and traffic for species that depend on cover (Donald & Cassady St Clair, 2004; Huijser & Clevenger, 2006; Lewis et al., 2011; Ascensão et al., 2016; Kite et al., 2016; Galantinho et al., 2020).

Costs of the measure

Mowing roadsides cost $30 USD per acre for the Illinois Department of Transportation in 1997 (Caylor, 1998). It costs the Idaho Transportation Department $204/acre to mow its roadsides or $55.76 per person hour in 2018 (pers. comm., Cathy Ford, Roadside Program Administrator, Idaho Transportation Department). Roadside brush cutting cost the Idaho Transportation Department $24.08/person hour in 2018 (pers. comm., Cathy Ford, Roadside Program Administrator, Idaho Transportation Department).

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2.2.7 Increase visibility: Widen road striping

Summary

Wider reflective highway striping may make an animal more visible to drivers, and narrower lanes, obtained through wider striping, could result in lower operating speed of a vehicle because the driver may perceive the design speed of a highway to be lower than it really is. However, the effect of wider striping and narrower lanes on potentially reducing collisions with wild large mammals is not known. Wider striping and narrower lanes do not reduce the barrier effect on wildlife.

Descriptive narrative

In theory, if reflective highway striping is made wider, then an animal's presence on the road may be more noticeable; its body would block part of the striping and the break in the reflective striping could alert the driver, even if the animal itself is difficult to see in the dark. If a driver detects the animal earlier, the driver may be able to avoid a crash. In addition, if the width of the pavement remains the same, wider striping results in narrower lanes and makes drivers perceive the road to be narrower than it really is. This can result in lower vehicle speeds (Godley et al., 2004; see other section in this report on traffic calming and reducing design speed). Wider lines on the edges also reduce overall crashes (USDOT, 2025). The effectiveness of widening roadway striping on reducing collisions with large wild mammals is unknown (Huijser et al., 2008), but the measures does not reduce the barrier effect.

Potential undesirable side effects

Depending on the paint, wider stripes can be more slippery, especially for motorcyclists under wet conditions and when they turn or brake (WISDOT, 2010; Rodin et al., 2018).

Costs of the measure

Unknown, but wider stripes require more paint and associated costs for logistics.

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2.2.8 Reduce traffic volume on road network

Summary
The effect of traffic volume on collisions with large wild mammals is mixed. However, the occurrence of collisions is highest on low volume two lane roads. Wider roads (e.g. four lanes or wider) with higher traffic volume may be more of a barrier to animals, and therefore generally have fewer reported collisions. Therefore, the relationship between traffic volume and collisions with large wild animals is not necessarily linear. While reducing traffic volume from an intermediate level to a lower level can reduce collisions, reducing traffic volume from a high level to a lower level can increase rather than decrease collisions.

Descriptive narrative
Reducing traffic volume results in longer gaps between vehicles, allowing wildlife to more easily cross the road. However, the relationship between traffic volume and collisions with large wild mammals is not necessarily linear. While reducing traffic volume from an intermediate level to a lower level can reduce collisions, reducing traffic volume from a high level to a lower level can increase rather than decrease collisions.

For the range of traffic volumes studied, increases in traffic volume were positively correlated with wildlife road mortality rates for all taxonomic groups (Bennett, 2017) and for terrestrial mammals in specific (Shilling et al., 2021). Overall, most collisions with large mammals occur on relatively low traffic volume roads (e.g., 1,000-9,000 AADT) (Huijser & Bell, 2025). However, corrected for the length of roads that have different traffic volume categories, roads with less than 5,000 AADT have fewer collisions with large wild mammals than roads over 5,000 AADT (Huijser & Bell, 2025). Other research suggests that the effects of traffic volume are variable, coincide with high ungulate activity around dusk and dawn, or are non-existent (Bissonette & Kassar, 2008; Steiner et al., 2014; Bíl, et al., 2020; Huijser & Bell, 2025). In some cases, reduced traffic volume can result in an increase in collisions, presumably through increased wildlife presence on the road (Abraham & Mumma, 2021). There is substantial evidence that the effects of traffic volume on collisions are species specific (Ree et al., 2011; Jacobson et al., 2016). Each species has a different response to traffic volume and perceives threats at different levels. The type of response to traffic influences the likelihood of an animal being on the road to begin with and what it does when traffic approaches. While lowering traffic volume on an individual road can reduce collisions, it is not good practice to build multiple low traffic volume roads rather than one high traffic volume road that is properly mitigated. A properly mitigated high volume road, e.g., equipped with wildlife fences and underpasses and overpasses, is better than several parallel low volume roads that result in more habitat loss and higher levels of habitat degradation and fragmentation (Rhodes et al., 2014).

As traffic volume increases, gaps between vehicles decrease, making it harder for animals to cross the road (e.g. Waller & Servheen, 2005). This is in addition to the disturbance in a zone adjacent to the road that may keep animals from approaching the road to begin with (Bennett, 2017). Examples of such disturbances include wildlife seeing the moving vehicles and experiencing the associated noise and light. Ungulates tend to avoid crossing roads during high traffic volume hours (Kušta et al., 2017; Wattles et al., 2018; Adams et al., 2023). This suggests that some species perceive roads as a more substantial barrier when the traffic volume is high (Huseby, 2013), but some species may also experience the road as a barrier at low traffic volumes (Jacobson et al., 2016). For some species, the open unnatural substrate of a road itself may be a barrier, regardless of the traffic volume. Nonetheless, lowering traffic volume can reduce the overall barrier effect of a transportation corridor, at least for some species.

Potential undesirable side effects

While reducing traffic volume from an intermediate level to a lower level can reduce collisions with large wild mammals, reducing traffic volume from a high level to a lower level can increase rather than decrease collisions (Huijser & Bell, 2025). Therefore, a planned reduction in traffic volume should be carefully assessed for each location. However, for nearly all roads, traffic volume will continue to increase over time. Even "old" roads can experience higher use when a "new" road is built (Nowakowski et al., 2021). Thus, reducing traffic volume as a mitigation method is more likely used in the context of concentrating traffic on roads where collisions with wildlife are less of an issue or where mitigation measures are in place.

Costs of the measure

Changing traffic volumes can be achieved by closing roads, altering traffic routes, and other methods that restrict the number of vehicles on a road. However, if reducing traffic volume on one road means constructing or reconstructing other roads, this measure can be quite expensive. In addition, the problems may be moved to the other roads, unless these other roads have fewer issues with wildlife-vehicle collisions.

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2.2.9 Reduce posted speed limit

Summary
Speed management is often suggested as a strategy to reduce wildlife-vehicle collisions. However, speed management is complex, and not an effective strategy to reduce collisions with large wild mammals along through-roads in rural areas. Furthermore, reducing vehicle speed does not necessarily reduce the barrier effect of the transportation corridor.

Descriptive narrative
Speed management is often suggested as a strategy to reduce wildlife-vehicle collisions. However, speed management is complex, and it is important to distinguish between three types of speed:

- The design speed of a highway. This is used by engineers who, given a certain desired speed, then design the associated road characteristics such as lane and shoulder width, curvature, access density, and sight distance. These characteristics physically allow drivers to drive at a certain speed in a safe and responsible manner.
- The posted speed limit. This is the legal speed limit depicted on signs. This is typically at the 85^{th} percentile of the vehicle speeds and should not exceed the design speed of a road.
- The operating speed of the vehicles. This is the speed that drivers drive their vehicles at.

Most collisions with large wild mammals happen between dusk and dawn when visibility is limited (Huijser et al. 2008; Huijser & Bell, 2025). However, the design speed, posted speed limit and operating speed of major highways is typically too high and the head lights of vehicles do not shine far enough to detect large mammals early enough to allow drivers to stop their vehicle in time (Huijser et al., 2017). With median headlights (low beam) and a 1.5 second reaction time, drivers can, at a maximum, drive about 40 mi/h (64 km/h) and still avoid a collision with a large mammal (moose size) (Huijser et al., 2017). Higher vehicle speeds do not allow most drivers with median headlights to avoid a collision with a large mammal on the highway, unless the animal moves out of the way, or unless the driver makes the vehicle depart its lane, which is typically not advisable. Since half the cars have headlights that have a shorter reach, an operating speed of 40 mi/h (64 km/h) would still not allow half the drivers to stop their vehicle in time. To allow (almost) all drivers to stop their vehicle in time, operating speed may need to be as low as 25-30 mi/h (Huijser et al., 2017). This is far lower than the design speed of most roads. Therefore, reduction of posted vehicle speed is not a feasible mitigation measure for through-roads that are also meant to provide efficient transportation (i.e. short travel times). Reducing the posted speed limit on one road can also be used to encourage drivers to use other roads that are safer and better equipped to deal with high traffic volume, high vehicle speed, and that may have robust mitigation measures in place to reduce collisions with large wild mammals. On the other hand, reducing the posted speed limit or having a very low posted speed limit, can be a viable option for “Park Roads” or other roads for which “efficient” transportation is not necessarily the most important purpose. For example, the main purpose of “Park Roads” is to allow for access to areas to experience the landscape and wildlife from the road, and to allow for access to trailheads and non-motorized forms of transportation. Two types of roads through Yellowstone National Park demonstrate this concept. “Park roads” (posted speed limit typically 45 mi/h (72 km/h)) had fewer collisions with large wild mammals than a road that is managed as a through-road rather than a park road (posted speed limit 55 mi/h (88 km/h)) (Gunther et al., 1998).

Most drivers drive a speed (operating speed) that is close to or higher than the design speed of a rural road, regardless of the posted speed limit (Fitzpatrick et al., 2003; Jiang et al., 2016; Donnell et al., 2018; Riginos et al., 2022). If the posted speed limit is substantially reduced below the design speed for a rural road section through a sensitive area, and if the design speed remains the same for this road section, the following scenario is likely:

- Most drivers will ignore the lower posted speed limit and continue to drive a speed close to or higher than the design speed of the highway (Riginos et al., 2022).
- Some drivers will adhere to the lowered posted speed limit.
- The mix of fast and slow-moving vehicles on a highway is referred to as “speed dispersion” and this is associated with more interaction between vehicles, dangerous driving behavior (e.g. irresponsible maneuvers to overtake slow vehicles) and an overall increase in crashes (Huang et al. 2013, Elvik 2014).

For these reasons alone, it is never a good idea to implement a posted speed limit that is substantially lower than the design speed of a highway. Transportation and law enforcement agencies typically respond to drivers who ignore the posted speed limit and who drive a speed that is close to the design speed of a road by increasing enforcement of the lowered posted speed limit (e.g. through radar measurements of vehicle speed and fining the speeders). If the radar posts are at fixed locations, drivers who travel the road section regularly will quickly learn about the location of the radar posts and lower the speed of their vehicle only in the immediate vicinity of the radar posts. This leads to further speed variation and associated risks, additional use of fuel through braking and acceleration, and the road sections in between the radar posts do not actually have slower moving traffic. Finally, drivers that do get “caught” are likely to experience the situation as “unjust”. One cannot reasonably be expected to drive “slow” on a highway that has “wide” lanes, “wide” shoulders, “gentle” curvature and “long” sight distances. This is likely to eventually result in pressure to make the posted speed limit more consistent with the design speed of the road.

Suggestions and considerations:

- It is not an effective or wise strategy to implement a posted speed limit that is substantially lower than the design speed of a highway (e.g., Riginos et al., 2022).
- Only consider lowering the posted speed limit if the design speed is reduced accordingly. Depending on the purpose of a highway, lowering the design speed and lowering the posted speed limit may be in direct conflict with the need for “efficient” transportation and this may therefore not be a viable strategy for most highways that are managed as a “through-road”.
- For speed management to be substantially effective as a measure to reduce collisions with large mammals for more than half the drivers, the design speed, mandatory speed limit, and actual operating speed of the vehicles at night may need to be 35-40 miles per hour (56-64 km/h) at a maximum (Huijser et al., 2015; Huijser et al., 2017).
- Reducing vehicle speed does not necessarily reduce the barrier effect of the transportation corridor.

Potential undesirable side effects

A posted speed limit that is substantially below the design speed of a highway results in speed dispersion; a mix of fast and slow-moving vehicles. This is associated with more interaction between vehicles, dangerous driving behavior (e.g., irresponsible maneuvers to overtake slow vehicles) and an overall increase in crashes (Huang et al., 2013; Elvik, 2014).

Costs of the measure
Not evaluated as it would not only involve posted speed limit signs but also a lowering of the design speed of a road and a transition from a “through-road” to a “park-road”.

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2.2.10 Reduce vehicle speed: Posting lower speed limits at night

Summary
There is no consistent reduction in collisions with large wild mammals through reduced night-time speed limits on rural highways. In addition, reducing vehicle speed does not necessarily reduce the barrier effect of the transportation corridor.

Descriptive narrative
While several studies have found that higher speed limits increase the risk of collisions with large wild mammals, there is typically little or no change in collisions when reduced speed limits are implemented (Bissonette & Kassar, 2008; Riginos et al., 2022). This may be because the reduction in posted speed limit is often insufficient, and because substantial reductions in posted speed limit that are well below the design speed of a road are unlikely to be observed (Riginos et al., 2022; see previous section on reduced posted speed limit). Studies on moose from Maine in the USA and from Sweden report that the probability of hitting a moose increases with increased speed (Danks & Porter, 2010; Neumann et al., 2012). Danks and Porter (2010) found that the odds of hitting a moose increased by 35% with each 8 km/h (5 mi/h) increase in speed limit, with the highest odds of hitting a moose occurred when speed limits were >72 km/h (45 mi/h) (Danks & Porter, 2010). Meisingset et al. (2014) modeled deer-vehicle collision risk as a function of speed limit, season, road characteristics, and habitat features, and found that the relative risk for collisions with deer increased with higher speed limits. A change in speed limit from 50 km/h (31 mi/h) to 60–70 km/hr (37-44 mi/h) and from 50 (31 mi/h) to 80 km/h (50 mi/h), increased relative risk by a factor 3.9 and 8.6, respectively, and the increase in relative risk from 50 (31 mi/h) to 80 km/h (50 mi/h) was lower for secondary roads compared to major roads (Meisingset et al., 2014).

Even though higher posted speed limits are known to increase risk of collisions with large wild mammals, and that reducing posted speed limits appears an attractive mitigation measure for reducing collisions due to its relatively easy implementation over long distances at relatively low-cost, very little research exists to date on the impacts of reducing posted speed limits on collisions with large wild mammals. A study in Jasper National Park, Canada compared bighorn sheep crash rates for eight years before and eight years after reducing the posted speed limit (Bertwistle, 1999). Bertwistle (1999) found a slight increase in the number of crashes, but this was potentially associated with substantial increases in traffic volume and bighorn sheep habituating to vehicles and not leaving the road when vehicles approached (Bertwistle, 1999).

The Colorado Department of Transportation conducted a study resulting from the passing of a "wildlife crossing zones" bill, which included provisions to implement and enforce reduced night-time speed limits at over 100 miles of marked wildlife crossing zones throughout the state (CDOT, 2014). Posted speed limits were reduced to 55 mi/h (88 km/h) from dusk to dawn, a 10-15 mi/h (16-24 km/h) decrease. Collisions with large wild animals were compared for two years before and two years after posted speed limit reductions in 14 areas (CDOT 2014). The study found that the reduced posted night-time speed limits were ineffective in providing the desired reduction in operating speed, with drivers exceeding the night-time posted speed limit by an average of 7 mi/h (11 km/h), even with a 43% increase in the number of law enforcement citations distributed during the study period (CDOT 2014). In 8 of the 14 study areas collisions with wildlife decreased during the study, while in the other 6 of the 14 study areas these collisions increased (CDOT, 2014). Overall, the DOT concluded that the night-time posted speed limit reductions were ineffective due to poor driver compliance and variable effectiveness in collision reduction.

Both of the studies described above suffered from a study design problem: comparing collision rates before and after the reduction in speed limit without controls where the posted speed limit remained the same. Not having controls means that the assumption is that all other factors, other than the reduction in the posted speed limit, remain the same before and after implementation of the measure. However, in reality, wildlife population size, traffic volume, and other factors can change over time (Riginos et al., 2022). In pursuit of more conclusive knowledge on the effectiveness of reducing night-time speed limits on lowering rates of collisions with large wild mammals, Riginos et al. (2022) conducted a study with both spatial and temporal controls in Wyoming. In this study, posted speed limits were reduced from 70 mi/h (113 km/h) to 55mi/h (88 km/h) seasonally at 6 road sections (during seasonal migration, and during winter in winter habitat of mule deer). The seasonal nature of the posted speed limit reduction targeted the times of year with the highest risk for collisions with mule deer, and this also made it less likely that drivers would habituate to the signs and ignore the reduced posted speed limit (see Huijser et al., 2015; Sullivan et al., 2004). Overall, the results showed that, on average, drivers did respond to the reduced posted speed limits, but the speed reduction was only 3-5 mi/h (5-8 km/h). This is substantially less than the 15 mi/h (24 km/h) reduction that was required based on the signs (Riginos et al., 2022). At the 3 road sections through mule deer winter habitat, there was no evidence of an effect of reduced night-time speed limits on either crashes or carcass counts (Riginos et al., 2022). Crash rates were 20-70% higher under reduced speed limits, while carcass rates remained almost identical (Riginos et al., 2022). At road sections through migration corridors for mule deer, there was some indication that the reduced night-time speed limits resulted in reduced numbers of crashes and carcasses. The average number of crashes per mile was 31% lower in reduced night-time speed limit road sections compared to the controls. However, this was not statistically significant (Riginos et al., 2022). The average number of carcasses per mile was 19% lower in road sections with reduced night-time speed limit than in the controls, and this result was statistically significant (Riginos et al., 2022). Overall, driver compliance with the reduced night-time speed limit was low, even with law enforcement presence, and there was no consistent reduction in collision reduction across the study sites. Furthermore, reducing vehicle speed does not necessarily reduce the barrier effect of the transportation corridor.

Potential undesirable side effects

Reducing the posted speed limit far below the design speed of a road can lead to speed dispersion; a mixture of fast- and slow-moving vehicles on the same road. This is associated with an overall increase in crashes (see section on reducing the posted speed limit and Huijser et al., 2008). It is considered good practice for the posted speed limit to be very similar to the design speed of a highway.

Costs of the measure

In the most recent case study in Wyoming, there were 3 types of signs installed: the 70 mi/h (113 km/h) day / 55 mi/h (88 km/h) night signs with solar flashing beacons, “Caution watch for wildlife on road next 5 miles” signs, and “end night speed limit” signs. A total of 57 signs were deployed across the 66 road miles studied. A total of 26 signs with solar flashing beacons were purchased at a total price of US $70,200.

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2.2.11 Reduce vehicle speed and traffic volume: Traffic calming measures

Summary

Though little information is available, speed bumps have been reported to decrease mammal mortality by 59%. Reduced traffic volume can also improve the permeability of roads to animals.

Descriptive narrative

Traffic calming relies on physical changes to the roadway such as speed bumps, rumble strips, bulb-outs, wider striping, narrower lanes, or adding curves to the road. The aim is to reduce vehicle speed and to reduce traffic volume through discouraging people from using the route and encourage them to choose another route instead. Adding traffic calming features also requires greater attention from drivers, potentially making them more alert to their surroundings, including the potential presence of large animals. Reduced vehicle speed, more alert drivers, and fewer vehicles can result in fewer collisions with large wild mammals, but it is most often used in residential areas and in areas with non-motorized road users (e.g. bicyclists, pedestrians). Recent developments include using hedgerows, plantings or railings on bridges to decrease traffic speed (e.g. Jaarsma et al., 2013).

Van Langevelde et al. (2008) make the case for traffic calming in rural areas through a combination of narrower pavement width and lower vehicle speeds on minor roads in the Netherlands and elsewhere, which would allow for safer native mammal movement. Theoretical modeling showed that traffic calming on minor roads at a regional scale could improve the population persistence of roe deer (Van Langevelde & Jaarsma 2009). In Spain, traffic calming was found to protect one species of amphibian, a toad, *Lissotriton helveticus,* but not a newt, *Alytes obstetricans* (Garcia-Gonzalez et al., 2012). The use of a series of rumble strips and associated mitigation measures deployed as a trial at 3 roadkill hot spots on a road in Tasmania, Australia, decreased mammalian roadkill by 59% (Lester, 2015).

Lower traffic speed and traffic volume can increase successful wildlife crossings of low volume roads, from small to large animal species (e.g. Gagnon et al., 2007). It is uncertain if traffic calming on high volume roads increases permeability. However, traffic calming on high volume roads is typically not realistic to begin with.

Potential undesirable side effects

If rumble strips are selected as the traffic calming measure, they create noise when vehicles pass over them and it is louder the faster the traffic is moving over the strips. Such noise could adversely affect the movement of wildlife near the road. Other measures, e.g. speed bumps, can result in lower vehicle speed on the spots the speed bumps or bulb-outs have been installed, but not necessarily in the road sections between the speed bumps or bulb-outs. However, braking before an obstacle, and subsequent acceleration after passing an obstacle can result in higher fuel consumption, increased pollution, higher noise levels and unsafe driving to make up for lost time. Physical obstacles may result in maintenance challenges where snow needs to be removed from the roadway.

Costs of the measure

According to the FHWA, the cost of installing a rumble strip is about $2.84 per linear yard ($5,000/mile). Milling rumble strips varies depending on whether the substrate is asphalt or concrete and for other reasons (FHWA, 2015). In Montana, center line rumble strips vary in width between 6-8 inches (15-20 cm) (MDT, 2019). For wildlife crossings, a milled rumble strip would normally traverse the entire lane, perpendicular to the direction of traffic. This results in higher costs than for the normal application of rumble strips, but the perpendicular application is at select spots only and not continuous. Rubber rumble strips come in different lengths (i.e., 6, 8 or 10 ft (1.8, 2.4 or 3.0 m) long) Thus, they vary in cost between US $78-$105 for each one. Those that are made of recycled rubber cost substantially more. Some may come with yellow safety striping. Depending on the site and speed, the number of rubber strips to be installed will vary. Treating two lanes of highway with a series of five strips at one location could cost around US $1,000 plus the installation fees.

Speed bumps are much larger than the rumble strips and are 2.5 to 4 inches (6-10 cm) high at the center. They usually are 10 ft (3 m) long and costs vary, but average US $2,500 for each bump (Bushnell et al., 2013)

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2.3 Mitigation measures aimed at influencing animal behavior or population size

In this section we summarize mitigation measures that aim to reduce collisions with large wild mammals through influencing animal behavior of population size.

2.3.1 Visual or audio signals along roadside

Summary
Wildlife reflectors and audio signals do not change the behavior of large animals along roads and are, in general, not associated with a reduction in collisions with large wild mammals. Visual and audio signals do not reduce the barrier effect of roads and traffic. Rather, if they are effective to begin with, they would increase the barrier effect of the transportation corridor.

Descriptive narrative
Visual and audio signals are sometimes placed in the right-of-way with the goal of reducing collisions with large wild mammals. Visual signals are typically reflectors that reflect the light from the headlights of approaching vehicles onto the road and into the adjacent right-of-way. Audio signals may be activated by the headlight of the approaching vehicles. As a result of these visual or audio stimuli, large ungulates are hypothesized to display behavior that would reduce the probability of a collision. They can become more alert and aware of the approaching vehicle, or they may move away from the road surface and adjacent right-of-way.

Several extensive reviews of wildlife warning reflector studies have been conducted (D'Angelo & van der Ree 2015; Brieger et al., 2016; Benten et al., 2018a), with the most recent (Benten et al., 2018a) finding and reviewing 76 publications evaluating the effectiveness of reflectors between 1964 and 2017. Warning reflectors have been produced since the 1960's and come in a variety of brands and colors (white, red, amber, blue, green (Benten et al., 2018a)). While some studies have documented decreased collisions after reflectors were installed, these were primarily studies which employ only a before-after approach, and thus lacked a control to imply causation. In addition, most of these studies were short (<12 months) and had test sites shorter than 5 km (3 mi) in length (Benten et al., 2018a). Most studies have either been inconclusive or showed no effect of the reflectors in reducing collisions with large wild mammals, and some studies have even shown an increase in collisions after installation rather than a decrease (D'Angelo & van der Ree, 2015; Benten et al., 2018a; Brieger et al., 2016). Reflectors are aimed at eliciting a behavioral response from animals in the immediate vicinity of a moving vehicle, such as a directional flight away from the moving vehicle, or increased vigilance (stop and observe) (D'Angelo & van der Ree, 2015). However, in a behavioral study, reflectors did not result in less dangerous deer behavior. Rather, reflectors were associated with more dangerous deer behavior (D'Angelo et al., 2006). In addition, a study by Ujvári et al. (1998) showed that deer habituated quickly to reflectors, with deer fleeing from a reflector placed at a bait site 99% of the time the first night of the study but showing increasing indifference to the stimuli over the course of the 16-day study (Ujvari et al., 1998). Interestingly, another study found that covering the reflectors with white canvas bags resulted in decreased carcass rates and decreased accident-causing deer behavior over the course of the treatment (Riginos et al., 2018). However, the white canvas bags were alternated in short bursts which may have remained a novel stimulus over the course of observation (Riginos et al., 2018). Overall, the literature on this topic suggests that wildlife warning reflectors are not an effective strategy to mitigate wildlife-vehicle collisions (Reeve & Anderson, 1993; Ramp & Croft, 2006; D'Angelo & van der Ree, 2015; Brieger et al., 2016; 2017; Benten et al., 2018a; 2018b; Jasińska et al., 2022). Furthermore, should wildlife warning reflectors be effective is scaring animals away from the road, they would increase the barrier effect.

Auditory deterrents have been used to warn animals of approaching trains (Babinska-Werka et al., 2015, Backs et al., 2017). In a test of a train-triggered wildlife warning system in Poland, animals reacted to trains earlier and were more likely to leave the track when a precisely timed acoustic warning (mimicking multiple animal distress calls) was provided (Babinska-Werka et al., 2015). They noted that for wildlife to learn to associate the noise with danger, the warning system must function properly and only signal when a train is imminently approaching so that the noise is always associated with the danger or fear of the train. False positives (i.e., if the system is producing noise when no train is approaching) could cause animals to habituate to the noise and no longer associate it with danger. Backs et al. (2017) studied a simple and low-cost method to warn wildlife of an approaching train and found it to be successful in identifying approaching trains and signaling at the desired temporal precision, but they did not measure wildlife responses to the system (Backs et al., 2017). While this may be an effective method to reduce train collisions with wildlife, the situation for roads is more complex. First, the volume of trains is generally much lower than road traffic volume, so these systems would be activated much more frequently along roads than on railroads. On many roads, the auditory signal may be activated for a much larger portion of each day. For the train studies, the signals were activated for ≥20 seconds before the train arrived, which, if that was the case for each passing car on a busy road could mean that the signal would be active for a large portion of the day. This could cause animals that are frequently in the vicinity of the road to become habituated to the signal and to no longer associate it with an impending threat. Alternatively, the near continuous noise of the warning signal could increase the barrier effect of a road and further deteriorate the habitat quality in a zone adjacent to the road. Regardless, testing audio warning signals along a road did not change in long-term behavioral effects of deer (Ujvári et al., 2004). Overall, audio signals in the right-of-way have not been studied for their effectiveness in reducing collisions with large animals along roads, and there are a number of complexities that make their application on roads much less feasible and likely much less likely to be effective than along railroads.

Potential undesirable side effects

Reflectors: An increase in animal-vehicle collisions is possible because deer displayed more dangerous behavior with some reflector colors (D'Angelo et al. 2006).

Auditory signals: Continuous activation along busy roads would likely increase the barrier effect and would also reduce the habitat quality in a zone adjacent to the road.

Costs of the measure

The typical cost for one mile (1.6 km) of reflectors ranges from US $3,400–$4,000, depending upon quantities purchased. Most reflectors average 12.5 years of service thus costing $272 to $320 per mile per year. The total cost of installation with reflectors, posts, equipment, and labor is $10,000–$15,000 per mile. Thereafter, only maintenance expenses are required. Based on several states' maintenance records, the cost per mile per year to maintain the reflectors is $500 (Streiter-lite, 2019). The following passage is from the Montana Department of Transportation Research Program report on maintaining reflector systems: "In general, the maintenance of the reflector system is time consuming and challenging. Summertime they are difficult to run mowers around because of the spacing and have required some hand mowing between them to address visibility issues. Wintertime is a concern since the system tends to be damaged or misaligned by accidents and plows and reflectors get covered with snow and debris" (MDT, 2016).

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2.3.2 Rear-facing light to make vehicles more visible to the animals

Summary
A rear-facing white light on the front of a vehicle aims to make the approaching vehicle better visible to large mammals, increasing their awareness of the approaching danger. This measure was not investigated in terms of collision reduction, only in terms of risky behavior by white tailed deer. However, if all dangerous behavior by deer would have resulted in a collision, then deer-vehicle collisions could potentially be reduced by 71%, but this is an extrapolation, and it is based on one study only. This measure does not reduce the barrier effect of roads and traffic for wildlife.

Descriptive narrative
A rear-facing white light on the front of a vehicle aims to make the approaching vehicle better visible to large mammals, increasing their awareness of the approaching danger. Although flight initiation distance by white-tailed deer did not differ between vehicles with headlights only and vehicles with both headlights and rear-facing lights, the likelihood of a dangerous deer-vehicle interaction decreased from 35% of vehicle approaches (headlights only) to 10% (both headlights and rear-facing lights). The deer demonstrated less “freezing” behavior with approaching vehicles that were also equipped with a rear-facing light. While there were more road crossings when a vehicle with rear-facing light approached, the distance (>50 m (>164 ft)) at which the road crossings occurred were classified as “not increasing the risk of a collision”. This measure was not investigated in terms of collision reduction, only in terms of risky behavior by white tailed deer. However, if all dangerous behavior by deer would have resulted in a collision, then deer-vehicle collisions could potentially be reduced by 71%, but this is an extrapolation, and it is based on one study only. Furthermore, this measure does not reduce the barrier effect of roads and traffic for wildlife.

Potential undesirable side effects
Fuel use may increase by a few percent because of additional lights, but LED lights are more energy efficient than traditional headlights (SWOV, 2013).

Costs of the measure
Depending on brand or model, potentially US$50-100 per vehicle.

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2.3.3 Deer whistles installed on vehicles

Summary
Deer whistles mounted on vehicles are designed to emit sounds audible to deer and warn them of an approaching vehicle. However, when exposed to deer whistles, deer do not display behavior that would potentially reduce the likelihood of a collision. If deer whistles have the effect claimed by the manufacturers, they could potentially increase the barrier effect of a road and reduce the habitat quality in a zone adjacent to the road.

Descriptive narrative
Few scientific evaluations of auditory deterrents to reduce collisions with large wild animals have been conducted. Romin and Dalton (1992) found that mule deer behavior did not change in response to deer whistles. A study on the range of deer hearing range found that white-tailed deer hear within the range of 0.25–30 kilohertz (kHz), with best sensitivity between 4–8 kHz (D'Angelo et al., 2007). Because the upper limit of human hearing lies at about 20 kHz, and white-tailed deer can detect frequencies to at least 30 kHz, auditory deterrents at ultrasonic frequencies (>20kHz) may be audible to deer without being audible to humans (D'Angelo et al., 2007). Deer-whistle manufacturers claim to produce products that emit sound at frequencies of ≥15kHz (review in Valitzski et al., 2009), while others reported that the sound frequencies emitted by deer whistles generally falls within the range of 3-12 kHz and may not even be audible to deer when combined with the masking effect of road and car noise (Scheifele et al., 2003).

Valitzski et al. (2009) conducted a study using high-tech sound emitting devices and speakers mounted to the front and sides of a vehicle to test deer reactions. By only sampling during favorable conditions (when there was no heavy precipitation, fog, or high winds that could hinder sound from traveling at the calibrated intensities), based on deer hearing abilities (D'Angelo et al., 2007), and the researcher's calibration, all treatments tested were audible to deer within the "area of influence" (10 m along each side of the road). This study is unique in that it replicates what deer whistles claim to do (deliver pure-tone sounds at the right frequencies and high enough levels to be audible by deer) using fully calibrated and monitored sound equipment, thereby removing any influence of malfunctioning, improperly mounted, or poorly manufactured products. They recorded 319 observations of deer responses to the test vehicle and scored deer responses as: 1) negative reaction- the deer behavior was more likely to result in a collision; 2) positive reaction- the deer behavior was less likely to result in a collision; and 3) neutral reaction- no change in risk of a collision. The same researcher scored all deer reactions to eliminate any observer bias. They had six sound treatments that were randomly assigned to deer including a control (no sound), and 5 pure-tone sounds ranging from 0.28kHz-28kHz (0.28kHz, 1kHz, 8kHz, 15kHz, 28kHz). They found that none of the pure tone sounds they tested altered deer behavior in a way that would reduce the likelihood of a collision (Valitzski et al., 2009). Given the lack of response by deer to sound treatments, the authors concluded that "deer confronted with a vehicle and additional stimuli from auditory deterrents may: 1) have too little time to react as desired, 2) lack the neurological ability to process the alarm information efficiently and respond as desired, or 3) not recognize the sounds we tested as threatening." They conclude that auditory deterrents do not appear to be appropriate for prevention of collisions with deer (Valitzski et al., 2009). In a earlier study, deer were also found not to respond to deer whistles (Schober & Sommer, 1984). Overall, deer whistles do not appear to reduce the likelihood of collisions with deer. In addition, deer whistles do not reduce the barrier effect of roads and traffic.

Potential undesirable side effects

If deer whistles have the effect claimed by the manufacturers, they could potentially increase the barrier effect of a road and reduce the habitat quality in a zone adjacent to the road.

Costs of the measure

Available from online merchants for less than $10 (USD).

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2.3.4 Olfactory repellants

Summary
Olfactory repellents are intended to reduce the presence of large wild mammals on and adjacent to a road. Scents that repel large wild mammals, mainly ungulates, could potentially reduce collisions with large wild mammals by 26-43%. Repellents may increase the barrier effect of roads, alter animal behavior near the repellents, and reduce the habitat quality in a zone adjacent to the road.

Dscriptive narrative
Olfactory and other chemical repellents are designed to deter animals away from the location where they are applied. Commonly used repellents include synthesized animal odors, natural predator excretions, bittering agents, garlic, particulates, and putrescent eggs (Kinley et al., 2003). Relatively few studies have been conducted to investigate their effectiveness in reducing collisions. Through a before-after-control-impact (BACI) design, collisions with large wild mammals decreased between 26- 43% along roads in the Czech Republic (Bíl et al., 2018). Another study estimated that the application of olfactory repellents resulted in a 29% reduction in collisions with roe deer (*Capreolus capreolus*) along sections of roads and railways in the Czech Republic, but it was based on a very small sample size (7 road-killed roe deer before application, and 6 and 4 after application) (Kušta et al., 2015). In addition, the comparison in this study was based on before-after comparison only; the study design did not include control sites.

There are multiple companies that produce olfactory scents, and their ability to repel wildlife is extremely variable (Reidinger & Miller, 2013; Seamans et al., 2016). Often, they do not work as well as they are advertised. Some repellents can keep animals from highly palatable food sources (Cox et al., 2015), or only during certain times of year with lower animal densities (Curtis & Eshenaur, 2022.) while deer can become habituated to others (Elmeros et al., 2011). The type of scent selected depends on the species that is targeted. For example, repellents used to target deer did not repel reptiles and amphibians (Kušta et al., 2015).

The purpose of olfactory repellents is to create a barrier around the area where the scent is applied. When applied along roads, this means repellents increase the barrier effect of the transportation corridor. In addition, the repellents may also result in reduced habitat quality in a zone adjacent to the road.

Potential undesirable side effects
Repellents may increase the barrier effect of roads, alter animal behavior near the repellents, and reduce the habitat quality in a zone adjacent to the road.

Costs of the measure
The cost of a 32-ounce container of liquid chemical olfactory repellent can run as low as \$20 - \$40. One container can cover approximately 1,000 ft^2. In addition to this, the costs of labor and repeated applications should be considered.

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2.3.5 Hazing or aversive conditioning of wildlife

Summary
While data are limited, hazing appears to be not effective at reducing collisions with large ungulates, at least not how it has been applied so far (Sielecki, 2004; Thomas, 2005). Hazing does not reduce the barrier effect of transportation corridors. In some cases, if hazing is "effective" in scaring wildlife away from the road, it can increase the barrier effect of the transportation corridor.

Descriptive narrative
Aversive conditioning or hazing is a technique that uses a negative stimulus to cause fear, pain, avoidance, or irritation in an animal engaged in unwanted behavior (Mazur, 2010; Proppe et al., 2017; Found et al., 2018). Measures that have been tried include pyrotechnics (imitating gunshot sounds), predator-resembling chasing by humans and dogs, chasing with snowmobiles and helicopters, lasers, pepper-spray, throwing/using slingshots to project rocks, shooting with rubber slugs, and changing hunting regimes to extend game species' fear of running into humans going for more than just discreet hunting seasons and areas (Mazur, 2010; Cromsigt et al., 2013; Bonnell & Breck, 2016; Proppe et al., 2017; Found et al., 2018). It is primarily used to keep wildlife from accessing areas where they come into conflict with humans such as urban areas, crop fields, and campsites (Mazur, 2010; Proppe et al., 2017; Bonnell & Breck 2016; Found et al., 2018). This context differs from road applications which are linear, often over long distances. Hazing has not been applied at a large scale for ungulates along rural roads in multifunctional landscapes, presumably because of the relatively high level of continuous effort and associated costs, and the likelihood of habituation. Hazing or aversive conditioning has been used with some success to keep wildlife from entering or staying at specific areas where conflict with human activities are likely (Kloppers et al., 2005; Mazur, 2010; Found et al., 2018). These applications have all been essentially directed towards maintaining a perimeter around conflict zones. In addition, the effectiveness of hazing is generally measured in terms of producing a flight response, and while this may temporarily move animals away from a conflict area, the treatment must be administered frequently (Kloppers et al., 2005; Mazur, 2010; Found et al., 2018). Such frequent interactions with humans and hazing activities may also cause wildlife to become more habituated to humans and hazing situations, diminishing hazing effectiveness over time (Mazur, 2010; Found et al., 2018). Wildlife responses to hazing also varies greatly depending on the species, whether they are already habituated to human activities, age-class, differences in individual animal's personality traits, and landscape variables, such as the presence of predators (Kloppers et al., 2005; Mazur, 2010; Bonnell & Breck, 2016; Found et al., 2018; Found & Cassady St. Clair, 2018). Hazing was not effective in reducing collisions with moose (*Alces americanus*) in Alaska (Thomas, 2005). In British Columbia, Roosevelt elk (*Cervus canadensis roosevelti*) were relocated when hazing failed as a collision reduction mitigation measure (Sielecki, 2004). Green and blue lasers were found to be ineffective as frightening devices to disperse deer at night (VerCauteren et al., 2006). During treatment and control (observation with no laser) behavioral experiments, deer saw and followed the laser light and appeared to be more curious than frightened (VerCauteren et al., 2006). Lights and water sprays have only limited effectiveness on dispersing white-tailed deer (*Odocoileus virginianus*) (DeNicola et al., 2000). Hazing with sounds (e.g., pyrotechnics, cannons, guns, and helicopters) may offer a temporary solution for dispersing animals, but noise is a consideration in areas of human populations (DeNicola et al., 2000; Peterson, 2003). Aversive conditioning treatments resembling predatory chases by humans and dogs were effective in increasing flight responses in 24 moderately habituated radio-collared elk (*Cervus canadensis*); habituated animals have been associated with collisions in Banff National Park (Kloppers et al., 2005). Natural wolf activity, however, appeared to reduce the efficacy of the aversive conditioning techniques (i.e., elk remained closer to town sites) (Kloppers et al., 2005). Aversive conditioning has shown some success in

keeping grizzly bears off roadsides (Gibeau & Heuer, 1996). While data are limited, hazing appears to be not effective at reducing collisions with large ungulates, at least not how it has been applied so far (Sielecki, 2004; Thomas, 2005). In addition, hazing can cause animals to panic, and some flight responses can be towards the road rather than away from the road (Proppe et al., 2017). Finally, hazing could potentially increase the barrier effect by driving animals away from roads.

Potential undesirable side effects

If hazing is effective in keeping wildlife away from roads it increases the barrier effect. Because hazing usually exposes wildlife to contact with humans, animals may also become more habituated to humans and their hazing efforts, potentially leading to more conflicts in the future (Found et al., 2018). Hazing also subjects wildlife to frequent bouts of increased stress, which may affect their survival probability (Proppe et al., 2017).

Costs of the measure

Wyoming Game and Fish Department uses pyrotechnics, snowmobiles, and helicopters for hazing operations to keep elk from foraging on hay crop stores and reduce the risk of disease transmission by keeping cattle and elk separated during winter months when large numbers of elk congregate in lower elevation areas. The Game and Fish Department has spent between $1,000 and $10,000 in most years using helicopters to haze elk in the Bridger-Teton area. Annual snowmobile operation costs in this area routinely exceed $10,000. These costs are in addition to personnel salaries, which they estimated to be $176/game warden/day (Hamilton, 2008). Active hazing of animals using helicopters can cost in the tens of thousands of dollars, depending on the number of days hazing is required. Using personnel to haze can cost approximately $200/day for the individual plus additional costs of vehicles, gas, etc.

Mazur (2010) used aversive conditioning to keep wild and food-conditioned black bears out of campsites, garbage cans, and other conflict areas. They used a variety of methods including chasing, throwing rocks, slingshots, pepper spray, and shooting with rubber slugs. They found that the costs of firearms, ammunition, and training was about $400 per year (the authors did not specify if this was per person or total costs), and that personnel salaries prorated by the portion of time spent on aversive conditioning costs were around $4,200/person/year. They noted that while aversive conditioning can be successful to drive bears away from developed areas, the results are short-lived especially with bears that were already food conditioned (they measured effectiveness in terms of hours the bears stayed away). They found that the main uses for aversive conditioning with food-conditioned bears was to: 1) Modify unacceptable behaviors (i.e. grabbing food off a picnic table occupied by people) to those deemed acceptable for human safety (i.e. waiting until the people had moved out of the area before scavenging for food), 2) Keep bears out of the area for long enough to install bear-proof facilities, and 3) Keep females with cubs out of developed areas so the cubs do not learn the undesired behavior from their mother.

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2.3.6 Wildlife crossing personnel or guards that stop traffic

Summary
In some cases, agency personnel direct traffic or help guide animals across the road. It is unknown if this effort reduces collisions, though it seems likely. If traffic is halted to allow animals to approach and cross the road, the effort reduces the barrier effect of the road and traffic.

Descriptive narrative
In some cases, agency personnel direct traffic or help guide animals across the road. This situation typically occurs in National Parks where mini-traffic jams (referred to as "animal jams") occur as vehicles stop on the highway to view wildlife (Richardson et al., 2014). In some cases, this traffic control is conducted by park staff. In other situations, it may be conducted by volunteers. The efforts are typically directed at managing traffic flow and not having people block the road with their vehicles as they view wildlife near the road. In addition, if animals appear interested in crossing the road, personnel may stop traffic so that animals have an opportunity to come close to the road and successfully cross to the other side. This effort can be conducted by agency personnel or volunteers. For example, Bugle Corps in Rocky Mountain National Park manages traffic along the park's roads during the Rocky Mountain elk (*Cervus elaphus nelsoni*) rutting (breeding) season (USA Today, 2006). The effectiveness of wildlife crossing personnel or guards in reducing collisions with wild large mammals is unknown. However, if the personnel or volunteers stop traffic to allow animals to approach and cross the road, the effort reduces the barrier effect of the road and traffic.

Potential undesirable side effects
People directing traffic are at risk because of close proximity to vehicles in combination with distracted drivers. However, an unmanaged traffic jam associated with wildlife on or near the road also represents a dangerous situation for pedestrians, wildlife, and people in their vehicles.

Costs of the measure
Personnel costs or staff time to train volunteers to act as wildlife guards.

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2.3.7 Deicing alternatives that are a non-attractant to animals

Summary
While removing road salt pools is likely to reduce collisions with moose, there were no studies identified that evaluated the potential benefits of reducing the amount of road salt or applying alternatives to road salt on collisions with large mammals in general. Eliminating or reducing road salt, or applying alternatives to road salt, does not reduce the barrier effect of the transportation corridor. If road salts or alternative deicers are combined with repellents, they have the potential to increase the barrier effect of the transportation corridor.

Descriptive narrative
Road salts (e.g. sodium chloride (NaCl)) are substances used on roads to combat slippery conditions as a result of snow and ice. Distributing salt to the road surface results in a lower freezing point of water, and allows for better grip of the vehicles' tires on the pavement. Some animal species, especially moose (*Alces americanus*) and bighorn sheep (*Ovis canadensis*), are known to be attracted to roads and adjacent rights-of-ways because of road salt (Huijser et al., 2008; Laurian et al., 2008; Grossman et al., 2011). The animals are attracted to the salt licks because they provide essential minerals. Animals that spend more time on and adjacent to highways are at increased risk of being hit by vehicles. While reducing or eliminating road salt can result in fewer collisions with large wild mammals, road safety for people would deteriorate. Therefore, potential alternative de-icers have been investigated over the last few decades. The objective is to identify alternative de-icers that are at least as effective in combatting slippery road conditions as road salt, but that are not, or far less, attractive to wildlife. However, many alternatives to road salt are also detrimental to the environment and quantitative data on the potential to reduce collisions with large wild mammals are lacking.

Chloride salts are often added to sand or gravel in winter road maintenance to combat slippery roads. While such chemicals reduce snow and ice on the road surface, they can also attract some wildlife species to the road surface and adjacent rights-of-way. This can result in an increase in collisions with vehicles, especially in areas where natural salt licks are limited (Brownlee et al., 2000). Examples of large mammal species known to be attracted to roads and adjacent rights-of-ways because of road salt are moose (*Alces americanus*) and bighorn sheep (*Ovis canadensis*) (Huijser et al., 2008; Laurian et al., 2008; Grossman et al., 2011). However, the use of road salt is also known to negatively affect water quality, aquatic species (e.g., amphibians), vegetation, and birds (e.g. Mineau & Brownlee, 2005; Laurian et al., 2012; Cosentino et al., 2014).

A study of radio-collared moose in New Hampshire determined that their home ranges converged on the area containing roadside salt (NaCl) licks formed by runoff of road salt (Miller & Litvaitis, 1992). These roadside salt licks increased the probability of moose-vehicle collisions and increased brain worm infections in moose and white-tailed deer (Miller & Litvaitis, 1992). Based on modeling GPS movements of moose in relationship to salt pools, there was an estimated 49% reduction in road crossings when salt pools were removed (Grosman et al., 2009). Models estimated a 22-79% reduction in moose road crossings with the removal of salt pools (Grosman et al., 2011). While reducing or eliminating chlorides and favoring the use of alternative deicers (without salt) seems an advisable strategy to reduce the attractiveness of road corridors to certain wildlife species, great care must be given to the effectiveness to combatting slippery road conditions in winter. Road salt (NaCl) can be mixed with calcium chloride ($CaCl_2$) or magnesium chloride ($MgCl_2$) and organic additives. Some of the alternatives or mixtures have greater melting ability and penetrates ice faster (Government of Canada, 2001). These mixtures have a lower freezing point. Some additives to road salt can reduce the attractiveness to ungulates while others do not, or evidence is lacking (Brown et al., 2000; Cryotech, 2019), but no evidence is provided. Organic matter is also being tested as a sustainable deicer, with current applications including organic waste, wastewater, cheese brine, pickle brine, potato juice, and beet juice (EDI, 2015; Reddington, 2018; Schuler & Relyea, 2018). While removing road salt pools is likely to reduce collisions with moose, there were no studies identified that evaluated the potential benefits of reducing the amount of road salt or applying alternatives to road salt on collisions with large mammals. Eliminating or reducing road salt, or applying alternatives to road salt, does not reduce the barrier effect of the transportation corridor. If road salts or alternative deicers are combined with repellents, they have the potential to increase the barrier effect of the transportation corridor.

Potential undesirable side effects

Some deicing alternatives may be similarly damaging to the environment as traditional road salt (Hanslin, 2011; Harless et al., 2011; Nutile & Solan, 2019) while others can be more damaging and reduce oxygen concentration in water, have detrimental effects on aquatic species and the ecosystem (e.g., Jouiti et al., 2003; Harless et al., 2011; Schuler et al., 2017; Schuler & Relyea, 2018).

Costs of the measure

The cost for removing salt pools can be expensive, as some will require earth-work and additional changes to the geometric design of the road. The costs for de-icing alternatives is highly variable. However, acetates may be about 10 times as expensive as traditional road salts (Kelting & Laxson, 2010). Nonetheless, cost-benefit ratios can be complex depending on the parameters included (Fay et al., 2015).

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2.3.8 Reduce nutritional value of roadside vegetation

Summary
Vegetation clearing can result in about 50% reduction in collisions with large mammals, but it may also not be effective at all. See the section on "increasing visibility: vegetation management" for more details. Vegetation mowing and clearing can both positively and negatively affect the habitat for various species in the right-of-way. It can negatively affect the barrier effect of roads and traffic for species that depend on cover when approaching a road.

Descriptive narrative
Roadside vegetation such as herbs and grasses can attract wildlife, including deer and bear species, increasing the likelihood of collisions (Reinhart et al., 2001). Vegetation along roads may start to grow earlier in the season (light, south slopes receive more sunlight and warmth) than in surrounding forested habitat (Bellis & Graves, 1971; Feldhamer et al., 1986; Kinley et al., 2003). Relatively green and abundant vegetation along roads has also been reported in relatively dry areas (Lee et al., 2004). Run-off from roads and relatively high levels of nitrogen deposition (Angold, 1997) may also help explain the sometimes relatively abundant and attractive vegetation in rights-of-way.

Some management efforts of vegetation in the right of way are focused on making vegetation less of an attractant to wildlife (i.e., by planting unpalatable species, reducing forage quality, removing shrubs, or applying noxious chemicals) (e.g. Rea, 2003). However, cutting and mowing may also increase the nutritional value of vegetation for foraging by ungulates. The regrowth and new sprouts of the vegetation after cutting can be an attractant to ungulates, although it depends on the timing of the cutting (Rea, 2003; Guyton et al., 2014). However, in Newfoundland, vegetation cutting reduced the attractiveness of the vegetation to moose (Tanner & Leroux, 2015). Dandelion and clover in roadside vegetation can be especially attractive to bears (Reinhart et al., 2001). See the section on "increasing visibility: vegetation management" for more details. Overall, while vegetation clearing can result in about 50% reduction in collisions with large mammals, but it may also not be effective at all. See the section on "increasing visibility: vegetation management" for more details. Furthermore, vegetation mowing and clearing can both positively and negatively affect the habitat for various species in the right-of-way (Huijser & Clevenger, 2006; Silva et al., 2019). It can negatively affect the barrier effect of roads and traffic for species that depend on cover (Huijser & Clevenger, 2006; Lewis et al., 2011; Kite et al., 2016).

Potential undesirable side effects
Cutting and mowing may increase rather than decrease the nutritional value of vegetation for foraging by ungulates. The regrowth and new sprouts of the vegetation after cutting can be an attractant to ungulates, although it depends on the timing of the cutting (Rea, 2003; Guyton et al., 2014). However, in Newfoundland, vegetation cutting reduced the attractiveness of the vegetation to moose (Tanner & Leroux, 2015).

Costs of the measure
See the section on "increasing visibility: vegetation management" for more details.

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2.3.9 Alter wildlife habitat outside of right-of-way and intercept feeding

Summary
Intercept feeding is a specific form of habitat alteration; instead of reducing the quantity or quality of the habitat, food is provided away from the road with the intent that that will keep animals from coming close to the road where they may be hit by vehicles. For habitat alteration measures to result in a substantial reduction in collisions with large wild mammals, the activities would have to take place on a very large spatial scale and take a long time to take effect. For intercept feeding the benefits may be temporary, and result in negative side effects. The effectiveness of this measure in reducing large mammal-vehicle collisions is unknown. Habitat alterations away from the road do not decrease the barrier effect of the transportation corridor. However, if intercept feeding is successful, fewer individuals may approach and cross the road.

Descriptive narrative
When there is a matrix of good cover with good feeding habitat, deer population densities are typically relatively high. The size of the herd can be reduced through culling, relocation, or anti-fertility treatment, but if the habitat remains similar, deer densities will quickly return to their original levels, partly as the result of density-dependent fertility. Therefore, habitat alterations that limit the population density in certain areas can be considered. Intercept feeding is a specific form of habitat alteration; instead of reducing the quantity or quality of the habitat, food is provided away from the road with the intent that that will keep animals from coming close to the road where they may be hit by vehicles. For habitat alteration measures to result in a substantial reduction in collisions with large wild mammals, the activities would have to take place on a very large spatial scale and take a long time to take effect. For intercept feeding the benefits may be temporary, and result in negative side effects. In addition, approval and coordination with the landowners would be required, and changes in land use are likely problematic. However, habitat alteration, does have the potential to reduce the frequency and level of population culling, relocation, and anti-fertility treatment needed to reduce deer population density to an “accepted” level.

Population density for a wildlife species usually heavily depends on the quality of their habitat. For example, an abundance of food and cover, in combination with an absence of predators and hunting, allows for relatively high deer population densities (e.g., Porter & Underwood, 1999; Côté et al., 2004). In general, good feeding habitat for deer may include young forests (e.g., in harvested areas that have been replanted or that have naturally regenerated), agricultural lands (hay or alfalfa meadows, especially if they are fertilized and irrigated, and crop lands), lawns and gardens (including golf courses), and riparian habitat. Good cover is provided by forests or shrubland. When there is a matrix of good cover with good feeding habitat, deer population densities are typically relatively high. The size of the herd can be reduced through culling, relocation, or anti-fertility treatment, but if the habitat remains similar, deer densities will quickly return to their original levels, partly as the result of density-dependent fertility. Therefore, habitat alterations that limit the population density in certain areas can be considered. These measures may include reducing the amount of edge habitat by having larger patches of cover and feeding habitat or reducing the quality and quantity of the available food (e.g., Pettorelli et al., 2005). Reducing the quality of the available food may be achieved by certain mowing or cutting practices, allowing for natural succession to more mature forests (where applicable) with different grass-herb and shrub vegetation on the forest floor, and reducing or stopping irrigation and the use of fertilizers (Gill et al., 1996). Reducing the quantity of the available food can be achieved by allowing the natural succession to more mature forests (where applicable) with less grass-herb and shrub vegetation on the forest floor, or making prime feeding habitat unavailable to the deer, e.g., through using wildlife fencing (Gill et al., 1996).

Intercept feeding is a specific form of habitat alteration; instead of reducing the quantity or quality of the habitat, food is provided away from the road with the intent that that will keep animals from coming close to the road where they may be hit by vehicles. An experiment with intercept feeding for mule deer indicated that collisions may have been reduced by about 50% (Wood & Wolfe, 1988). However, no information was provided on the number of deer-vehicle collisions before intercept feeding stations were operational. After testing the effectiveness of scent marking, forest clearing, and supplemental feeding, researchers in Norway concluded that these combined efforts might help reduce (but not eliminate) moose-train collisions if applied over long distances (Andreassen et al., 2005). Attempts at discouraging animals from accessing road salt using intercept mineral baiting were unsuccessful in Jasper National Park, Canada (Bertwistle, 1997). Diversionary salt licks have been testes to reduce mortality of small populations of Mountain goats (*Oreamnus americanus*) (<50 individuals) in select locations in British Columbia, Canada. For these small populations, mortality of even a few individuals represents an unacceptable loss for the population (Harper, 2019). No results are available at this time.

Intercept feeding may work in some cases, such as for short-term reductions in areas of high deer concentrations or in combination with other mitigation measures (Wood & Wolfe, 1988; Farrell et al., 2002; Knapp, 2005). However, intercept feeding is labor intensive and may create a dependency on supplemental food and may eventually increase population size (Wood & Wolfe, 1988; Farrell et al., 2002). In addition, non-natural high concentrations of wildlife may also increase the transmission rate and spread of contagious diseases.

For habitat alteration measures to result in a substantial reduction in collisions with large wild mammals, the activities would have to take place on a very large spatial scale and take a long time to take effect. For intercept feeding the benefits may be temporary, and result in negative side effects. In addition, approval and coordination with the landowners would be required, and changes in land use are likely problematic. However, habitat alteration, does have the potential to reduce the frequency and level of population culling, relocation, and anti-fertility treatment needed to reduce deer population density to an "accepted" level. Overall, the effectiveness of this measure in reducing large mammal-vehicle collisions is unknown. Habitat alterations away from the road do not decrease the barrier effect of the transportation corridor. However, if intercept feeding is successful, fewer individuals may approach and cross the road.

Potential undesirable side effects
Intercept feeding may lead to dependency of wildlife on unnatural food sources and increased transmission of diseases.

Costs of the measure
Unknown but likely highly variable.

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2.3.10 Expand road median

Summary
Wide vegetated medians may allow animals to cross the lanes for one travel direction and rest and assess traffic going in the opposite direction before completing their crossing. However, wide medians may provide food and shelter from some human disturbances (e.g. hunting) and can be associated with higher risk of collisions rather than lower risk. It is unclear whether a vegetated median reduces the barrier effect of roads.

Descriptive narrative
Crossing multiple lanes of traffic, especially when traffic volume is high and comes from both directions, is a difficult task for any animal. It has been suggested that wider medians can provide a “refuge” for the animals and allow them a chance to stop and reevaluate. The assumption is that expanded, vegetated medians may allow animals to deal with only one direction of traffic at a time, giving them the opportunity to stop halfway and wait for an adequate gap in traffic before attempting to cross the remaining lanes. However, a literature review found that it was unclear whether a vegetated median improved the crossing opportunity for wildlife (Clevenger & Kociolek, 2006). Moreover, wide medians have been associated with higher risk of collisions with large wild ungulates rather than lower risk (Prendergast, 2009). Median barriers (e.g., concrete “Jersey” barriers, guardrails, and cable barriers) can increase the barrier effect of roads and increase collisions if an animal spends more time figuring out how to cross such a barrier (Clevenger & Kociolek, 2013). Overall, wider median barriers have not been documented to reduce collisions with large wild mammals. Instead, wider median barriers may be associated with higher risk of these types of collisions.

Expanded, vegetated medians may allow animals to deal with only one direction of traffic at a time, giving them the opportunity to stop halfway and wait for an adequate gap in traffic before attempting to cross the remaining lanes. However, a literature review found that it was unclear whether a vegetated median improved the crossing opportunity for wildlife (Clevenger & Kociolek, 2006). Medians with barriers (such as concrete “Jersey” barriers, metal guardrails, or cables) can increase the barrier effect of roads. Wide medians do not reduce the barrier effect for small mammals (McLaren et al., 20211).

Potential undesirable side effects
Wide medians may have attractive vegetation for large wild ungulates, and despite their proximity to traffic, they may also have little disturbance from people. Food and shelter from humans (e.g., hunters) may cause animals to spend more time in wide medians and, as a result, increase the probability of collisions with vehicles.

Costs of the measure
Unknown, but potentially extensive as a much wider right-of-way is involved.

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2.3.11 Wildlife culling

Summary
Depending on the extent of deer population reduction and the size of the culling area, collisions with deer were reduced by 68.4% on average (range 30-94%). Culling animals does not reduce the barrier effect of transportation infrastructure and traffic

Descriptive narrative
Culling is the process of killing animals in an effort to reduce their population size because of human-wildlife conflicts, disease, or conflicts with other species (Urbanek et al., 2011; Williams et al., 2013; Muller et al., 2014; Mawson et al., 2016). In some cases, especially on islands, the objective is to not just reduce the population size of a species, but to eradicate a non-native species from the area with the goal to restore native species (Portelli & Carlile, 2020; Serr et al., 2020). In this report the focus is on reducing the population size of large wild mammal species rather than eliminating these populations altogether. Culling to reduce the population size of large wild mammals has been applied to both native (e.g. deer species) and non-native species (e.g. feral hogs) (Massei et al., 2011; McCann et al., 2016; Mysterud et al., 2019; Portelli & Carlile, 2020). Culling methods for large mammals include trapping and euthanizing animals, increased hunting efforts (e.g. firearms or archery by the public) through higher quotas and special permits (e.g. sharpshooting by professionals in (sub)urban areas) (Doerr et al., 2001). Reducing a white-tailed deer population by 46% in Bloomington (Minnesota) was associated with a 30% reduction in deer-vehicle collisions in the same area (Doerr et al., 2001). In New Jersey, three cities reduced urban deer populations in an effort to reduce collisions. The average deer population was reduced by 67% and this was associated with a 67% reduction in collisions with deer (DeNicola & Williams, 2008). In the 2,200 ha community of Sea Pines on Hilton Head Island, sharpshooters reduced the population by approximately 50% and reduced collisions with deer by 80% (Warren, 2011). The Hemlock Farms Community Association is a >4,500-acre community located in Pike County, Pennsylvania. The deer population was reduced by 84% and this was associated by a 94% reduction in collisions with deer (D'Angelo et al., 2012). Three townships in New Jersey reduced deer populations by 52% on average and then collisions with deer decreased by 71% (Williams et al., 2013). The removal of animals is more effective in reducing populations size than sterilization programs because survival contributes more to population growth in deer populations than fecundity (Grund, 2011). Nonetheless, culling must be carefully evaluated, including for ethical, economic, social and ecological aspects (Warren, 2011).

Besides active culling by people, large wild ungulate population size may also be reduced through the reintroduction of predators. A few years after bobcats were restored onto Cumberland Island, deer herd abundance on the island decreased by about 50% and age- and sex-specific bodyweights of deer increased significantly. The growth rate of the deer population was reduced because bobcats were targeting the fawns (Warren, 2011). Deer population models showed that cougars could reduce deer densities and deer-vehicle collisions by 22% in Eastern United States, preventing over 21,000 human injuries and 155 fatalities within 30 years of re-establishment (Gilbert et al., 2017). Before-after-control-impact analyses showed that cougars reduced deer-vehicle collisions by 9% within 8 years of establishment (Gilbert et al., 2017). Overall, depending on the extent of deer population reduction and the size of the culling area, collisions with deer were reduced by 68.4% on average (range 30-94%).

Culling animals does not reduce the barrier effect of transportation infrastructure and traffic. However, reduced deer density may result in increased movement from neighboring areas, including across roads.

Potential undesirable side effects

Culling or mass killing is not always supported by the public (Warren, 2011, Urbanek et al., 2015). In general, the public is more accepting of non-lethal methods (e.g. anti-fertility treatments) (Urbanek et al., 2015). However, culling may be less stressful compared to capturing and also potential relocation of animals (Williams et al., 2008). In addition, there are concerns about allowing for general hunting by the public vs. professional sharpshooters, and hunting method and associated success rate (e.g. firearm vs. bow and arrow) (Weckel & Rockwell, 2013).

Costs of the measure

The costs to administer a culling program depends on the extent of the operation. Culling can be done from ground, vehicle, or helicopter. Financial incentives to commercial hunters tend to be more cost-effective than funded culling (Nugent & Choqunot, 2004). Replacement hunts, where a hunter can harvest more than one deer, are also cost-efficient in terms of deer harvested and can meet high population reduction goals (Hubbard & Nielsen, 2011). The effectiveness of these types of hunts depends on forest density and the experience of the hunters. Costs for controlled hunts ranged from $117 to $120/deer, depredation hunts using conservation officers and park rangers ranged from $70 to $121/deer, and using police officers as sharpshooters was about $194/deer (Doerr et al., 2001; Hygnstrom et al., 2011). Raiho et al. (2015) estimated costs for culling at $350 per white-tailed deer doe. However, culling costs can be offset by savings through fewer collisions and reducing vehicle repair costs (DeNicola & Williams, 2008).

The costs for the removal of feral hogs through culling is more varied. Costs ranged from $3,118/hog for the removal of 200 hogs, to $283/hog for the removal of over 12,000 hogs, illustrating the benefits of scale. These costs associated with culling feral hogs included personnel, transportation, dogs, housing, traps, trapping support, firearms, exclusion fencing, administration, and miscellaneous supplies (McCann & Garcelon, 2008).

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2.3.12 Wildlife relocation

Summary
Wildlife relocation involves the capture, transport, and release of animals to another location. Depending on the extent of deer population reduction and the size of the area, collisions with deer may be reduced by 68.4% on average (range 30-94%) (see previous section on wildlife culling). However, while seemingly more humane than culling (or killing), wildlife relocation is, in general, not recommended. Relocating animals does not reduce the barrier effect of transportation infrastructure and traffic.

Descriptive narrative
Wildlife relocation involves the capture, transport, and release of animals to another location. It is typically considered for individual animals that are considered a danger or a nuisance to people (e.g. habituated bears) of for a species whose population size is considered "too high". This may be based on human-wildlife conflicts, or because the population size is higher than what is considered desirable for other reasons (e.g., above the carrying capacity of the habitat) (Warren, 2011). However, the fate of the released animals on the other location is often unknown, and there may be conflicts (e.g., territory, disease transmission) with the animals that are already present at the release location. On Hilton Head Island, South Carolina, a white-tailed deer (*Odocoileus virginianus*) relocation experiment was conducted (Cromwell et al., 1999). The relocated deer experienced relatively high mortality from capture-related causes, and 50% of the relocated deer dispersed from their release site. For the relationship between deer population size (or reduction in population size) and collisions with vehicles see the section on wildlife culling. The effect of all population size reduction projects can be seriously diminished if it is an open population that allows the individuals from neighboring populations to fill the gaps or that allows the relocated individuals to return. Depending on the extent of deer population reduction and the size of the area, collisions with deer may be reduced by 68.4% on average (range 30-94%) (see previous section on wildlife culling). Relocating animals does not reduce the barrier effect of transportation infrastructure and traffic. However, relocated animals may disperse from the release site, resulting in increased movements across roads at or near the release site.

Potential undesirable side effects
With an open population or relocation over relatively short distances, individuals from neighboring populations may fill the gaps or a substantial portion of the relocated individuals may return to the original location, seriously limiting the effectiveness of this measure (Cromwell et al., 1999). In one study, 50 percent of the relocated deer did not remain in their release area (Cromwell et al., 1999). The effort will have to be repeated periodically as the deer population will grow back to the same levels (growth, immigration, including of individuals that were relocated) if the habitat conditions remain similar; it is not a one-time-only measure. Relocated individuals tend to experience a lower survival rate and increased human-induced mortality, including from the capturing effort (Cromwell et al., 1999). Relocation of deer can result in the spread of infectious diseases (Beringer et al., 2002). Relocated individuals may compete with individuals that are already present at the release site, or they may contribute to the growth and overpopulation at the release site and the negative effects associated with overpopulation (Porter et al., 1999).The effort may not be favored or accepted by the public, especially in areas that have a high degree of ecological integrity ("hands-off" approach). Wildlife relocation is, in general, not recommended (Craven et al., 1998).

Costs of the measure

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

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2.3.1 Anti-fertility treatment

Summary
Reducing deer population size can result in near proportional reduction in collisions with vehicles. Anti-fertility treatment does not reduce the barrier effect of roads and vehicles.

Descriptive narrative
Anti-fertility treatments have been used to lower reproduction animal populations considered over-abundant. Examples of species that have been subject to the treatments include white-tailed deer and feral horses (Fagerstone et al., 2010; Massei & Cowan, 2014; Ransom et al., 2014). Most recent studies of anti-fertility treatment have focused on immune-contraceptive vaccines (especially PZP and GnRH vaccines), which can prevent ovulation, sperm production, or fertilization (Massei & Cowan, 2014). These vaccines are typically administered through injection either by trapping animals and injecting them by hand, or by darting them remotely (Fagerstone et al., 2010; Warren, 2011; Ransom et al., 2010; Ransom et al., 2014; Massei & Cowan, 2014). Immuno-contraceptive vaccines can impede reproduction for multiple years with a single dose and are often pursued to control populations where lethal management (such as culling) is either illegal, impractical, or strongly opposed by one or more stakeholders (Fagerstone et al., 2010; Warren, 2011; Massei & Cowan, 2014; Raiho et al., 2015). Several recent reviews of anti-fertility treatments for wildlife and feral animal control have been conducted (Fagerstone et al., 2010; Warren, 2011; Massei & Cowan, 2014; Ransom et al., 2014).

Ransom et al. (2014) reviewed 479 scientific papers on wildlife fertility control, and found that overall, anti-fertility treatment is best suited to maintain population densities rather than reduce them. Reduction of population growth is possible in small, and "closed" or isolated populations that have no influx (immigration) of individuals from other populations that can undo the effects of lower birth rates. Depending on the degree in which the population is closed or open, 50-90% of the females must be treated to achieve a moderate reduction in population growth (Ransom et al., 2014). Several studies suggest that, in cases where a substantial reduction in population is necessary to reduce human-wildlife conflict, culling be used first to reduce population size, followed by anti-fertility treatment to maintain the desired population levels (Fagerstone et al., 2010; Ransom et al., 2014; Massei & Cowan, 2014; Raiho et al., 2015). Anti-fertility treatments in recent literature are primarily focused on immune-contraceptive vaccines generally administered via injection.

DeNicola and Williams (2008) suggest that reducing deer population size can result in near proportional reduction in collisions with vehicles. The literature on anti-fertility treatment suggests that it is better suited to maintain populations rather than reduce them. Reductions in population size are most likely to be realized in small, isolated populations, and, even then most animals must be treated regularly for long periods of time, from 5-10 years (Ransom et al., 2014; Massei & Cowan, 2014). Anti-fertility treatment does not reduce the barrier effect of roads and vehicles.

Potential undesirable side effects
Immuno-contraceptive vaccines can cause injection-site lesions in some animals, and can have numerous unintended consequences including altering population demographics, social behavior, fitness, ecosystem interactions, and survival in a variety of ways depending on the species and type of vaccine used (Massei et al., 2014; Ransom et al., 2010; Ransom et al., 2014). Ransom et al. (2014) suggests the need for research to expand the "birth-centric" theme of the existing literature to include

more thoughtful methods that consider births, deaths, immigration, emigration, gene flow, and ecological interactions (Ransom et al., 2014).

Costs of the measure

The most recent available numbers from Raiho et al. (2015) are that it costs $750 per doe for contraceptive fertility control.

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2.4 Mitigation measures aimed at separating animals from the road

In this section we summarize mitigation measures that aim to reduce collisions with large wild mammals through separating animals from the road.

2.4.1 Wildlife barriers: fences, boulders, and walls

Summary

Long fences (>3 mi (5 km) road length) typically result in >80% (average 84%) reduction in collisions with large mammals. Short fences (≤ 3 mi (≤5 km) road length) have lower (52.7%) and more variable (0-94%) effectiveness, probably because of fence-end effects. A well designed, constructed and maintained wildlife barrier is a near absolute barrier for the target species and potential other species, fragmenting their populations, and putting them at higher risk of local or regional extirpation. Therefore, as a rule, wildlife barriers should only be implemented in combination with wildlife crossing structures. Fences increase the wildlife use of structures and thereby help decrease the barrier effect further compared to wildlife crossing structures that are not associated with fences. Fences in combination with wildlife crossing structures can result in higher permeability of a highway than an unmitigated highway.

Descriptive narrative

Wildlife barriers are designed to keep animals off the highway. Fences are the most frequently used barrier type, but in some cases walls or rows of boulders have been used. The type of barrier, the height of the barrier, fence material, posts, and potential fence overhang or fence dig barrier all depend on the target species' capability to jump, climb, dig, or push through obstacles. In most cases there are multiple target species that inform the design of a barrier. For example, it is not uncommon to also attach finer mesh fence material for medium sized mammals or plastic sheets for reptiles or amphibians to a taller fence that is primarily designed for large ungulates. A well designed, constructed and maintained wildlife barrier is a near absolute barrier for the target species and potential other species, fragmenting their populations, and putting them at higher risk of local or regional extirpation. Therefore, as a rule, wildlife barriers should only be implemented in combination with wildlife crossing structures.

Wildlife barriers have two main objectives: 1) to keep animals off the highway, reduce collisions, improve human safety, and reduce unnatural mortality for wildlife, and 2) to guide animals to crossing structures that allow for safe daily, seasonal and dispersal movements between the areas on either side of a highway (Dodd et al., 2007a; Gagnon et al., 2010; Huijser et al., 2015; 2016a). Barriers for large mammals mostly consist of fences. Large ungulate fences are typically 8 ft (2.4 m) tall, have wooden posts and 6 x 9 inch (about 15x18 cm) openings in mesh wire fence material and vertical length of the mesh may be reduce closer to the bottom to exclude medium-sized mammals. Species that can climb or jump well such as black bear or mountain lions require taller fences (10-12 ft; 3.0-3.7 m) with metal poles, smaller mesh sizes (e.g. chain-link), and an overhang on top of the fence angled away from the road. The fence should be flush to the ground to prevent animals from crawling under the fence. Special attachments, rubber flaps or chains attached to the main fence may be required at stream crossings (Kruidering et al., 2005). If the target species are able to dig, a buried fence or "apron" may have to be attached to the main fence and dug into the soil, angling away (45°) from the road (Clevenger & Huijser, 2011). The buried fence may consist of a 4-5 ft (1.0-1.2 m) wide galvanized chain-link fence that is attached to the bottom of the actual fence. The buried fence should extend approximately 3.5 ft (1.1 m) under the ground (Clevenger & Huijser, 2011). Electric fencing for large ungulates can be lower than mesh wire fences; e.g. about 7 ft (2.1 m) (Leblond et al., 2007; Phillips et al., 2011; Clevenger & Huijser, 2011).

Opaque fencing is also sometimes thought to be more effective than woven wire mesh fencing allowing for reduced fence height. However, if animals are not naïve and know what may be on the other side of an opaque fence, there may not be any measurable benefit from opaque fencing compared to woven wire mesh fencing, suggesting that fence height for ungulates would still have to be about 8 ft (2.4 m), even if the ungulates cannot see through the fence (Stull et al., 2011).

Fence height may have to be adjusted if the fence is positioned on a slope. For example, fence height may be measured about 3.3 ft (1 m) from the fence on the "safe side" of the fence (Kruidering et al., 2005). Note that swaths of large boulders (>30 inches (>0.75 cm) in diameter) have been used as an alternative to wildlife fencing for elk in Arizona, but the use of large rocks as a barrier should be considered experimental (Dodd et al., 2007b). In road sections where landscape aesthetics and an unobstructed view of the landscape from the road are important, wildlife fences may not be desirable. In such situations, consider barrier walls integrated into the roadbed instead.

Long fences (>3 mi (5 km) road length) typically result in >80% (average 84%) reduction in collisions with large mammals (Huijser et al. 2016a). Short fences (≤ 3 mi (≤5 km) road length) have lower (52.7%) and more variable (0-94%) effectiveness, probably because of fence-end effects (Huijser et al., 2016a).

Fences, as a stand-alone measure, do not reduce the barrier effect of transportation infrastructure. A well designed, constructed and maintained wildlife barrier is a near absolute barrier for the target species and potential other species, fragmenting their populations, and putting them at higher risk of local or regional extirpation (Jaeger & Fahrig, 2004). Therefore, as a rule, wildlife barriers should only be implemented in combination with wildlife crossing structures. However, fences can help reduce the barrier effect of highways if they are combined with wildlife crossing structures (see separate section). Fences can help guide animals to crossing structures that allow for safe daily, seasonal or dispersal movements between the areas on either side of a highway (Dodd et al., 2007a; Gagnon et al., 2010; Huijser et al., 2015; 2016). Fences increase the wildlife use of structures and thereby help decrease the barrier effect further compared to wildlife crossing structures that are not associated with fences (Dodd et al., 2007a; Gagnon et al. 2010). Fences in combination with wildlife crossing structures can result in higher permeability of a highway than an unmitigated highway (Huijser et al., 2016b).

Potential undesirable side effects
A well designed, constructed and maintained wildlife barrier is a near absolute barrier for the target species and potential other species, fragmenting their populations, and putting them at higher risk of local or regional extirpation. Therefore, as a rule, wildlife barriers should only be implemented in combination with wildlife crossing structures. Furthermore, wildlife may be injured or killed in fences, e.g. through entanglement or low flying birds (especially grouse species) (e.g. Baines & Summers, 1997; Dobson, 2001). Careful design, oversight during construction, and fence maintenance is essential. Fences should have a tight connection to crossing structures or wingwalls associated with crossing structures, leaving no gaps for animals to access the fenced road corridor or places where they may get trapped between a fence and a wingwall. Access roads, and fence-end placement and treatments should be directed at reducing a fence end run (high number of animals crossing the highway at a fence-end) and intrusions into the fenced road corridor. These treatments may consist of wildlife guards (similar to cattle guards), electrified mats, or conductive concrete. Wildlife guards are typically a substantial barrier

to ungulates (though there is concern about ungulates getting injured when they do try to cross), but not to species with paws (e.g. bears, canids, felids). Species with paws may require an electrified barrier. Despite these efforts, some animals will end up in the fenced road corridor. While wildlife jump-outs or escape ramps are often used to allow animals to jump to the safe side of the fence, their design (height and other features) may need to be improved upon, especially when there are different species that have different jumping and climbing ability (Huijser et al., 2015).

Costs of the measure

The costs for 2.4 m (8 ft) high wildlife fencing along US Highway 93 on the Flathead Reservation in Montana varied depending on the road section concerned: US$26, US$38, US$41 per m in 2006 (material and installation combined) (Personal communication Pat Basting, Montana Department of Transportation; review in Huijser et al., 2009). A finer mesh fence was dug into the soil and attached to the wildlife fence for some fence sections at an additional cost of US$12 per m (Personal communication Pat Basting, Montana Department of Transportation; review in Huijser et al., 2009). In the Canadian National Parks in the Rocky Mountains, the costs for fences with wooden posts, including design and oversight during construction, varied between US$ 68.2/m (no apron) – US $ 88.0/m (with apron) (Personal communication Terry McGuire, McGuire Consulting) (in 2019 US$). With steel posts the costs varied between US$ 71.0/m (no apron) – US $ 96.8/m (with apron) (Personal communication Terry McGuire, McGuire Consulting) (in 2019 US$).

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2.4.2 Crossing structures: underpasses and overpasses

Summary
While wildlife crossing structures in combination with wildlife fences can substantially reduce collisions with large wild mammals, crossing structures as a stand-alone measure do not necessarily reduce collisions. Wildlife crossing structures can receive relatively high use by large wild mammals, regardless of whether the structures are connected to fences. Nonetheless, structures that are connected to fences tend to have increased use by wildlife. Wildlife crossing structures in combination with wildlife fences can maintain or improve habitat connectivity for large mammals.

Descriptive narrative
The term wildlife crossing structure describes a variety of structures that are designed or retrofitted to provide safe passage for wildlife above or below a highway (Clevenger & Huijser, 2011). Although wildlife crossing structures are not standardized designs, they can be categorized as two major types; underpasses (which allow animals to pass under the road) and overpasses (which allow wildlife to pass over the road). Crossing structures are often used in combination with fencing as fences help guide wildlife towards the structures. Wildlife underpasses range from very large structures to the small, hardly noticeable to drivers. Wildlife overpasses are generally the largest crossing structures. They extend habitat over highways and are considered the most effective means of re-connecting habitat over roadways.

The main objective of wildlife underpasses and overpasses is to connect wildlife populations or entire ecosystems and allow ecosystem processes to continue over or under a road. However, wildlife use of crossing structures increases when they are connected to wildlife fences. If sufficient structures are in place for the target species, and if they are at the correct locations, of the right type and dimensions, they can also help reduce collisions as animals are less likely to breach the fence to get to the other side of the road.

Both underpasses and overpasses can be used by a variety of wildlife species to cross roadways. How well underpasses and overpasses perform in providing connectivity for wildlife, and in reducing collisions with vehicles is dependent on wildlife fencing. These fences need to be impermeable to the target species, keep animals off roads and funnel them to the crossing structures. Fencing may be continuous running for long distances along highways (Clevenger & Barrueto, 2014) or partial fencing that consists of disjunct fenced segments of highway with numerous fence ends (Gagnon et al., 2011; Huijser et al., 2016a, b). The use of wildlife fencing in combination with wildlife crossing structures can increase the use of underpasses by elk (*Cervus elaphus*) and deer (Odocoileus sp.) (Dodd et al., 2007; Sawyer et al., 2012). For wildlife crossing structures in combination with partial fencing to reduce collisions by at least 80%, road needs to be fenced over a minimum of 5,000 m (3 mi) (Huijser et al., 2016a).

The location, type, dimensions, and slope of wildlife crossing structures must be carefully planned for the target species, sometimes even the sex and age of the animals (e.g., Ford et al., 2017), and surrounding landscape. For example, grizzly bears, elk, pronghorn and moose (*Alces alces*) tend to use wildlife overpasses to a greater extent than wildlife underpasses, while black bears and mountain lions use underpasses more frequently than overpasses (Clevenger & Waltho, 2005; Clevenger & Barrueto, 2014; Huijser et al., 2016b). In addition, different species use different habitats, influencing their movements and where they want to cross the road. Apart from habitat, other factors should be considered such as the vegetation and amount of cover adjacent to the crossing structure, amount of mixed use with humans and the level of their disturbance (e.g., motorized or non-motorized recreation). When assessing the performance of wildlife crossing structures in passing animals, it is important to allow for an adaptation period as wildlife use increases with the age of the structure (Gagnon et al., 2011; Clevenger et al., 2009; Huijser et al., 2016b). While wider structures are more expensive than narrow structures, the do provide better connectivity, consistent with expert advice on what is needed to reach the stated objectives (Brennan et al., 2022). Time allows wildlife to learn about the location of the structures and that it is safe to use them on a regular basis.

Wildlife crossing structures in combination with wildlife fences have a proven track record for reducing collisions with large wild mammals. Crossing structures and fences on the Trans-Canada Highway in Banff National Park reduced collisions involving all large mammals by >80% and ungulates >94% based on a comparison of a two-year pre-construction with a two-year post-construction analysis (Clevenger et al., 2001). A retrofit fencing project linking three existing crossing structures on Arizona SR 260 reduced elk-vehicle collisions by 98% over 6 years (Dodd et al., 2007). Seven small underpasses and fencing on US 30 in Wyoming reduced mule deer-vehicle collisions by 81% in the 3 years after their installation (Sawyer et al., 2012). However, wildlife crossing structures as a stand-alone measure do not necessarily reduce collisions with large wild mammals (Rytwinski et al., 2016). With 1-2 million large wild animals killed by cars every year; this mortality can significantly impact wildlife populations and threaten long-term population persistence, especially for threatened and endangered species (Huijser et al., 2007). Highways are the leading cause of mortality for some wide-ranging mammals (Maehr et al., 1991; Brandenburg, 1996). By physically separating wildlife from traffic, crossing structures protect individual animals from death or injury (Forman et al., 2003).

Wildlife crossing structures allow for safe passage across highways. More than 15,000 crossings by 16 species of animals were recorded at six underpasses along State Route (SR) 260 in Arizona over a seven-year period (Dodd et al., 2007). More than 49,000 crossings by mule deer were recorded at seven large culvert underpasses along US 30 in Wyoming in the first three years (Sawyer et al., 2012). More than 4,300 desert bighorn sheep crossed three overpasses on US 93 in Arizona in just over two years (Arizona Game and Fish Department, 2015). More than 150,000 crossings by 11 species of large mammals were detected between 1996-2014 at over two dozen crossing structures on the Trans-Canada Highway in Banff National Park, Alberta (Clevenger & Barrueto, 2014).

Highways can act as barriers that can isolate wildlife populations, disrupt seasonal migration, and alter gene flow (Riley et al., 2006). A system of wildlife crossing structures can allow individual animals to disperse, colonize or re-colonize other areas, and mate with individuals in other populations. Grizzly bear populations across western Canada and the northern U.S. have been documented as being genetically isolated by highways (Proctor et al., 2005). Research provided compelling evidence that wildlife crossing structures maintain genetically viable populations of black and grizzly bears that otherwise would be isolated by a high-volume highway (Sawaya et al., 2014). However, evaluating effectiveness of crossing structures in terms of improved connectivity is complicated and more research is warranted (Soanes et al., 2024)

The US Highway 93 North (US 93 North) reconstruction project on the Flathead Indian Reservation in northwest included the installation of wildlife crossing structures at 39 locations and approximately 8.71 miles (14.01 km) of road with wildlife exclusion fences on both sides. After reconstruction, 29 crossing structures were monitored with wildlife cameras to record wildlife use (Huijser et al., 2016b). Deer highway crossings (white-tailed deer and mule deer combined) either remained similar or increased after highway reconstruction. Black bear highway crossings remained similar after highway reconstruction. Since there was no indication of an increase in deer population size after reconstruction compared to preconstruction, the researchers concluded that the highway reconstruction and the associated mitigation measures did not reduce habitat connectivity for deer. Instead, when the learning curve is considered, habitat connectivity for deer across the highway increased in the mitigated road sections. The researchers did not have data on potential changes in black bear population size before and after highway reconstruction. Assuming there were no substantial changes in the black bear population size, habitat connectivity for black bear across the highway was at least similar before and after reconstruction in the mitigated road sections. This suggests that, even though wildlife could no longer cross the highway anywhere, the mitigation measures maintained or improved habitat connectivity for deer and black bear.

Potential undesirable side effects

Wildlife underpasses and overpasses are sometimes believed to attract predators, allowing them to hunt more efficiently (Hunt et al., 1987). However, this prey-trap theory was not confirmed in two separate studies, a literature review of the potential side effects of crossing structures as prey traps (Little et al., 2002) and using field data on predator-prey interactions (Ford & Clevenger, 2010; Plaschke et al., 2021).

Costs of the measure

As the rates of collisions with large wild mammals have increased over the past two decades, agencies are increasingly seeking to mitigate highways in more cost-effective ways. Wildlife crossing structures in combination with wildlife fences reduce collisions, thus effectively reducing the costs to society, e.g., human fatalities, human injuries, property damage, loss of hunting revenue, etc. (Conover et al., 1995; Huijser et al., 2009). These estimated annual benefits from reduced wildlife-vehicle collisions have exceeded $200,000/mile (Dodd et al., 2012).

The cost of a wildlife underpass or overpass varies greatly, even within the United States (Huijser et al., 2022). Highway configuration (size, dimensions) obviously will affect the cost of crossing structures. But if configuration was controlled for, factors such as the terrain at the site, proximity to construction materials and disposal, local or regional economic status (high market or low market value for services and supplies) and cost of prime materials (e.g., steel) all influence final cost.

The cost of the mitigation measures is based on a review of the literature and interviews with researchers, manufacturers, and transportation agency personnel. The following are costs for the most standard crossing structures types across a 4-lane highway. The smallest underpass is a prefabricated concrete box culvert (2.6 x 2.8 m) and generally costs $US 600,000. Elliptical multi-plate steel culverts (4 x 7 m) are roughly 1 million dollars. Large open span bridge underpasses (3 x 12 m) generally cost $2 million. The most recently constructed 50-m wide wildlife overpasses often cost in the range of $5-15 million.

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2.5 Summary of mitigation measures

The effectiveness of reducing collisions with large animals and reducing the barrier effect of the roads to wildlife movement for each of the mitigation measures that have been reviewed are summarized in Table 1. Color coding indicates how each effective each mitigation measure is in reducing collisions and increasing permeability for large wild animals. Question marks indicate the published and unpublished literature does not have any information on the measure’s effectiveness.

If reducing collisions with large wild mammals is the only objective, and if there are no side-boards (including ethics) the most effective measures include roadside animal detection systems, wildlife culling, wildlife relocation, anti-fertility treatments, wildlife barriers (fences), and wildlife fences in combination with wildlife crossing structures (Table 1). If the objectives include both reducing collisions with large wild mammals and maintaining or improving connectivity for large wild mammals, and if ethics regarding associated impacts are considered, then there is only one approach that is highly effective: wildlife barriers (fences) in combination with wildlife crossing structures.

Table 1. Summary table of mitigation measure effectiveness in reducing collisions with large mammals and reducing the barrier effect of roads. Legend: Red = effectiveness is unknown, not existent or negligible (<25%); Orange = effectiveness is moderate or potentially moderate (orange) (25-80%); Green = effectiveness is likely high or substantial (>80%), at least under some circumstances.

Measure	Effectiveness in reducing collisions with large mammals	Effectiveness in reducing the barrier effect of roads and traffic for large mammals
Mitigation measures aimed at influencing driver behavior		
Public information and education	Unknown-None	None
Standard wildlife warning signs	None	None
Large and other nonstandard wildlife warning signs (VMS)	None	None
Seasonal wildlife warning signs	9-50%	None
Roadside animal detection systems (RADS)	33-97%	None
On-Board Vehicle Warning Systems	Unknown, but has potential	None
Increase visibility: roadway lighting	57-68%	None. May increase barrier effect for some species
Increase visibility: vegetation removal/brushing	≤50%	None, May increase barrier effect for some species
Increase visibility: wider road striping	Unknown	None
Reduce traffic volume on road network	Unknown	Likely to reduce barrier effect
Reduce speed by reducing posted speed limit	(Almost) none (for through roads, given their design speed)	None
Reduce speed by reducing night-time posted speed limit	None	None
Reduce speed with traffic calming measures	Unknown - 59%	Unknown
Mitigation measures aimed at influencing animal behavior or population size		
Lines of visual or audio signals along roadside	None	None - Potential increase barrier effect
Lights on vehicle to increase visibility of vehicle to animals	71%	None
Deer whistles installed on vehicles	None	None - Potential increase barrier effect
Olfactory repellants	26-43% for certain species only	None - Potential increase barrier effect
Hazing	Unknown	None - Potential increase barrier effect
Wildlife crossing personnel	Unknown - Likely	None – Potential decrease barrier effect
Deicing- alternatives to salt	Unknown	None
Influence nutritional value of Right-of-Way vegetation	Unknown - ≤50%	None - Potential increase barrier effect

Habitat alteration outside ROW, Intercept Feeding	Unknown	None - Potential increase barrier effect
Vegetated median	Unknown	Unknown
Wildlife culling	30-94%	None
Wildlife relocation	30-94%	None
Anti-fertility treatment	Reduction proportional to reduction in population size	None
Mitigation measures that attempt to separate animals from the road		
Wildlife barriers (fencing/walls/boulders)	80-100% (83% on average)	None. Fences alone make the road into more of a barrier than without fences
Underpasses and overpasses	Not necessarily	Barrier effect can be substantially reduced
Underpasses/overpasses and fencing	80-100% (83% on average)	Barrier effect can be substantially reduced

3 Small wild animal species

3.1 Introduction

This chapter focusses on measures to reduce direct road mortality of small- and medium-sized wild animal species and on measures that provide safe crossing opportunities. For this chapter, small- and medium-sized animal species include mammal species up to coyote size, reptiles, and amphibians, with an emphasis on species that are of conservation concern in Wisconsin (Huijser & Bell, 2025). This chapter only relates to species that are fully or predominantly terrestrial (i.e. excluding flying species and arboreal species).

The findings for measures aimed at reducing collisions with large wild mammals (see earlier chapter) tend to also apply to small wild animal species. Rather than repeating the information from the earlier chapter, this chapter highlights the differences between measures aimed at reducing collisions with large wild mammals and those primarily aimed at small wild animal species. An important difference between collisions with large mammal species and small animal species is reduced risk for human safety. Small animal species are typically not large or heavy enough to result in substantial vehicle damage, human injuries or human fatalities in case of a collision. However, there are exceptions. For example, hard-shelled turtles may become a dangerous projectile when squeezed between the tires of another car and the pavement and may present a danger to drivers of other vehicles (CNN, 2020). But in most cases where substantial vehicle damage, human injuries of human fatalities have occurred in association with small animal species on the road, it is not the collision itself that presented the greatest risk. In general, swerving, and lane and road departure pose the biggest threat to human safety, as well as vehicle damage, human injuries and fatalities because of people who have stopped traffic in an effort to remove a small animal from the road.

Recording road-killed small species may require high frequency monitoring at slow speed, perhaps even traveling on foot (e.g. Langen et al., 2007; Teixeira et al., 2013). Some species can suffer massive road mortality, especially amphibian and reptile species (e.g. Aresco, 2005; Bouchard et al., 2009). Some amphibian and reptile species respond to approaching cars by staying immobile (Andrews & Gibbons, 2005; Mazerolle et al., 2005), contributing to increased time on the road and high mortality. Many reptile species depend on a long life-span for population persistence, and direct road mortality of adults, especially females, can result in population crashes and extirpation (Seburn & Seburn, 2000). Rare species are not only rarely encountered, but their carcasses may be removed (legally or illegally) by others before agency personnel, researchers, or citizen scientists come by. If the interest is to reduce road mortality of small or rare species, it becomes increasingly likely that reducing roadkill is not only or not primarily about human safety; it is more about biological conservation. In this context, it may be a good strategy to not only focus on current road mortality hot spots, but to also address historic roadkill hot spots that may have acted as a population sink in the past and where the population is now so depleted that it no longer shows up as a hot spot for collisions (Teixeira et al., 2017). Depending on species characteristics, sites that require mitigation for small or rare species may need to be primarily based on suitable habitat or corridors instead of carcass data (Jaeger & Fahrig, 2004).

Small animal species, especially small mammals, depend on cover and tend to avoid crossing open areas because of predation risk and abiotic conditions (Hampton, 2007; Bergstrom et al., 2018). Therefore, open linear corridors such as roads tend to represent a greater barrier effect to small animal species than to large mammal species. Not surprisingly, this barrier effect increases with increasing road width (e.g. Goosem, 2001; Rico et al., 2007). Some species, especially amphibian species including toads and salamanders, have strong seasonal migration. When a road crosses the animal's path between their hibernation sites and breeding and summer sites, mass mortality can occur (Ottburg & van der Grift, 2019; Seburn & Seburn, 2000). In addition, wetland dependent species may also move in high numbers when wetlands dry during droughts (Aresco, 2005; Rees et al., 2009). Other species, especially turtles and snakes, are attracted to the roadside environments for nesting or temperature regulation (Reses et al., 2015; Mccardle & Fontenot, 2016; Paterson et al., 2019, Piczak et al., 2019).

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3.2 Mitigation measures aimed at influencing driver behavior

In this section we summarize mitigation measures that aim to reduce collisions with small animal species through influencing driver behavior.

3.2.1 Outreach to drivers

Summary
No quantitative information is available about the potential effectiveness of outreach to drivers on reducing collisions with small animal species. However, given typical operating speed on most highways and given the small body size of the animals, the measure is not likely effective on most major highways. Providing outreach to drivers does not reduce the barrier effect of roads and traffic.

Descriptive narrative
Road signs, brochures and other outreach material are sometimes distributed to visitors of protected areas in an attempt to reduce direct road mortality of small mammal species. For example, Snow Canyon State Park in Utah, USA hands out brochures to visitors warning drivers about desert tortoises on and close to the road and how to move them off the road (Utah State Parks, 2018). Checking for tortoises that may be under parked vehicles because of the shade they provide is also encouraged. Wisconsin DOT has a citizen scien program to report turtles on roads (WisDNR, 2025).

No quantitative information is available about the potential effectiveness of outreach to drivers on reducing collisions with small animal species. However, given typical operating speed on most highways and given the small body size of the animals, the measure is not likely effective on most major highways. Furthermore, providing outreach to drivers does not reduce the barrier effect of roads and traffic.

Potential undesirable side effects
Unknown.

Costs of the measure
Unknown.

References

Utah State Parks. 2018. Snow Canyon State Park. https://site.utah.gov/stateparks/wp-content/uploads/sites/13/2018/05/Snow-Canyon-Brochure-2018_web.pdf

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3.2.2 Wildlife warning signs

Summary
The effectiveness of warning signs in reducing collisions with small animal species is poorly studied and could potentially be zero. Warning signs do not reduce the barrier effect of roads and traffic on wildlife as the measures do not make it easier for animals to cross the road.

Descriptive narrative
Warning signs for snakes may have resulted in fewer road-killed snakes, but the results were inconclusive for turtles (Ministry of Transportation, 2017). Other warning signs were not effective in reducing road mortality for turtles (Seburn & McCurdy-Adams, 2019). An experiment where dummy snakes were positioned on the road after warning signs showed that 61% of the drivers who had just passed the sign changed their behavior, compared to 37% with no sign present (Collinson et al., 2019). The change in driver behavior reduced collisions with the dummy snake; 98% of drivers who had changed their behavior did not hit the fake snake. Other drivers aim to hit and kill certain species (e.g. reptiles), and they may use the information provided by the warning signs to be more alert and try and hit the animals (Ashley et al., 2007). The effectiveness of warning signs in reducing collisions with small animal species is poorly studied and could potentially be zero. In addition, warning signs do not reduce the barrier effect of roads and traffic on wildlife as the measures do not make it easier for animals to cross the road.

Potential undesirable side effects
Wildlife warning signs that depict unusual species are prone to theft (Gunson & Schueler, 2012; Ministry of Transportation, 2017).

Costs of the measure
Warning signs usually cost a few hundred US $ each.

References

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3.2.3 Temporary or permanent road closure

Summary
The effectiveness of temporary or permanent road closure in reducing collisions with small animal species is 100% during the period the road is closed, as no as no vehicles drive on the road sections concerned. Temporary or permanent road closures do not necessarily reduce the barrier effect of roads and traffic on wildlife as a road closure still requires the animals to travel across an open area with unnatural substrate.

Descriptive narrative
Temporary or permanent road closures can reduce collisions with small animal species by 100% during the time of closure as there are no vehicles present. The road closures can be night-time only, migration season only, or they can be permanent (e.g., McNamara, 2015). Such temporary or permanent closures typically occur on low volume roads and in locations where there is extensive community support, and where there is a short migration season (e.g., spring migration of amphibians or snakes) (Jackson et al., 2015; U.S. Forest Service, 2016; Scruton, 2017; An, 2018). Depending on the species and when they move, closures may only be in effect during the night.

The effectiveness of temporary or permanent road closure in reducing collisions with small animal species is 100% during the period the road is closed, as no as no vehicles drive on the road sections concerned (Katz, 2017). Temporary or permanent road closures do not necessarily reduce the barrier effect of roads and traffic on wildlife as a road closure still requires the animals to travel across an open area with unnatural substrate.

Potential undesirable side effects
No vehicle can drive on the closed road sections during the closures. This makes it only feasible in select situations. Gates or other barriers that are put in place to deny access to vehicles may be vandalized, removed and the closure may not be respected. Diverting traffic to other roads can increase traffic volume and collisions with wildlife species on those other roads.

Costs of the measure
Unknown.

References

An, B. 2018. South Park Drive to close for newt migration, breeding season. Retrieved from https://www.dailycal.org/2018/11/12/south-park-drive-to-close-for-newt-migration-breeding-season/

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3.2.4 Road removal

Summary
The effectiveness of road removal in reducing collisions with small animal species is 100%. If road removal is combined with recontouring, and if soil, hydrology, and vegetation are restored similar to that of the surrounding area, the barrier effect of roads and traffic on wildlife can disappear.

Descriptive narrative
Road removal can include the removal of unnatural substrate (e.g., asphalt, concrete, or gravel), recontouring, and the restoration of soil, hydrology, and vegetation. This means that collisions with vehicles can be reduced by 100% and that the barrier effect of the former road corridor can also be removed. Such road removal typically occurs on low volume resource extraction roads that may no longer be needed such as roads associated with logging or mining (e.g., Simmers & Galatowitsch, 2010; Switalski & Nelson, 2011). If road removal is combined with recontouring, and if soil, hydrology, and vegetation are restored similar to that of the surrounding area, the barrier effect of roads and traffic on wildlife can disappear.

Potential undesirable side effects
Traffic can no longer drive on a removed road and if the road bed is removed, the road cannot simply be reopened. This makes it only feasible in select situations, usually for resource extraction roads after the extraction is completed.

Costs of the measure
Unknown.

References

Switalski, A.T & C.R. Nelson. 2011. Efficacy of road removal for restoring wildlife habitat: Black bear in the Northern Rocky Mountains, USA. Biological Conservation 144 (2011) 2666–2673

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3.3 Mitigation measures aimed at influencing animal behavior or population size

In this section we summarize mitigation measures that aim to reduce collisions with small animal species through influencing animal behavior or population size.

3.3.1 Passage friendly curbs

Summary
The effectiveness of passage friendly curbs in reducing collisions with small animal species is not or barely studied. The same applies to reducing the barrier effect.

Descriptive narrative
Small animal species may not be able to leave the roadway if they cannot pass the steep curbs on the edge of the road. This means that animals spent more time on the pavement, have increased risk of being killed by a vehicle, and that the barrier effect of the road and traffic is higher than a road with a passable curb. Impassable curbs may also guide small animal species to drainage pits, leading to entrapment, drowning, and death (see e.g., Jackson et al., 2015). More gentle slopes of curbs can allow small animals such as salamander species to depart the roadway (Fukumoto & Herrero, 1998; Jackson et al., 2015; Parks Canada 2021). In addition, a rougher texture on curbs and openings in the curbs have been created to allow desert tortoises to leave the roadway in Joshua Tree National Park (Pers. Com. Michael Vamstad, Joshua Tree National Park). Overall, the effectiveness of passage friendly curbs in reducing collisions with small animal species is not or barely studied. The effectiveness of passage friendly curbs in reducing the barrier effect with small animal species is not or barely studied. However, salamanders were able to climb the gentle slopes of curbs in Waterton Lakes National Park (Fukumoto & Herrero, 1998) and desert tortoises can climb a rougher texture on curbs (Pers. Com. Michael Vamstad, Joshua Tree National Park)

Potential undesirable side effects
No immediate undesirable side effects.

Costs of the measure
Unknown.

References

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Parks Canada. 2021. Waterton Lakes National Park. Saga of the salamander. https://www.pc.gc.ca/en/pn-np/ab/waterton/nature/faune-wildlife/salamandre-salamander

3.4 Mitigation measures aimed at separating animals from the road

In this section we summarize mitigation measures that aim to reduce collisions with small animal species through separating animals from the road.

3.4.1 Assisted road crossings

Summary
The effectiveness of assisted road crossings in reducing collisions with small animal species is not or barely studied. However, if assisted road crossings take place in combination with barriers such as drift fences, and if such barriers indeed keep most animals off the road, a substantial reduction in road mortality is likely. The effectiveness of assisted road crossings in reducing the barrier effect with small animal species is not or barely studied.

Descriptive narrative
Assisted road crossings involve people that carry an animal across the road in the direction it was moving. This can be a concerned traveler responding to an individual animal on or near the road (e.g., Utah State Parks, 2018), or it can involve a more coordinated approach for specific road sections where small animal mortality and crossings are a major concern (e.g., Jackson et al., 2015). The latter often relates to road sections with seasonal migration of amphibian or reptile species. “Bucket Brigades” may carry animals to the other side of the road (Jackson et al., 2015; Ottburg & van der Grift, 2019; Harris Center, 2021). In some cases, animals are kept off the road by a temporary barrier (e.g., a drift net fence) and this drift net guides the animals towards pit-falls (e.g., a bucket buried into the soil). People, often organized volunteers, can then transport the animals to the other side of the road. Such efforts are usually along specific road sections, along low volume roads, and during migration season only.

The effectiveness of assisted road crossings in reducing collisions with small animal species is not or barely studied. However, if assisted road crossings take place in combination with barriers such as drift fences, and if such barriers indeed keep most animals off the road, a substantial reduction in road mortality is likely. The effectiveness of assisted road crossings in reducing the barrier effect with small animal species is also not or barely studied.

Potential undesirable side effects
People that walk on or along the road in the dark may be in danger because of passing traffic. In addition, some snake or turtle species (e.g. snapping turtles) may pose a risk for human safety. While assisted migration can reduce the barrier effect of roads and traffic for the target species, other species do not benefit.

Costs of the measure
Unknown.

References

Harris Center 2021. Harris Center for conservation education. https://harriscenter.org/programs-and-education/citizen-science

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Utah State Parks. 2018. Snow Canyon State Park. https://site.utah.gov/stateparks/wp-content/uploads/sites/13/2018/05/Snow-Canyon-Brochure-2018_web.pdf

3.4.2 Alternate habitat creation

Summary
If the original habitat remains, collisions and the barrier effect may not be reduced. Instead, the mortality and barrier effect in the original habitat are compensated for through the creation of new habitat and improving connectivity between habitat patches.

Descriptive narrative
Alternate habitat creation requires careful planning to influence the movement of animals away from a road or lessen the need for an animal to be near a road or cross a road. Examples are artificial nesting mounds created for turtles (Paterson et al., 2013), or new wetlands for amphibians (Merrow, 2007; Hamer et al., 2021). The effectiveness of these measures at reducing road mortality are not known and difficult to quantify. New habitat should preferably be created outside of the road effect zone (e.g., perhaps at least 1 km from roads for amphibians (Hamer et al., 2021). This can be described as "off-site mitigation" or "compensation" rather than "avoidance" or "on-site mitigation". If the original habitat still remains near a road, the negative effects on the animals that live in that habitat will continue to occur. The creation of the new habitat is intended to compensate for these negative impacts on habitat close to the road.

The effectiveness of creating alternative habitat in reducing collisions with small animal species is largely unknown. However, if the original habitat remains, collisions may not be reduced. Instead, the losses in the original habitat are compensated for through the creation of new habitat, if the animals reach that habitat and build up a local population.

This measure does not reduce the barrier effect for the individuals that live in the original habitat close to the road. Instead, the barrier effect in the original habitat is compensated for through the creation of new habitat, and connectivity between other habitat patches, as long as the animals reach that habitat, build up a local population, and are effectively connected to nearby habitat patches.

Potential undesirable side effects
Direct road mortality will continue to occur in the original habitat. This may be a public relation problem. In addition, care must be taken that the original habitat close to the road is not a population sink that draws individuals from "safe" locations further away from the road.

Costs of the measure
Unknown.

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3.4.3 Fences or barrier walls

Summary
A review of the effectiveness of fences or barrier walls in reducing direct road mortality of small animal species found an average reduction of 65% (minimum 16%, maximum 100%). Barriers as a stand-alone mitigation measure do not reduce the barrier effect of a road corridor; they increase the barrier effect.

Descriptive narrative
The primary function of barriers is to reduce direct road mortality by keeping the animals off the road. However, barriers alone result in habitat fragmentation, and smaller and more isolated populations have reduced survival probability. Therefore, barriers are typically combined with safe crossing opportunities such as underpasses and overpasses. In some cases, direct road mortality is an immediate threat to a species' continued presence in the landscape, and measures to reduce direct road mortality need to be taken "immediately" (Jaeger & Fahrig, 2004). In such cases, fences or other barriers as a stand-alone measure may be considered as a short-term emergency measure. Nonetheless, the long-term application of barriers should typically be combined with safe crossing opportunities. This is not only because of the target species' need for connectivity, it is also because of other species that may be affected by the near absolute barrier that the road corridor now represents.

Barriers can consist of fences, or they can be barrier walls. A barrier wall can either be erected on the surface or be integrated into the roadbed. The latter does not obstruct the view of the landscape from the road, and small animals can exit the road corridor anywhere by jumping or falling off the barrier wall that is integrated into the roadbed. Depending on the target species, local soil and hydrology, and desired long-term maintenance effort, fences can be constructed from a variety of materials including chain-link, concrete, plastic, hardware cloth, or wood, typically varying in height between 40-120 cm (16-47 inches) and are usually dug into the ground 11-15 cm (>4-6 inches) (Gunson & Huijser, 2019; Huijser & Gunson, 2019; Langton & Clevenger, 2020). A review on the effectiveness of barriers in reducing direct road mortality of small animal species found an average reduction of 65% (minimum 16%, maximum 100%) (Gunson & Huijser, 2019). The design or selection of a barrier should be consistent with the behavior and abilities of the target species (e.g. Macpherson et al., 2021). Barriers may include a lip or overhang (e.g., Dodd et al., 2004). Solid fences result in fewer attempts to breach the fence and faster movement rates than transparent or semi-transparent barriers (Brehme & Fisher, 2021).

Barriers are typically combined with fence-end treatments, access road treatments, and jump-outs (Langton & Clevenger, 2020). Fence-end treatments can include a fence that angles away from the road, or even angle back 180 degrees (Langton & Clevenger, 2020), and they are important to the overall effectiveness of a barrier (Helldin & Petrovan, 2019). Access road treatments can include tunnels under the side road that are connected to the barrier along the main road (Langton & Clevenger, 2020). Jump-outs can have varied designs (Langton & Clevenger, 2020).

A review on the effectiveness of barriers in reducing direct road mortality of small animal species found an average reduction of 65% (minimum 16%, maximum 100%) (Gunson & Huijser, 2019). The design of the barriers needs to take the behavior and other biological characteristics of the target species into account (e.g., Woltz et al., 2008; Boyle et al., 2021). Maintenance of fences or other barrier structures is critical to its effectiveness in reducing direct road mortality (Baxter-Gilbert et al., 2015; Reses et al., 2015). Barriers as a stand-alone mitigation measure do not reduce the barrier effect of a road corridor but they increase the barrier effect.

Potential undesirable side effects

Barriers as a stand-alone mitigation measure do not reduce the barrier effect of a road corridor but they increase the barrier effect. In general, barriers should be combined with safe crossing opportunities such as underpasses and overpasses. When animals spend substantial time walking along or at barriers, overheating can result (Peaden et al., 2017; Boyle et al., 2019). Remedies include fence material that the animals cannot see through (opaque vs. translucent) and that do not cause the animals to try and go through mesh fences or to try and climb the barrier (Sievert & Yorks, 2015). Other measures include the provision of shade structures along a barrier (USFWS, 2020).

Costs of the measure

Barriers for small animal species can vary in costs between $40 and >$100 per meter (Huijser & Gunson, 2019). In Minnesota, the costs for chain-link fence on different project was $45,117 for 1640 ft ($90 per meter), $19,186 for 610 ft ($103 per meter), and $47,366 for 1640 ft ($95 per meter) (Pers. comm. Chris Smith, Minnesota Department of Transportation).

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3.4.4 Crossing structures

Summary
Crossing structures alone do not necessarily reduce direct road mortality. Effectiveness in collision reduction is highest and most consistent in combination with physical barriers that keep wildlife off the highway and that guide them towards the crossing structures. Much of the research has only evaluated the use of crossing structures by small animal species and has not adequately measured the barrier effect reduction. However, small animal species do use wildlife crossing structures.

Descriptive narrative
Crossing structures allow animals to cross a road safely under (underpass) or over the road (overpass) The most important parameters for crossing structure effectiveness are the location, the type of crossing structure, and its dimensions. The primary function of crossing structures is to provide connectivity for wildlife. Thus, crossing structures should be located where connectivity is needed most. Often, the location is based on where animals are successfully or unsuccessfully crossing a road, but in other situations a crossing structure and associated measures may be required where good habitat is present, but where the local population has already been much depleted through direct road mortality and isolation from other populations. Crossing structures alone do not necessarily reduce direct road mortality (e.g. Cunnington et al., 2014; Rytwinski et al., 2016). Therefore, crossing structures should, in general, be combined with fences or barrier walls. Crossing structures may also be warranted in places where good habitat is present, where the animals still have good population size, but where the physical characteristics associated with a road may make crossing difficult (e.g., steep slopes associated with the road corridor, retaining walls, median barriers, wide open medians or wide open shoulders with habitat that is avoided by the species concerned).

Overpasses are typically large enough to host a variety of habitat types and micro-climates. This makes most overpasses well suited for a variety of species groups, including amphibians, reptiles, and small mammals. While some overpasses include amphibians, reptiles, or small mammals among the target species and while they are designed to meet their specific habitat requirements (van der Grift et al., 2010; see Huijser & Gunson, 2019), most overpasses are primarily constructed for large mammals and happen to also accommodate small animal species. In general, overpasses tend to be well suited for small animal species. It may take the animals days or weeks to cross to the other side of the road. Therefore, it is important that they find everything they need on top of or inside a crossing structure; continuous suitable habitat (soil, hydrology, light, temperature, vegetation, food, water, shelter). On the other hand, underpasses usually have limited light and precipitation, and this severely reduces vegetation, cover, and food inside many underpasses. In some situations, cover can still be provided through either natural (e.g., branches, root wads, rocks) or artificial materials (e.g. concrete center blocks, PVC pipes) (D'Amico et al., 2015; Langton & Clevenger, 2020). Water may be available in some underpasses, e.g., if the underpass is combined with a stream or river crossing, or where it crosses a wetland. A stream or river crossing should preferably have natural stream dynamics and natural substrate so that the hydrological conditions are similar to those outside the structure for aquatic species. Riparian and terrestrial habitat can further increase the use by species that depend on those habitat types. In some cases, dry wildlife passage opportunities are created through the installation of concrete, wood, and metal shelves that are 'built-in' (Martinig & Bélanger-Smith, 2016) and or added to an existing structure (Foresman, 2004). This is most common as a retrofit for a culvert that was originally installed for hydrology.

Underpasses can be made more suitable for small animal species by increasing the width and height and reducing the length to allow for light and precipitation further into the structure and to allow the air and soil temperature and moisture to be more similar to that of the surroundings (Matos et al., 2017; 2019). A bottomless structure allows for natural substrate that is less susceptible to erosion than a structure with a bottom and limited substrate. Finally, openings such as a semi-open roof in an underpass allows for more similar conditions inside and outside an underpass. The latter is often an integral part of the design of an "amphibian tunnel or culvert" (Andrews et al., 2015).

Underpass structures vary in size from small diameter culverts (e.g., 2 ft in diameter) to box culverts (2-3 m wide and high), to large underpasses (e.g. 7 m wide, 4-5 m high) up to bridges (e.g. 30-100 m wide or more) (Langton & Clevenger, 2020). Blockage of underpasses with leaves and other dead plant material, larger branches, logs, and other debris carried by water in a stream or river, and snow can be an issue, especially for relatively small culverts (Ford & Clevenger, 2009; Schroder & Sato, 2017; Langton & Clevenger, 2020).

Crossing structures alone do not necessarily reduce direct road mortality (e.g., Cunnington et al., 2014; Rytwinsk et al., 2016). Effectiveness in collision reduction is highest and most consistent in combination with physical barriers that keep wildlife off the highway and that guide them towards the crossing structures. However, in some cases, crossing structures with minimal guide-walls to crossing structures will reduce risk of road mortality when the crossing structure is situated entirely within specialized habitat used by the species, and the species will likely not use the road surface to travel to required habitat (e.g., Koehler & Gilmore, 2014; Buchanan, 2007).

Much of the research has only evaluated the use of crossing structures by small animal species and has not adequately measured the barrier effect reduction, i.e. the number of animals that safely crossed a road before mitigation versus the number of animals that safely crossed after mitigation. However, small animal species do use wildlife crossing structures (Chambers & Bencini, 2015; Schroder & Sato, 2017; Ford & Clevenger, 2019; Ottburg & van der Grift, 2019; Boyle et al., 2021). The location, type and dimensions of a crossing structure should take the habitat, species presence and abundance, and species behavior and other biological characteristics into account (Woltz et al., 2008; Wang et al., 2019). Note that insufficient mitigation can be harmful to a population; too few crossing structures have led to severe population decline for common toads (Ottburg & van der Grift, 2019).

Potential undesirable side effects

If crossing structures are not used by the target species, the road can become an absolute barrier. This is especially true when the road is upgraded and widened, and the target animal can no longer successfully cross the road at-grade. Furthermore, when crossing structures are not adequately spaced or there are not enough structures to match the movement distances of the target species, animals will either turn back or find a way to cross at-grade. Insufficient mitigation, including insufficient crossing structures can cause local population decline (e.g., Ottburg & van der Grift, 2019).

Costs of the measure

Crossing structures are priced by materials, and by installation. Maintenance costs will vary, especially in relation to erosion and debris in and at underpasses. Vernal pools and associated pumps and lines also required maintenance on top of an overpass in the Netherlands. Shelving systems and ramps installed in an underpass may require annual cleaning for debris or if the units have become dislodged. Costs of small examples of animal crossings are listed in Table 2. In general, underpasses, depending on their dimensions can cost between several tens of thousands of US$ and several hundreds of thousands US$ (Huijser & Gunson, 2019). Overpasses can cost between several million US$ and 10 million US$ or more.

Table 2. Examples of approximate costs (in Canadian Dollars) of crossing structures installed in Canada for small animal species.

Material type	Approximate Material Costs (per meter length)	Installation Costs (per meter length)	Comments
60 m wide wildlife overpass (mulit-species)	CDN $6.6 million dollars*		Combined installation and materials, cost of overpass in Yoho National Park, Canada
ACO wildlife tunnel (open top. 0.5 m wide and high)	CDN $800	CAN $1,000	Installed in various locations in Ontario, and B.C., Canada
Concrete box culvert (2.8 m x 3.3 m)	CDN $7,800	CAN $6,700	Installed in various projects in North America
Concrete box culvert (3.0 m x 2.1 m)	CDN $3,500	CAN $2,500	Installed on Monkton Road, Vermont (Slesar, 2017)

*Total cost, not per meter.

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3.5 Summary of mitigation measures

Mitigation measures aimed at reducing collisions with small animal species (amphibians, reptiles, small mammals) are partially similar to those for large wild mammals (Table 3). However, temporary or permanent road closure and road removal are sometimes implemented for small animal species, but rarely for large mammals. Since these measures limit the routes people can drive, these measures are usually very local and they mostly relate to short road sections that have, or had, very low traffic volume. Local measures are unlikely to benefit large mammal species that have large home ranges and that have populations that tend to occur over large areas. But small animal species may have very specialized habitat (e.g. a wetland) and small home ranges. Therefore, the small spatial scale of temporary or permanent road closure and road removal can be meaningful to small animal species. Nonetheless, the barrier effect of a road with open habitat and a non-natural substrate remains with temporary or permanent road closure. Only when road removal is combined with habitat restoration can the barrier effect disappear. Assisted road crossings for small animal species are somewhat comparable to wildlife crossing personnel for large mammals. This can reduce direct road mortality, but the barrier effect may or may not be addressed.

Barriers for small animal species tend to be, on average, less effective than those for large mammal species. This is likely because it is harder to design effective barriers for species that are small or species that are good at climbing or digging. It is possible to design barriers for small animal species that would be 80-100% effective in reducing direct road mortality. However, this requires more effort during the design and installation. Since maintenance is often poor or insufficient, it seems prudent to design robust barriers that do not require regular inspection and maintenance. Similar to large mammal species, crossing structures for small animal species can provide connectivity, but without fences they do not necessarily reduce direct road mortality. As a general rule, barriers for small animal species should be combined with crossing structures; these measures should be regarded as a package. For high volume roads and roads that cannot be closed or removed, the combination of barriers and crossing structures is the most robust and effective way to reduce direct road mortality for small animal species and while also allowing the animals to cross to the other side of a road.

Table 3. Summary table of mitigation measure effectiveness in reducing collisions with small animal species and reducing the barrier effect of roads. Legend: Red = effectiveness is unknown, not existent, or negligible (<25%); Orange = effectiveness is moderate or potentially moderate (orange) (25-80%); Green = effectiveness is likely high or substantial (>80%), at least under some circumstances.

Measure	Effectiveness in reducing collisions with small animal species	Effectiveness in reducing the barrier effect of roads and traffic for large mammals
Mitigation measures aimed at influencing driver behavior		
Public information and education	Unknown-None	None
Warning signs	None	None
Temporary or permanent road closure	100%	Unknown: Traffic is no longer present, but open area with unnatural substrate remains
Road removal	100%	100% if soil, hydrology, and vegetation is restored
Mitigation measures aimed at influencing animal behavior or population size		
Passage friendly curbs	Unknown, but it can reduce the time spent on road by the animals	Unknown, but the barrier effect of the road and traffic remain
Mitigation measures that attempt to separate animals from the road		
Assisted road crossings	Unknown, but a reduction in likely	Unknown
Wildlife barriers (fencing/walls/boulders)	65% (range 16-100%)	None: barrier effect increases
Underpasses and overpasses	Not necessarily	Likely effective
Underpasses/overpasses and fencing	65% (range 16-100%)	Likely effective