AN ANALYSIS OF WILDLIFE-VEHICLE COLLISIONS, WILDLIFE CONNECTIVITY CONCERNS AND POTENTIAL MITIGATION MEASURES, US HWY 89, NATIONAL ELK REFUGE, JACKSON HOLE, WYOMING, USA

by

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16. Abstract

The National Elk Refuge is managed as winter habitat for elk. The elk receive supplementary feed on the refuge as a substantial part of their former winter range is now used for housing and agriculture. The elk migrate north, east, and west to their summer range in the spring, and migrate back to the refuge in fall/early winter (peak around mid-November – early December). The elk that migrate west in the spring are suspected to primarily cross under the bridge across the Gros Ventre River and around the north end of the wildlife fence. However, when the elk return in the fall they also approach the refuge further south (between the Gros Ventre River and Jackson). These elk then encounter a wildlife fence on the east side of the road. The elk have to use one of seven jump-outs or escape ramps integrated into the wildlife fence to enter the refuge, or walk north to the bridge across the Gros Ventre River. Many of the elk have trouble finding and using the jump-outs, causing them to run back and forth along the fence on the east side of the highway resulting in additional risk of wildlife-vehicle collisions and potentially failed migratory movements. This report is at the request of US Fish & Wildlife Service and it explores potential future mitigation measures aimed at reducing large-mammal-vehicle collisions on US Hwy 89/191/26 alongside the National Elk Refuge, and allowing migrating elk, specifically during the fall migration, to more easily access the refuge.

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1. INTRODUCTION

1.1. Background

The National Elk Refuge is located just northeast of the town of Jackson, Wyoming (Figure 1). The refuge, about 24,700 acres in size, is situated adjacent to Grand Teton National Park to the north, and the Bridger-Teton National Forest to the east. The western boundary coincides with US Hwy 89/191/26 between Jackson and Gros Ventre Jct. The transportation corridor consists of a highway and a paved trail for bicyclists and pedestrians. The road section that borders the park is about 5.7 mi long (between the bridge across Flat Creek on northern edge of Jackson and the Gros Ventre River (Figure 1). A wildlife fence is situated between the transportation corridor and the refuge between the town of Jackson and the bridge across the Gros Ventre River. The fence is only situated on east side of the transportation corridor, not on the west side. The fence is adjacent to the transportation corridor, except where the fence goes around the fish hatchery (Figure 2). On the north end the fence ties into the bridge across the Gros Ventre River. The fence is relatively close to the edge of the pavement of US Hwy 89 south of the fish hatchery (12-22 m (39-72 ft)) and further away north of the fish hatchery (40-60 m (131-197 ft)).

The National Elk Refuge is managed as winter habitat for elk. The elk also receive supplementary feed on the refuge as a substantial part of their former winter range is now unavailable (i.e. the land is now used for housing, agriculture). The elk migrate north, east, and west to their summer range in the spring, and migrate back to the refuge in fall/early winter (peak around mid-November – early December). The elk that migrate west in the spring are suspected to primarily cross under the bridge across the Gros Ventre River and around the north end of the wildlife fence (Figure 2). However, when the elk return in the fall they also approach the refuge further south (between the Gros Ventre River and Jackson). These elk then encounter a wildlife fence on the east side of the road (Figure 2). The elk have to use one of seven jump-outs or escape ramps (height varies between 150-213 cm (59-84 inches), see Table 1) integrated into the wildlife fence to enter the refuge, or walk north to the bridge across the Gros Ventre River (Teton County, 2014) (Figure 2). Many of the elk have trouble finding and using the jump-outs, causing them to run back and forth along the fence on the east side of the highway. When the elk are disturbed or scared by humans (note that they are exposed to hunting), they tend to go back west, crossing the highway once again, resulting in additional risk of wildlife-vehicle collisions and potentially failed migratory movements. This is one of the reasons the bicycle/pedestrian path is closed to the public between 1 October and 30 April (Teton County, 2014), and there are no dogs allowed on the trail. The presence of bicyclists and pedestrians in winter would likely lead to an increase in failed attempts to cross the highway and enter the refuge and an increase in wildlife-vehicle collisions because of elk panicking, turning back and crossing the highway once again. Another reason the bicycle/pedestrian path is closed in winter is that the elk would likely not use a zone (perhaps 400-500 m wide) alongside the transportation corridor. This would reduce the carrying capacity of the refuge for elk, increase the need for supplementary feeding, increase stress and energy expenditure for the elk in winter, and increase elk concentrations and the potential for disease transmission. In addition, there are sleigh rides for tourists in winter (usually from the mid December – early April). The sleigh rides start from the highway, about 3 miles north of Jackson. The elk are not afraid of the horses pulling the sleigh, of the sleigh itself,

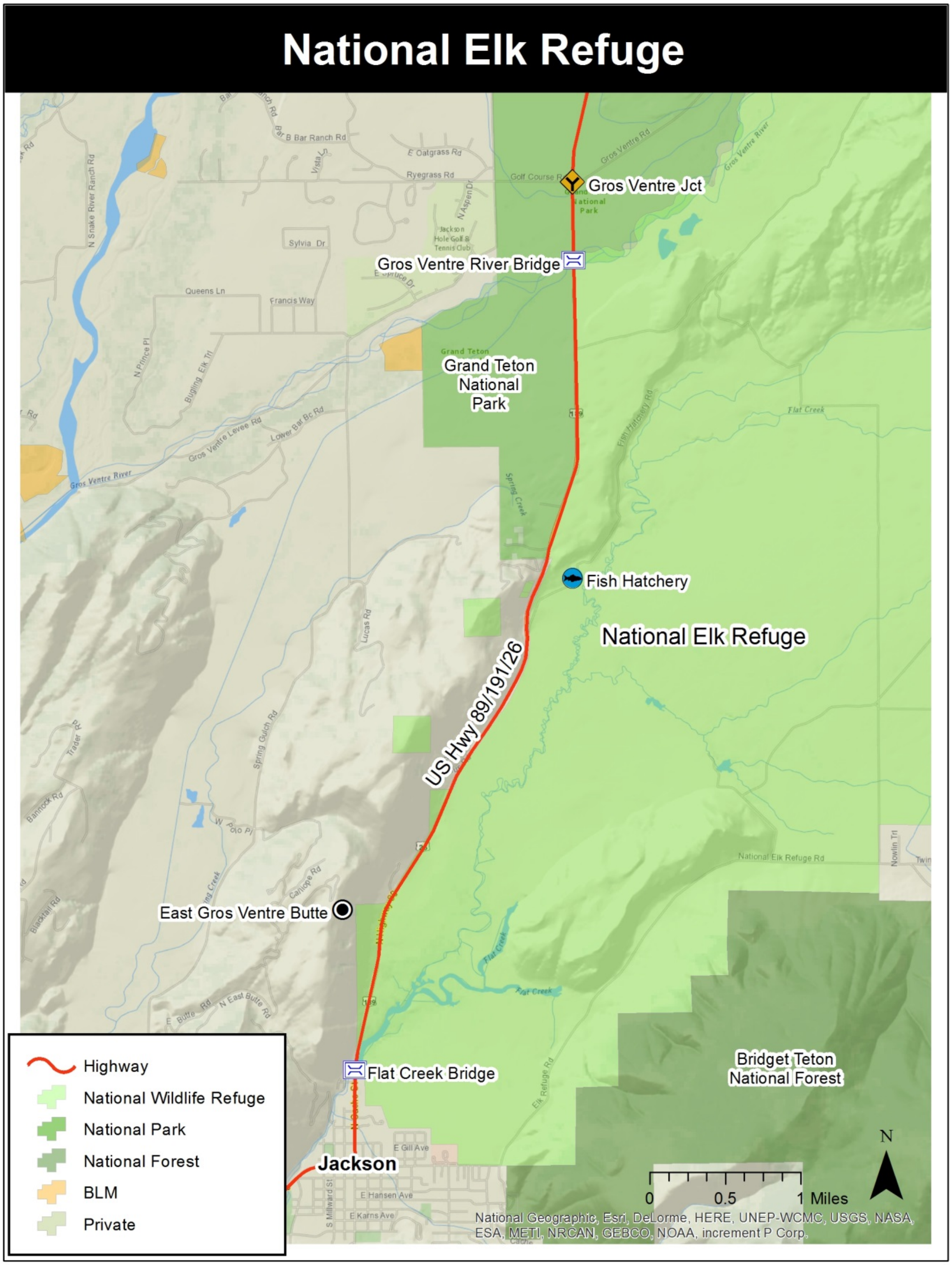

Figure 1: US Hwy 89/191/26 between Jackson and Gros Ventre Jct. The National Elk Refuge borders US Hwy 89/191/26 for about 5.7 mi between Flat Creek Bridge (south end) and Gros Ventre River bridge (north end).

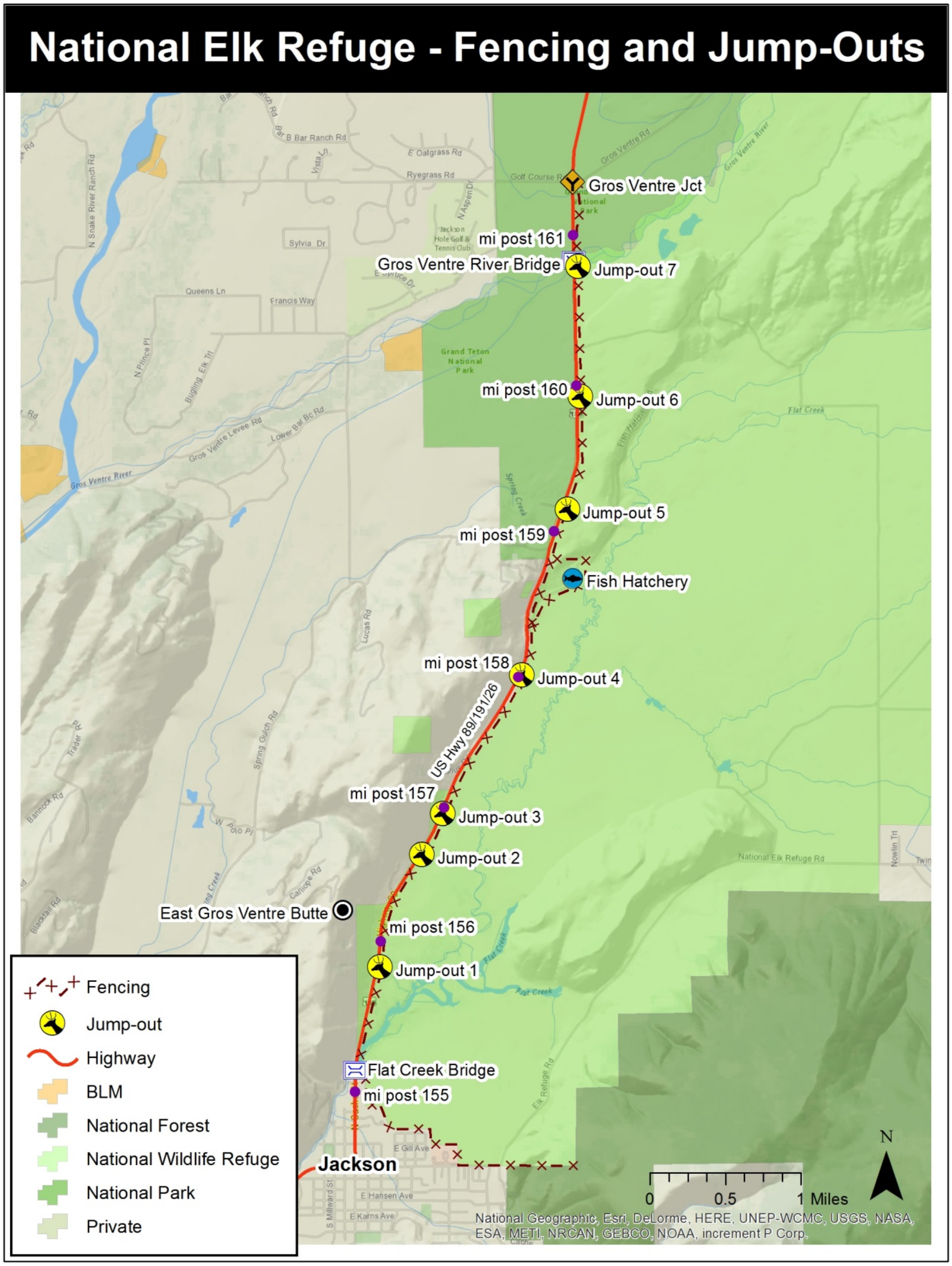

Figure 2: The location of the 2.4 m (8 ft) tall wildlife fence and the seven wildlife jump-outs along US Hwy 89/191/26 between Jackson and Gros Ventre Jct. The fence is also located along the northern edge of the town of Jackson.

Table 1: The height of the jump-outs shown in Figure 3. The height was measured from the top of the jump-out to the base, directly alongside the "wall" of the jump-out.

Jump-out #	Height (cm)	Height (inches)
1	150	59
2	178	70
3	196	77
4	213	84
5	180	71
6	163	64
7	178	70

nor of the people in the sleigh (as long as the people remain in the sleigh), allowing for excellent elk viewing opportunities. Experience has shown that pedestrians using the pathway during the closed season cause the elk to panic and flee away from the pathway. This would reduce wildlife viewing opportunities for the horse-drawn sleigh interpretive tours and for the public using US Hwy 89.

1.2. Existing Mitigation Measures

The primary purpose of the wildlife fence and jump-outs on the east side of the highway (see Figure 2) is to keep large ungulates, specifically elk and bison on the refuge in the winter months. However, if the goal is to reduce wildlife-vehicle collisions, wildlife fencing on both sides of the road, starting and ending at the same mile marker on opposite sides of the highway is generally recommended. It is generally not recommend installing wildlife fencing on only one side of the road. In this particular context though the wildlife fence was constructed by the National Elk Refuge on the refuge land, and the National Elk Refuge did not have authority over constructing a fence on the west side of the highway.

Measures aimed at reducing wildlife-vehicle collisions that are currently in place between Jackson and Gros Ventre Jct include wildlife warning signs and speed limit reduction (Figure 3). The posted speed limit is 55 mi/h along the east side of East Gros Ventre Butte. In the flats between the north end of East Gros Ventre Butte and the river the night time posted speed limit is reduced to 45 mi/h (since about 2012 (Pers. Comm. Steve Kallin, National Elk Refuge). North of the Gros Ventre River the posted speed limit is 45 mi/h day and night.

Note that standard or enhanced (i.e. with flags, permanently flashing warning lights, and non-standard images or symbols or text) wildlife warning signs are generally not considered effective in reducing collisions with large ungulates (see review in Huijser et al., 2009; in press). Reducing posted speed limit may only be effective if the new posted speed limit is 45 mi/h or less (Gunther et al., 1998), suggesting that wildlife-vehicle collisions may be reduced just north (both day- and night-time collisions) and south (night-time collisions only) of the Gros Ventre River. Night-time posted speed limit reduction from 60 or 65 mi/h to 55 mi/h may reduce ungulate-vehicle collisions by about 9% (CDOT, 2012).

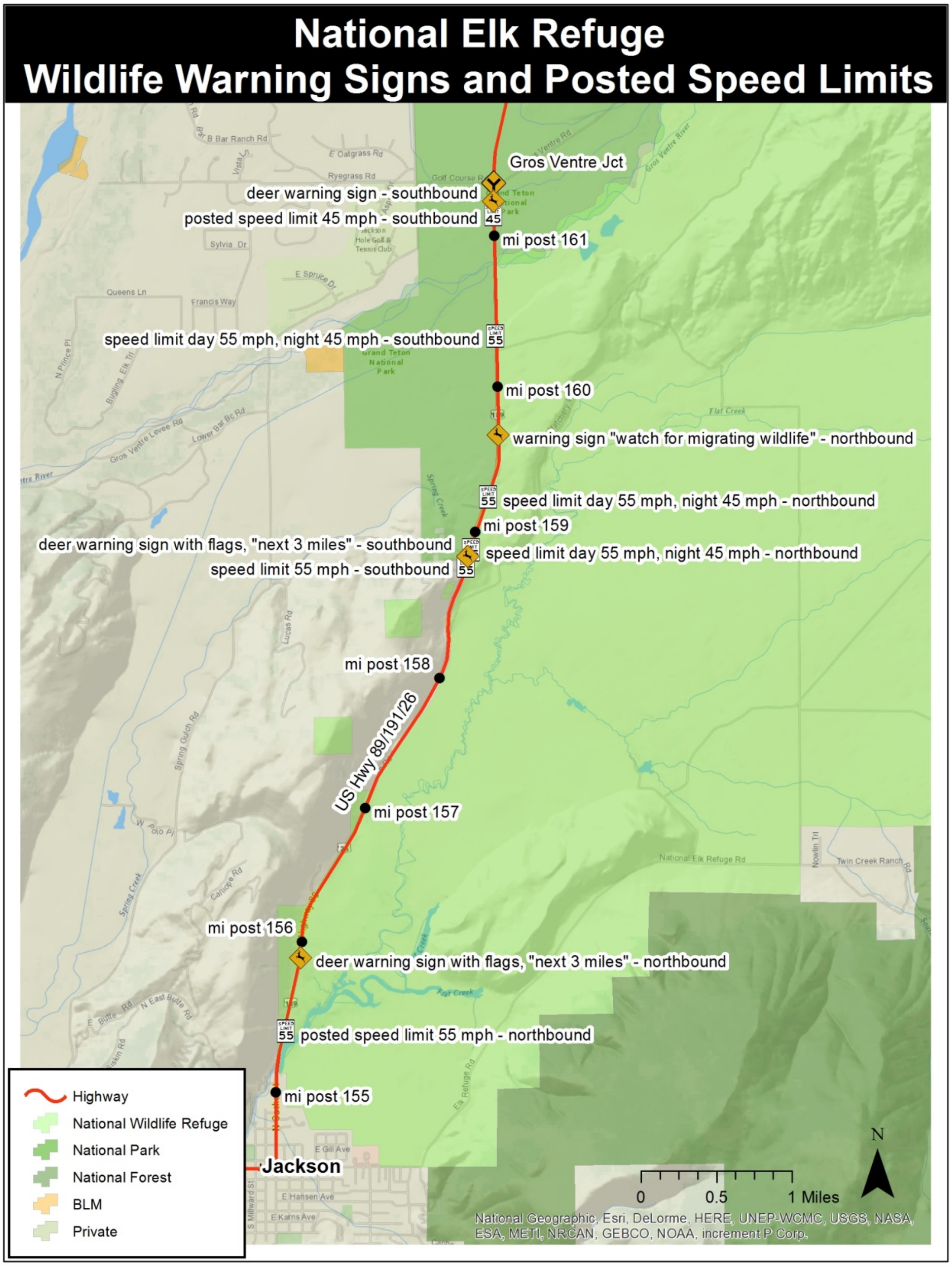

Figure 3: The location wildlife warning signs and the signs with the posted speed limit along US Hwy 89/191/26 between Jackson and Gros Ventre Jct.

1.3. Goals and Objectives

The general goal of the current project is to explore potential future mitigation measures aimed at reducing large-mammal-vehicle collisions on US Hwy 89/191/26 alongside the National Elk Refuge, and allowing migrating elk, specifically during the fall migration, to more easily access the refuge (Pers. Comm. Steve Kallin, National Elk Refuge).

The objectives are (Pers. Comm. Steve Kallin, National Elk Refuge):

1. Explore options for potential future safe crossing opportunities for large mammals under, across, or over US Hwy 89/191/26 between the bridge across Flat Creek on northern edge of Jackson and the Gros Ventre River. This would allow large mammals to enter and leave the refuge safely along the western border of the refuge. The crossing opportunities need to be suitable for bighorn sheep (*Ovis canadensis*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), and bison (*Bison bison*) Note that grizzly bears (*Ursus arctos*) are occasionally seen on the refuge, suggesting that they may also benefit from safe wildlife crossing opportunities across the highway corridor.
2. Explore options to make the potential future safe crossing opportunities a barrier for elk and bison attempting to leave the refuge during the winter months (especially February – April when elk or bison may abort their calves should they have been infected with brucellosis). Keeping the elk on the refuge when contamination is most likely reduces exposure of the cattle in the surrounding areas to brucellosis. The safe crossing opportunities should still allow for elk to enter the refuge (coming from the west, especially during fall migration mid-November – early December). Ideally the safe crossing opportunities should also allowing bighorn sheep to both leave and enter the refuge to improve connectivity with the bighorn sheep herd west of the Snake River. Note that a potential (seasonal) barrier to some species (e.g. elk, bison) should be "removable" should elk and bison be allowed to range free at some point in the future, especially if supplementary feeding is reduced or halted altogether. Note that mitigation measures should avoid or minimize impacting the viewshed from houses (i.e. occupants of houses would likely demand that the view of certain mountains (e.g. the Teton Range, Sleeping Indian Mountain) not be impacted by wildlife fencing, wildlife underpasses, overpasses or other mitigation measures.
3. Explore options to reduce large mammal-vehicle collisions along US Hwy 89/191/26 between the bridge across Flat Creek on northern edge of Jackson and the Gros Ventre River. Note that safe wildlife crossing opportunities (i.e. wildlife underpasses and overpasses) combined with wildlife fencing typically substantially reduce collisions with large mammals. A 79-97% reduction in collisions is expected (compared to unmitigated highways without fencing and without safe crossing opportunities) (review in Huijser et al., 2009). At grade crossing opportunities (i.e. a gap in the fence, with or without an animal detection system, with electric mats embedded in roadway to encourage the animals to cross the road straight rather than wander off in the fenced right-of-way) may also substantially reduce large mammal-vehicle collisions, but they may not be quite as effective (40-97% reduction in collisions) (review in Huijser et al., 2009). Note that animal detection systems should still be considered experimental with a relatively high risk of technological and management problems.

1.4. Tasks

The tasks for this project are described below:

Task 1. Conduct a field visit along US Hwy 89/191/26 between Flat Creek Bridge and Gros Ventre River bridge to:

a. Verify the location and dimensions of the wildlife fence, jump-outs, and potential gaps in the fence (e.g. access roads).
b. Record the GPS coordinates for the mile markers along US Hwy 89/191/26 between Flat Creek Bridge and Gros Ventre River bridge.
c. Obtain first impressions of the problems and potential solutions associated with the highway, wildlife and the management of the refuge.

Task 2. Obtain existing animal-vehicle crash data and carcass removal data from Wyoming Department of Transportation for US Hwy 89/191/26 between Flat Creek Bridge and Gros Ventre River bridge for the past 10 years or more (if data are indeed available). Use these data to identify road sections that may have a concentration of collisions with large mammals. Note that Huijser et al. (2011) already conducted similar analyses for the different highways around Jackson.

Task 3. Interview representatives of stakeholders including Grand Teton National Park, Bridger-Teton National Forest, the Wyoming Game and Fish Department, Teton County, and the Wyoming Department of Transportation with regard to:

a. The identification of (potential) problems related to the highway section described above, wildlife and the management of the refuge.
b. The potential future mitigation measures along US Hwy 89/191/26 between Flat Creek Bridge and Gros Ventre River bridge that would be supported. Note that the mitigation measures would be aimed at 1. Providing safe crossing opportunities for large mammals, and 2. (Further) reducing collisions with large mammals.
c. The potential future mitigation measures along US Hwy 89/191/26 between Flat Creek Bridge and Gros Ventre River bridge that would not be supported. Note that the mitigation measures would be aimed at 1. Providing safe crossing opportunities for large mammals, and 2. (Further) reducing collisions with large mammals.
d. Data or local knowledge and experience on where large mammals, including elk and bighorn sheep, may currently cross the transportation corridor successfully.
e. Data or local knowledge and experience on the use of the existing jump-outs (escape ramps) and movements of large mammals through potential gaps in the fence (e.g. at access roads).

Task 4. Conduct cost-benefit analyses, based on Huijser et al. (2009), for both the crash and carcass data for US Hwy 89/191/26 between Flat Creek Bridge and Gros Ventre River bridge (Similar to Huijser et al., 2011).

Task 5: Conduct a review of different types and combinations of mitigation measures which provide safe crossing opportunities for wildlife and substantially reduce wildlife-vehicle collisions primarily for elk, bison, deer, bighorn sheep, and potentially also grizzly bear. Document the pros and cons of these mitigation measures and estimate the relative costs of implementation. Explore the potential to provide one-way traffic for elk and bison in winter and early spring (only enter refuge, not leave) and two-way traffic for bighorn sheep (see earlier).

Task 6. Based on crash data, carcass removal data, data or local knowledge and experience on successful wildlife crossing locations, and the cost-benefit analyses, identify and prioritize road sections along US Hwy 89/191/26 between Flat Creek Bridge and Gros Ventre River bridge that may qualify for safe wildlife crossing opportunities.

Task 7: Provide a written report and present to US Fish & Wildlife Service personnel of the National Elk Refuge.

2. PROBLEM DEFINITION AND STRATEGIES TO ADDRESS THE PROBLEM

2.1. Collision Data Types and Problem Definition

For most federal and state roads in the U.S. there are two types of wildlife-vehicle collision data available: crash data collected by law enforcement agencies and carcass removal data collected by road maintenance crews. By definition, the crash data relate to the most serious collisions from the human perspective with substantial vehicle damage and/or human injuries and human fatalities. The reported crashes are associated with large mammals because of their size and weight. Carcass removal data typically also relate to large mammals only as their size and weight can be a serious obstacle and safety risk and distraction to the traveling public. Small and medium sized animal species, including most amphibians, reptiles, and small and medium sized mammal species are typically not removed from the road and thus not recorded in carcass removal databases maintained by transportation agencies. Thus, in most cases, crash data and carcass removal data can only be used to identify and prioritize locations along highways that that may require wildlife mitigation measures from the perspective of human safety or from the perspective of reducing collisions with large mammals. Furthermore the crash and carcass data are dominated by the most common ungulates in North America such as white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*) and moose (*Alces alces*) rather than threatened or endangered large mammal species.

If the concern is with direct road mortality for species or species groups other than common large mammals, specifically large common ungulates, then data sources other than crash data and carcass removal data may be required. A specific road-kill monitoring program may have to be developed. Depending on the exact goals of the project and the associated requirements, data may be collected by personnel from natural resource management agencies, researchers or the public.

While there is much emphasis on mitigating for wildlife-vehicle collisions in North America, crashes, dead animals, and associated costs and risks to humans are not the only reason mitigation for wildlife along highways may be considered. The authors of this report distinguish five different categories of effects of roads and traffic on wildlife that may trigger action (Figure 4):

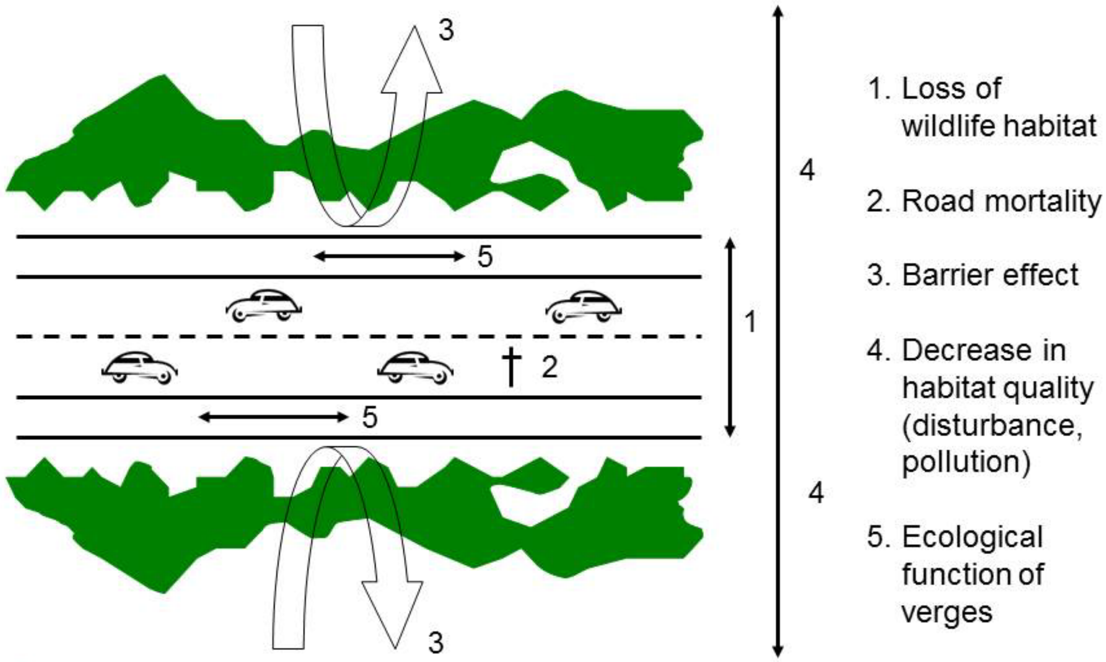

Figure 4: The effects of roads and traffic on wildlife.

- Habitat loss: e.g., the paved road surface, heavily altered environment through the road bed with non-native substrate, and seeded species and mowing in the clear zone.
- Direct wildlife road mortality as a result of collisions with vehicles.
- Barrier to wildlife movements: e.g., animals do not cross the road as often as they would have crossed natural terrain and only a portion of the crossing attempts is successful. This may disrupt daily, seasonal, and dispersal movements required for long term population persistence.
- Decrease in habitat quality in a zone adjacent to the road: e.g., noise and light disturbance, air and water pollution, increased access to the areas adjacent to the highways for humans.
- Right-of-way habitat and corridor: Depending on the surrounding landscape the right-of-way can promote the spread of non-native or invasive species (surrounding landscape largely natural or semi-natural) or it can be a refugium for native species (surrounding landscape heavily impacted by humans).

If mitigation is required for habitat loss, barrier effects, a decrease in habitat quality in a zone adjacent to the road, or the ecological functioning of right-of-ways, other types of data are needed than wildlife-vehicle collision data. Examples of such data are data on the quantity and quality of the habitat impacted, animal movement data, data on noise or chemical pollutants, and the presence and spread of non-native invasive species. Note that wildlife-vehicle collision hotspots are not necessarily the locations where animals cross the road most frequently or where safe crossing opportunities would have the greatest benefit to the long-term population viability for selected species.

For the current project, the problem, as defined by the U.S. Fish and Wildlife Service, is the relatively high number of ungulate-vehicle collisions, specifically elk, and wildlife, specifically elk, having difficulty accessing the refuge when they approach the refuge coming from the west (i.e. the highway, and the fence and jump-outs on the east side of the road are considered a barrier).

2.2. Strategies to Address the Problem

While mitigation (reducing the severity of an impact) is common, avoidance is better and should generally be considered first (Cuperus et al., 1999). For example, deer-vehicle collisions or the negative effects of roads and traffic on wildlife may be avoided if a road is not constructed, or the most severe negative effects may be avoided by re-routing away from the most sensitive areas (Figure 5). If the effects cannot be avoided, mitigation is a logical second step. Mitigation is typically done in the road-effect zone (Figure 5) and may include measures aimed at reducing wildlife-vehicle collisions and reducing the barrier effect (e.g., through providing for safe wildlife crossing opportunities) (Huijser et al., 2008a; b; Clevenger & Huijser, 2011). However, mitigation may not always be possible or the mitigation may not be sufficient. Then a third approach may be considered: compensation or mitigation off-site. Compensation may include increasing the size existing habitat patches, creating new habitat patches or improving the connectivity between the habitat patches that would allow for larger, more connected, and more viable network populations. Finally, in some situations a combination of avoidance, mitigation, and compensation may be implemented.

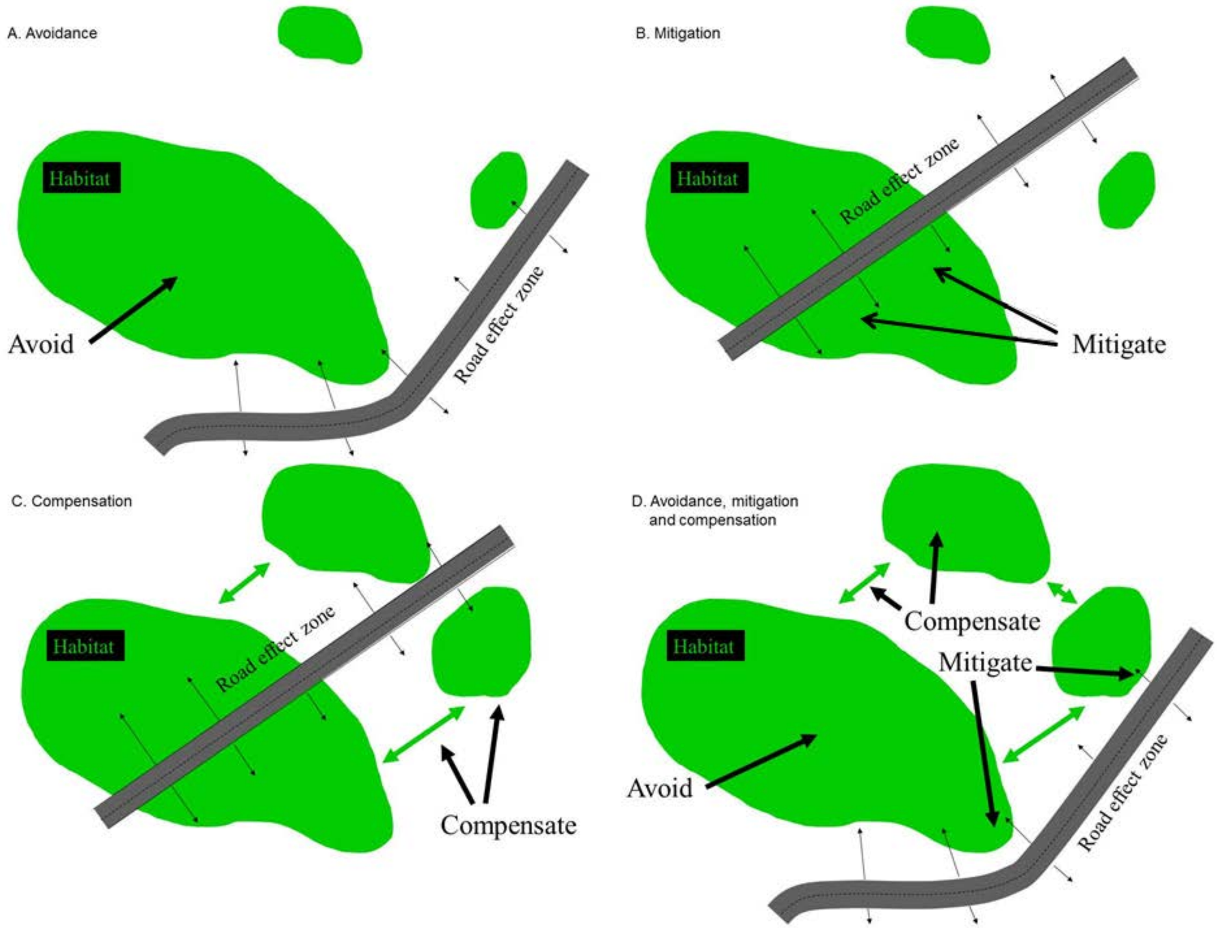

Figure 5: A three step approach: A. Avoidance, B. Mitigation, C. Compensation, D. Combination of avoidance, mitigation and compensation.

For the current project the approach is primarily to suggest measures aimed at mitigating (reducing) the relatively high number of collisions with large wild mammals, and elk in specific, and decreasing the barrier effect of the highway, and the wildlife fence and jump-outs on the east side of the road for large mammal movements, specifically elk, from west to east in the fall.

Note that the potential implementation of mitigation measures aimed at reducing wildlife-vehicle collisions should not increase the barrier effect of roads and traffic for wildlife, particularly not for species which may already be threatened or endangered. Therefore measures that keep (terrestrial) wildlife from entering the road (e.g. wildlife fencing) are typically implemented in combination with safe crossing opportunities for terrestrial wildlife (e.g. wildlife underpasses or overpasses).

3. WILDLIFE-VEHICLE CRASH AND CARCASS DATA ALONG US HWY 89/191/26 ALONG THE NATIONAL ELK REFUGE

3.1. Introduction

Wildlife-vehicle crash data and carcass removal data allow for the identification of road sections that may have a concentration of wildlife-vehicle collisions. This is one of the data sources that should be considered when deciding on the potential implementation of mitigation measures and their location.

3.2. Methods

The researchers obtained wildlife-vehicle crash and carcass removal data from the Wyoming Department of Transportation.

3.2.1. Crash Data

The wildlife-vehicle crash data related to 1 January 1994 through 31 December 2013. The researchers only included the road section between the northern edge of Jackson and Gros Ventre Jct (the lowest recorded mi marker for a wildlife-vehicle crash was 155.3 and the highest at 161.3). The crash data were usually recorded to the nearest 0.1 mi.

3.2.2. Carcass Data

The carcass removal data related to the period 1 January 2003 through 31 December 2013. The researchers only included the road section between the northern edge of Jackson and Gros Ventre Jct, but WYDOT tends to only collect carcasses until the park boundary at mi marker 158.2 (the lowest recorded mi marker of a carcass 155.0 and the highest at 159.0). The crash data were usually recorded to the nearest 0.5 mi.

3.3. Results

3.3.1. Crash Data

Deer – perhaps (almost) exclusively mule deer -, elk and moose were the species most frequently involved in wildlife-vehicle crashes (Figure 6). However, there was also one bison-vehicle crash recorded. The wildlife-vehicle crash data included records of 13 human injuries and 0 human fatalities.

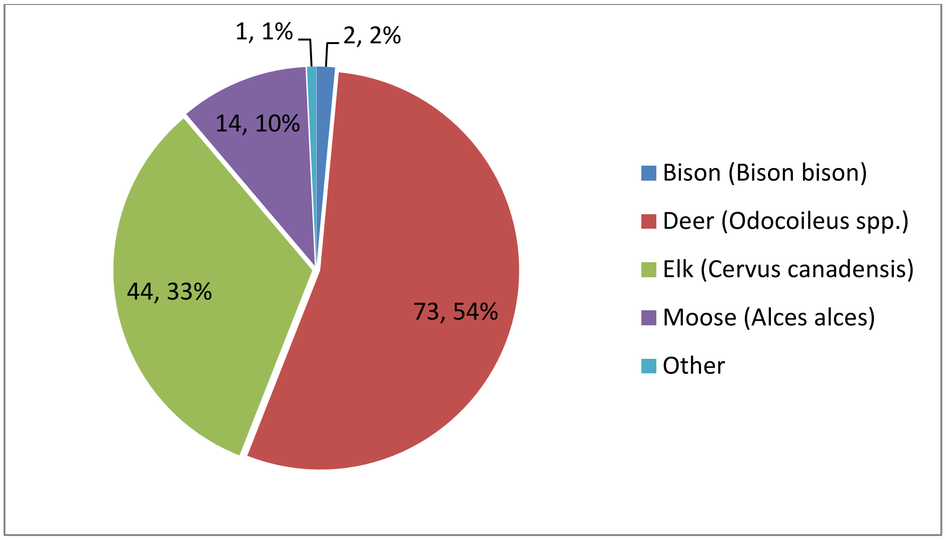

Figure 6: The species recorded based on crash data along US Hwy 89/191/26 between the northern edge of Jackson and Gros Ventre Jct between 1 Jan 1994 through 31 Dec 2013 (N=134) (Data courtesy of Wyoming Department of Transportation).

There appear to be two areas with a relatively high number of wildlife-vehicle crashes: between mi marker 156.0 and 158.3 (deer, elk, bison), and between mi marker 160.0-161.3 (deer, moose, elk) (Figure 7).

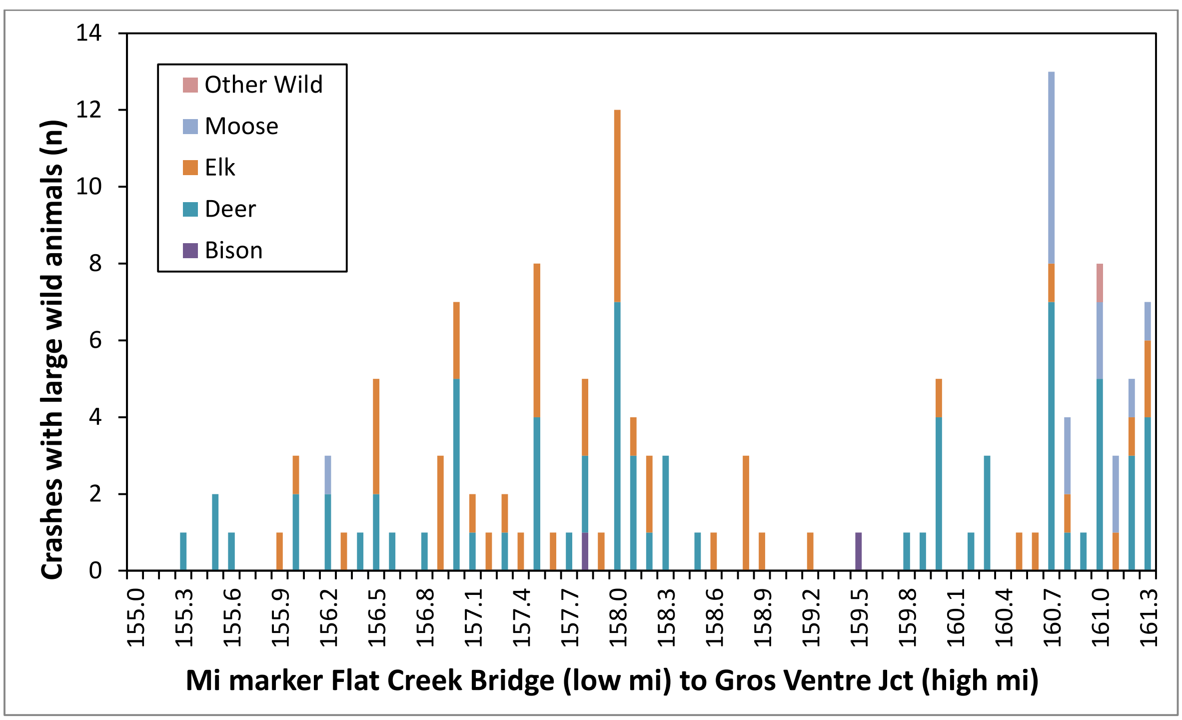

Figure 7: The number of road-killed large mammals per 0.1 mi based on crash data along US Hwy 89/191/26 between the northern edge of Jackson and Gros Ventre Jct between 1 Jan 1994 through 31 Dec 2013 (Data courtesy of Wyoming Department of Transportation).

3.3.2. Carcass Data

Deer – likely exclusively mule deer -, elk and moose were the species most frequently removed from the highway (Figure 8). However, there was also one bighorn sheep recorded.

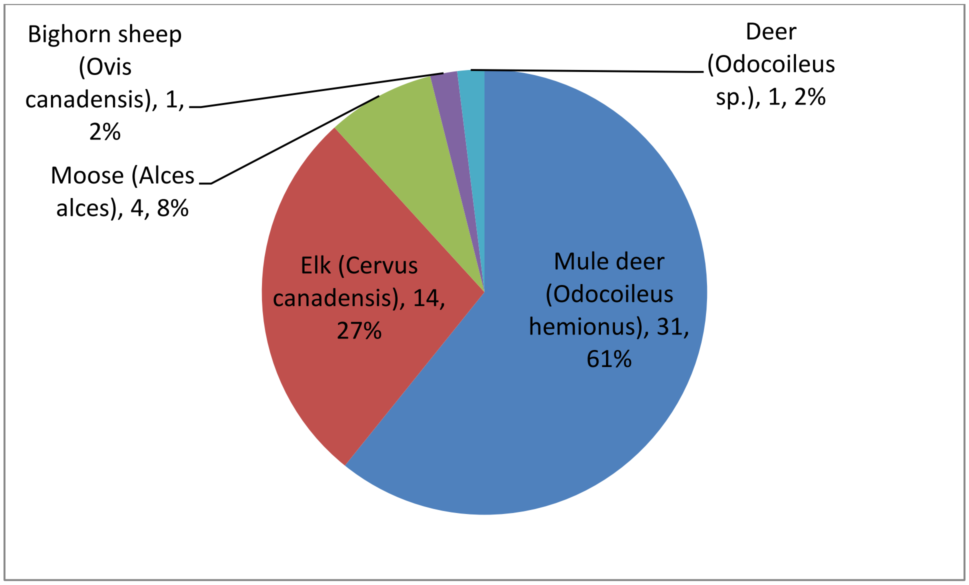

Figure 8: The species recorded based on carcass data along US Hwy 89/191/26 between the northern edge of Jackson and Gros Ventre Jct (or rather until about mi marker 158.2) between 1 Jan 1994 through 31 Dec 2013 (n=51) (Data courtesy of Wyoming Department of Transportation).

There appears to be one area with a relatively high number of wildlife-vehicle crashes: between mi marker 157.0 and 158.0 (mule deer, elk, moose, bighorn sheep (Figure 9). However, the most northern section (mi marker 159.0 until Gros Ventre Jct) was not monitored for carcasses.

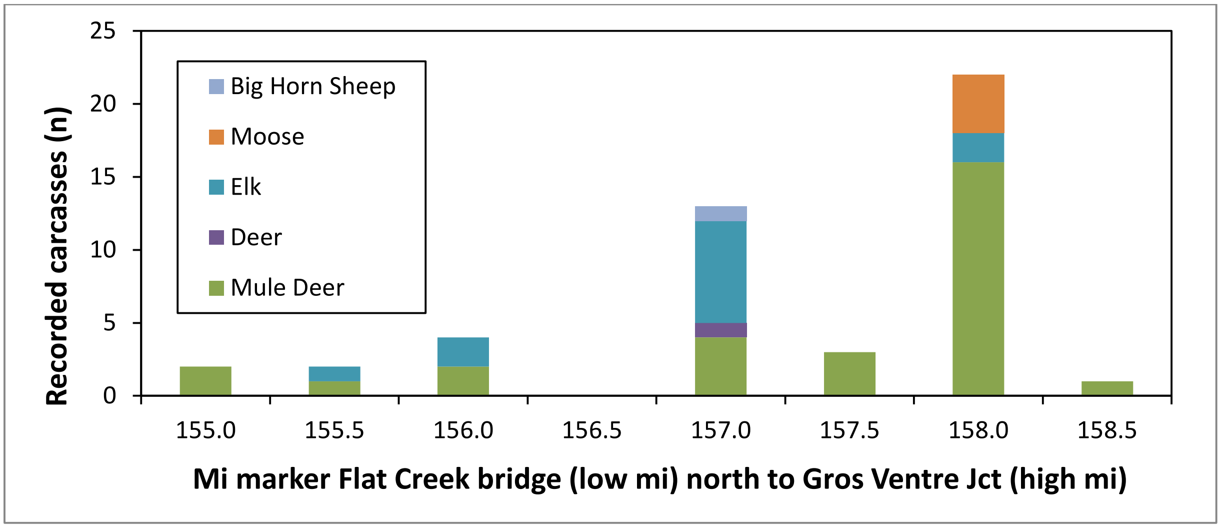

Figure 9: The number of road-killed large mammals per 0.5 mi based on carcass data along US Hwy 89/191/26 between the northern edge of Jackson and Gros Ventre Jct (or rather about mi marker 158.2) between 1 Jan 1994 through 31 Dec 2013 (Data courtesy of Wyoming Department of Transportation).

3.4. Discussion

If mitigation measures are implemented to improve human safety and to reduce direct wildlife road mortality the measures should primarily be aimed at deer, elk and moose, and to some degree also at bison and bighorn sheep.

Concentrations of wildlife-vehicle collisions appear to occur in two areas:

1. Between mi marker 156.0-158.3 (deer, elk, bison) based on crash data, or 157.0-158.0 (mule deer, elk, moose, bighorn sheep based on carcass data.
2. Between mi marker 160.0-161.3 (deer, moose, elk) based on crash data (no carcass removal data available for this road section around and south of the Gros Ventre River).

While wildlife-vehicle collision data are helpful in the identification and prioritization of road sections that may require mitigation measures, it is not necessarily the only data source that should be considered. Road sections where wildlife cross are successful in crossing the highway may be different from road sections where wildlife are not successful (e.g. because of wildlife-vehicle collisions). It is important that potential future mitigation measures to not block wildlife movements.

4. INTERVIEWS WITH STAKEHOLDERS

4.1. Introduction

The US Fish & Wildlife Service is concerned about wildlife being killed along the section of US Hwy 89/191/26 on the west side of the National Elk Refuge. In addition the US Fish & Wildlife Service would like wildlife, especially elk, to more easily access the refuge in the fall. Potential future mitigation measures that would address these issues would require agreement among the stakeholders. Stakeholders include the Wyoming Department of Transportation, Wyoming Game & Fish Department, adjacent landowners (e.g. Grand Teton National Park, National Forest Service), and Teton Conservation District. Therefore the researchers conducted interviews with these stakeholders, as well as a researcher from the Teton Science School, to document what the stakeholders perceive as (potential) problems in relation to US Hwy 89/191/26 and wildlife, what type of mitigation measure they would support and what type of mitigation measures they would not support.

4.2. Methods

The researchers contacted 10 stakeholders associated with 7 organizations for an interview (Table 2). The stakeholders were asked about what, if any, problems they perceived with regard to US Hwy 89/191/26 adjacent to the National Elk Refuge in relation to wildlife, what measures they would support implementing, and what measures they would not support. Note that the responses are based on the personal experience, knowledge, and opinion of the respondents, and that their responses do not necessarily reflect the position of the organizations they are affiliated with.

The interviews were an open conversation about the topics listed above. The interviewees were not presented a list of predefined problems or mitigation options.

Table 2: Stakeholder organizations and interviewees.

Stakeholder group	Stakeholder (organization)	Name interviewees
Natural resource management agency	US Fish & Wildlife Service, National Elk Refuge	Steve Kallin Eric Cole
	Wyoming Game & Fish Department	Doug Brimeyer
	Grand Teton National Park	Steve Cain
	National Forest Service, Bridger-Teton National Forest	Dale Deiter Darin Martens Kerry Murphy
	Teton Conservation District	Randy Williams
Transportation agency	Wyoming Department of Transportation	Bob Hammond
Nature oriented non-governmental organizations (NGO)	Teton Research Institute	Corinna Riginos

4.3. Results

There is general consensus among the stakeholders that wildlife-vehicle collisions along the road section concerned are a problem for both human safety and wildlife conservation, and that the highway and the fencing and jump-outs on the east side of the highway are a barrier for wildlife trying to access the refuge (Table 3). However, the wildlife-vehicle collisions along the highway section concerned do not rank among the highest in Wyoming (Pers. Comm, Bob Hammond, Wyoming Department of Transportation). Therefore mitigation measures along this highway section are not the highest priority for the Wyoming Department of Transportation. However, the Wyoming Department of Transportation is willing to partner with other stakeholders to address the problems (Pers. Comm, Bob Hammond, Wyoming Department of Transportation).

The US Fish & Wildlife Service has stated that potential future crossing opportunities need to be suitable for bighorn sheep (*Ovis canadensis*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), and bison (*Bison bison*) (Pers. Comm. Steve Kallin, National Elk Refuge). Note that grizzly bears (*Ursus arctos*) are occasionally seen on the refuge, suggesting that they may also benefit from safe wildlife crossing opportunities across the highway corridor. The safe crossing opportunities would need to be a barrier for elk and bison attempting to leave the refuge during the winter months (especially February – April when elk or bison may abort their calves should they have been infected with brucellosis). Keeping the elk on the refuge when contamination is most likely reduces exposure of the cattle in the surrounding areas to brucellosis. The safe crossing opportunities should still allow for elk to enter the refuge (coming from the west, especially during fall migration mid-November – early December). Ideally the safe crossing opportunities should also allow bighorn sheep to both leave and enter the refuge to improve connectivity with the bighorn sheep herd west of the Snake River. Note that a potential (seasonal) barrier to some species (e.g. elk, bison) should be “removable” should elk and bison

Table 3: Problems perceived by stakeholders in relation to US Hwy 89/191/26 and wildlife along the National Elk Refuge, and potential future mitigation measures that would and that would not be supported.

	US Fish and Wildlife Service	Teton Research Institute	Teton Conservation District	Wyoming Department of Transportation	Wyoming Game & Fish Department	Grand Teton National Park	Bridger-Teton National Forest
Problems perceived							
Wildlife-vehicle collisions (human safety)	X	X	X	X	X	X	X
Wildlife-vehicle collisions (wildlife conservation)	X	X	X		X	X	X
Barrier effect highway, fence and jump-outs	X	X	X	X	X	X	X
Potential measures that would be supported							
Wildlife fence on both sides highway	X				X		X
Wildlife fences on both sides of highway south of Gros Ventre River						X	
Underpass at Fish hatchery	X			X		X	X
Overpass south of Fish Hatchery							X
Safe crossing opportunities between East Gros Ventre Butte and Gros Ventre River							X
Potential at grade crossing opportunities							X
Gradual slopes on approaches to potential underpasses (with vegetation restoration)						X	
Measures that physically separate wildlife from traffic (underpasses and overpasses rather than at grade crossings)						X	
Move east side fence further away from road south of Fish Hatchery (better staging area before using jump-outs)	X				X		
Measures that would reduce unnaturally high elk concentrations on refuge (diseases, overgrazing/browsing)	X		X				
Measures that would allow for more natural habitat that would support other species on refuge	X						
Increase attractiveness elk winter habitat elsewhere (similar to South Park)			X				
Measures that reduce elk grazing on private ranches and that reduce damage to livestock fences	X		X		X		
Measures that reduce damage to private land and associated financial compensation by Wyoming G&F	X				X		
Measures that would reduce potential transmission of brucellosis from wild ungulates to cattle	X				X		
Evaluate assumptions on potential transmission of brucellosis from wild ungulates to cattle (leads to different mitigation options)							X
Potentially, in the future, reduce supplementary feeding on refuge	X						

– Continued from previous page –	US Fish and Wildlife Service	Teton Research Institute	Teton Conservation District	Wyoming Department of Transportation	Wyoming Game & Fish Department	Grand Teton National Park	Bridger-Teton National Forest
Potentially, in the future, remove fences intended to keep elk from leaving the refuge in winter	X						
Effective mitigation measures		X	X				
Replace standard livestock fences with wildlife friendly livestock fences			X				
If found to have been effective, reduce vehicle speed to 45 mi/h for entire road section (night only or night and day)			X				
Potential future mitigation measures need to be accompanied with education/outreach			X				
Safe crossing opportunities for wildlife (one-way traffic in winter)	X				X		
Remove or redesign kiosk on east side highway (elk are afraid of it, makes it more difficult to haze them towards jump-outs)					X		
Measures that keep the jump-outs functioning as one-way traffic; snow accumulation may make it two way traffic in winter					X		
Fence out jump-outs in winter to assure no animals will jump-up in winter (snow accumulation reduces effective height jump-outs)					X		
Measures that increase visibility of wildlife to drivers (i.e. lights), in town only					X		
Potential measures that would not be supported							
Measures that would impact landscape aesthetics (view of Teton Range)	X		X	X		X	
Measures that would jeopardize human safety on highway (increase in wildlife-vehicle collisions)	X						
Measures that would lead to higher transmission rates of brucellosis from wild ungulates to cattle	X				X		
Measures that would no longer allow the public to view elk and other wildlife on refuge or on East Gros Ventre Butte	X		X				
Measures that would impact human safety or commerce interests				X			
Measures that would increase light pollution				X	X		X
Measures that would increase light pollution on park lands						X	
Measures that would allow for two way elk traffic on west side of refuge in winter					X		
Wildlife fences north of Gros Ventre River						X	

be allowed to range free at some point in the future, especially if supplementary feeding is reduced or halted altogether.

Around the first week of December until early January elk migrate to the National Elk Refuge, coming from the north and west (Pers. Comm. Doug Brimeyer , Wyoming Game & Fish Department). Recently, as many as 8,000 elk have been feeding on supplementary feed at the National Elk Refuge (Pers. Comm. Doug Brimeyer , Wyoming Game & Fish Department). Wyoming Game & Fish Department hazes elk off private ranches west of the National Elk Refuge in the fall and early winter. Sometimes helicopters are used to drive the elk towards the refuge. Even with the ongoing hazing and supplementary feeding programs in the area, Wyoming Game & Fish Department has spent over $1.1 million to compensate private landowners for damage caused by wildlife throughout the entire state of Wyoming in fiscal year 2013 (Wyoming Game & Fish Department, 2014). For the Jackson Hole area this was about $116,000, with $36,000 related to elk (Wyoming Game & Fish Department, 2014). Once the elk are moving east towards the refuge, traffic is stopped on US Hwy 89/191/26 while Wyoming Game & Fish Department personnel drive the elk towards the jump-outs (Pers. Comm. Doug Brimeyer , Wyoming Game & Fish Department). In some cases elk are hesitant to jump down the jump-outs resulting in large groups of elk in between the highway and the fence on the east side of the highway (Pers. Comm. Dale Dale Deiter, Bridger-Teton National Forest).

Most elk that access the refuge cross US Highway 89/191/26 north of the Gros Ventre River (Pers. Comm. Steve Kallin and Eric Cole, National Elk Refuge). Elk also cross the highway in relatively high numbers on the flats between East Gros Ventre Butte and the Gros Ventre River (Pers. Comm. Steve Kallin and Eric Cole, National Elk Refuge). Replacing standard livestock fencing with wildlife friendly livestock fencing in this area may benefit the elk as well as other wildlife species (Pers. Comm. Randy Williams, Teton Conservation District). It appears that elk accessing the refuge just east of East Gros Ventre Butte include elk that have been hazed off private land further to the west (see previous section), and they appear to be in lower numbers than the elk that access the refuge further north. In spring, most elk cross the highway either under the Gros Ventre River bridge or just north of the fence end slightly north of the river (Pers. Comm. Steve Kallin and Eric Cole, National Elk Refuge; Pers. Comm. Randy Williams, Teton Conservation District).

The fence on the east side of the road is primarily to keep the elk on the National Wildlife Refuge during the winter months. Interestingly, one of the stakeholders suggested that it is possible that, at some point in the future, the fence may be used to keep the elk off the National Elk Refuge (Pers. Comm. Dale Deiter, Bridger-Teton National Forest). There is concern with the potential spread of Chronic Wasting Disease (CWD) to the wild ungulates around Jackson (Pers. Comm. Dale Deiter, Bridger-Teton National Forest). Should that happen then there may be substantial pressure to reduce elk concentrations and supplementary feeding in the area to limit the spread of the disease (Dale Deiter, Bridger-Teton National Forest).

East Gros Ventre Butte is important winter habitat for mule deer (Riginos et al., 2013; Pers. Comm. Corinna Riginos, Teton Research Institute). The winter range extends somewhat into the National Elk Refuge just north of Jackson and predominantly south of the Flat Creek bridge (Riginos et al., 2013). This is also where most mule deer cross the highway between East Gros Ventre Butte and the National Elk Refuge in winter. Non-migration mule deer crossings occur mostly at night (67% of the crossings were between 19:00-07:00 with a peak between 00:00-05:00 (Riginos et al., 2013).

Moose crossings mostly occur at Gros Ventre River bridge (Pers. Comm. Randy Williams, Teton Conservation District). In the last year bison have been spending more time just south of the Gros Ventre River in addition to just north of the river (Pers. Comm. Bob Hammond, Wyoming Department of Transportation; Steve Cain, Grand Teton National Park). Some bison are spending part of the winter on the National Elk Refuge or just west of there, south of the Gros Ventre River. In May these animals (about 35 individuals) move to the yards around houses in a subdivision near the airport (Pers. Comm. Doug Brimeyer, Wyoming Game & Fish Department). Bighorn sheep used to winter on East Gros Ventre Butte until the 1950s. The highway in combination with the wildlife fence has now separated the bighorn sheep in the Teton Range from those further to the east of US Hwy 89/191/26 (Pers. Comm. Dale Deiter, Bridger-Teton National Forest).

While over 40 different mitigation measures aimed at reducing collisions with wildlife – particularly with large ungulates - have been described (e.g. Huijser et al., 2008a; Huijser et al., 2009), the researchers consider wildlife fencing in combination with wildlife underpasses or overpasses the most effective and robust. One may also consider at grade crossing opportunities at gaps in a wildlife fence – with or without an animal detection system – but these measures are likely less predictable with regard to their effectiveness in reducing ungulate-vehicle collisions (40-97%) than wildlife fences in combination with underpasses or overpasses (79-97% reduction in ungulate-vehicle collisions) (see review in Huijser et al., 2009). The traffic volume on US Highway 89/191/26 was between 10,000-14,000 vehicles per day in the summer (June-September) and between 3,000-6,000 for the rest of the year (October-May) in 2013 (WYDOT data obtained through Bob Hammond and Thomas Carpenter, Wyoming Department of Transportation). This traffic volume, especially in the summer, is at the upper end or above of what the researchers still consider advisable for at grade crossing opportunities.

Based on the results of the interviews (Table 3), it appears that the stakeholders are accepting of wildlife fencing south of the Gros Ventre River, but not north of the Gros Ventre River. North of the Gros Ventre River the highway enters Grand Teton National Park where visitor experience and landscape aesthetics - especially an unhindered view of the Teton Range from the road – are considered especially important (Pers. Comm. Steve Cain, Grand Teton National Park). Should no wildlife fence be installed west of the highway south of the Gros Ventre River, then some stakeholders suggest increasing the distance of the fence to the highway so that the elk and other wildlife species are less likely to panic in response to traffic while they are trying to find and use the jump-outs (Table 3).

There is broad support for one or more safe crossing opportunities for wildlife between Jackson and the Gros Ventre River (Table 3). A potential underpass at the Fish Hatchery has been identified by several stakeholders. Interestingly, the stakeholders did not specifically identify potential wildlife crossings where most elk are said to cross the road (south of the Gros Ventre River); presumably because the terrain is largely flat and generally thought to be less suitable for potential wildlife underpasses or overpasses.

Some stakeholders are open to potential two-way wildlife traffic in wildlife crossings at some point in the future (Table 3). However, it is clear that the current situation would not allow for two-way wildlife traffic through safe wildlife crossing opportunities, especially not in winter and early spring.

5. COST-BENEFIT ANALYSES

5.1. Introduction

Over 40 types of mitigation measures aimed at reducing collisions with large ungulates have been described (see reviews in Hedlund et al. 2004, Knapp et al. 2004, Huijser et al. 2008a). Examples include warning signs that alert drivers to potential animal crossings, wildlife warning reflectors or mirrors (e.g., Reeve and Anderson 1993, Ujvári et al. 1998), wildlife fences (Clevenger et al. 2001), and animal detection systems (Huijser et al. 2006). However, the effectiveness and costs of these mitigation measures vary greatly. When the effectiveness is evaluated in relation to the costs for the mitigation measure, important insight is obtained regarding which mitigation measures may be preferred, at least from a monetary perspective.

5.2. Methods

For the purpose of this report the researchers conducted cost-benefit analyses for four different types and combinations of mitigation measures for the highway segments in Jackson Hole. The types and combinations of mitigation measures evaluated for this report included:

- Animal detection system
- Fence, gap (once every 2 km), animal detection system in gap, jump-outs
- Fence, under- and overpass (underpass once every 2 km, overpass once every 24 km), jump-outs
- Fence, under pass (once every 2 km), jump-outs

For details on the effectiveness and estimated costs of the mitigation measures per 0.62 mile (1 km) per year and other methodological aspects of the cost-benefit analyses see Huijser et al. (2009). This publication also provides a rationale for the estimated costs associated with each deer-vehicle collision ($6,617). The cost for deer-vehicle collisions is expressed in dollars per year per 0.62 mi (1 km).

For the purpose of these analyses the researchers selected crash data from a 20 year period (1994-2013), carcass removal data from an 11 year period (2003-2013), and calculated the average number of crashes with deer (*Odocoileus* spp.), Elk (*Cervus canadensis*), moose (*Alces alces*) and pronghorn (*Antilocapra Americana*) for each 0.1 mi (160.9 m) long road unit. Based on similarity in body size and weight crashes with pronghorn were combined with those of deer.

5.3. Results

Figures 10 and 11 show for which road sections the number of recorded wildlife-vehicle crashes and carcasses was high enough to meet or exceed thresholds for the implementation of four different types of mitigation measures. Both the crash and carcass data showed that there are highway sections where the threshold values for some of the four mitigation measures were (nearly) met or exceeded.

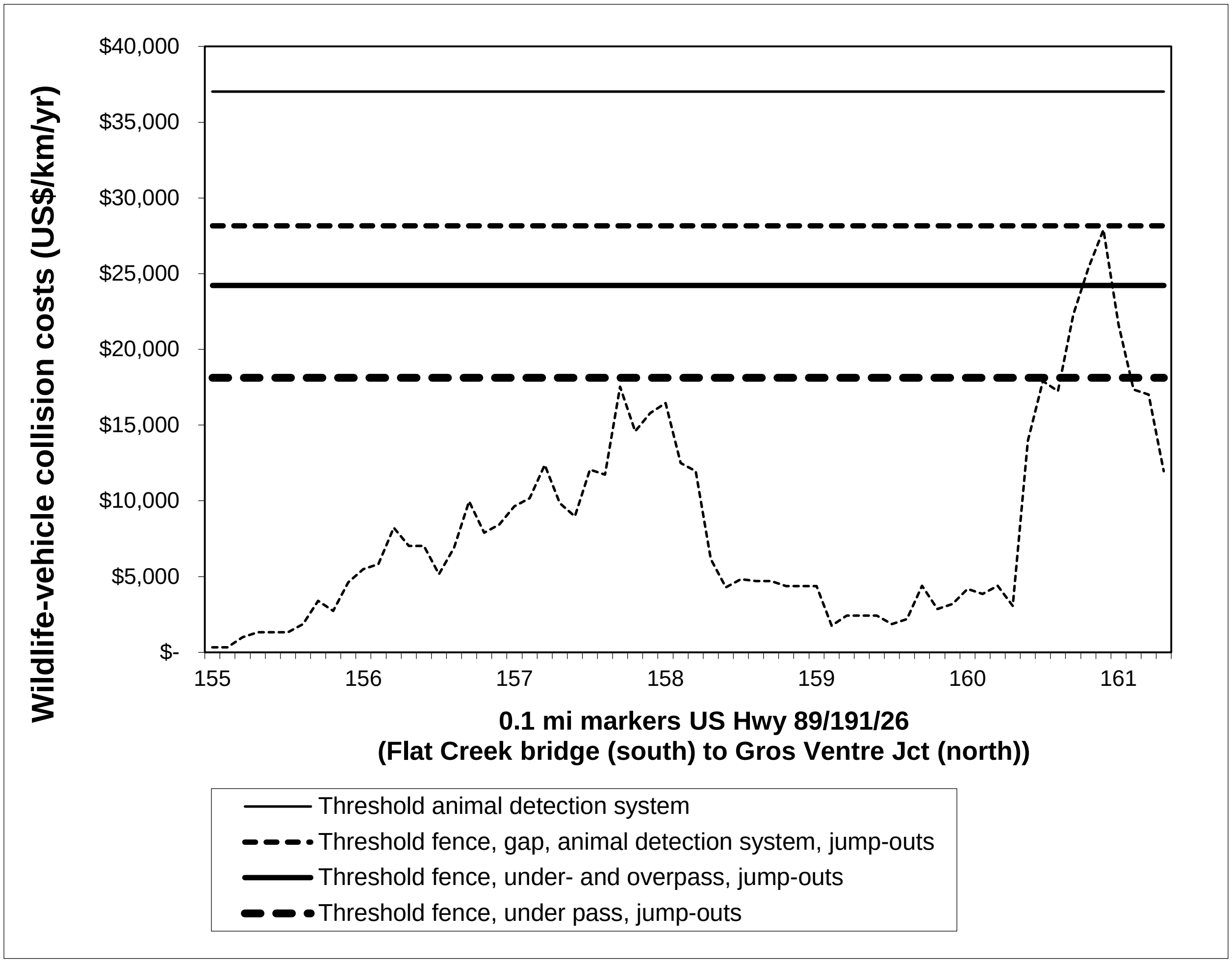

Figure 10: Hwy 89/191/26 from Flat Creek bridge just north of Jackson (south end, left side of graph) to Gros Ventre Jct (north end, right side of graph). The costs (in 2007 US$) associated with large mammal-vehicle crashes per year (annual average based on crash data 1994-2013), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer.

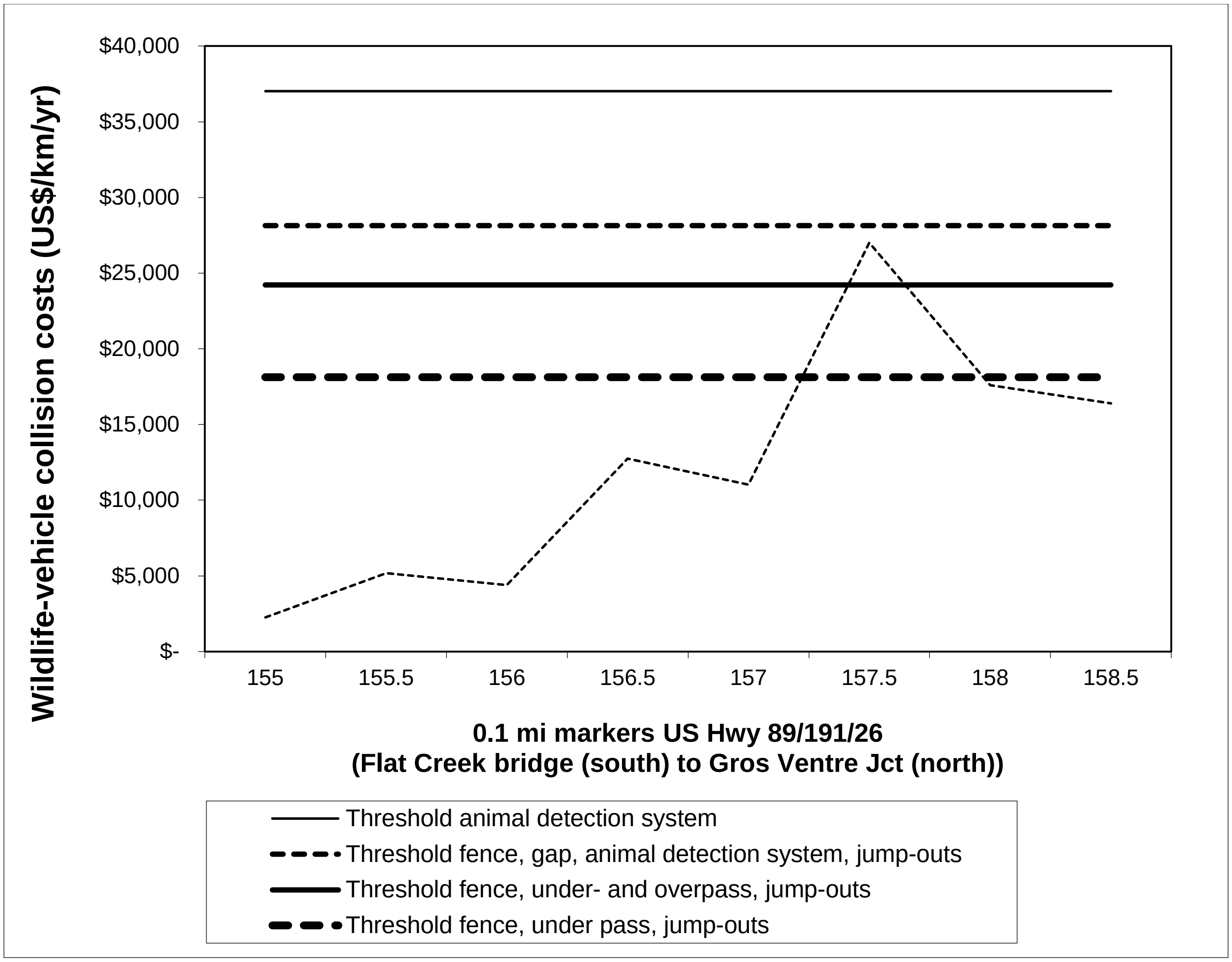

Figure 11: Hwy 89/191/26 from Flat Creek bridge just north of Jackson (south end, left side of graph) in the direction of Gros Ventre Jct (north end, right side of graph). The costs (in 2007 US$) associated with large mammal carcasses per year (annual average based on crash data 2003-2013), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer.

5.4. Discussion and Conclusions

There were highway segments where – based on both crash and carcass data - the threshold values for some of the four mitigation measures were (nearly) met or exceeded. Note that the carcass data were not available for the most northern section around the Gros Ventre river. However, for wildlife fencing with jump-outs and one wildlife underpass every two km, the threshold values have to be met for 2 km of road length. Similarly, for wildlife fencing with jump-outs and one wildlife underpass every two km and one wildlife overpass every 24 km, the threshold values have to be met for 24 km of road length. While the researchers strongly advise to use the cost-benefit analyses as a decision support tool they also urge users to recognize that it is only one of the factors that may or should be considered in the decision making process.

The cost-benefit analyses were based on both crash data and carcass data, even though the carcass data had lower spatial resolution than the crash data. However, crash data typically only represent a fraction, perhaps 50% or even less, of the carcass data, and not all carcasses are reported through carcass data collection programs to begin with (Tardif and Associates Inc. 2003, Sielecki 2004, Riley and Marcoux 2006, Donaldson and Lafon 2008). Crash data depend on reports filled out by law enforcement personnel and carcass data depend on forms filled out by road maintenance crews that pick up carcasses and dispose of them (Huijser et al., 2007). If crash data are indeed substantially underestimating the total number of wildlife-vehicle collisions that actually occur, the benefits of installing effective mitigation measures would be greater than the current analyses suggest. On the other hand, collisions for which no crash report is filled out may be, on average, less severe and less costly than collisions that do get recorded by law enforcement personnel.

Locations where animal-vehicle collisions occur are not necessarily the same locations where animals are crossing the road successfully. Decisions on the types of mitigation measures, especially barriers, should not only be based on where crashes occur or where carcasses are found, but data on successful crossings of the target species as well as other species should also be considered. Also, it is considered good practice to not increase the barrier effect of a road (e.g. through wildlife fences) without also providing for safe crossing opportunities.

The cost-benefit analysis is relatively conservative and does not include passive use values. For a full understanding what is and what is not included in the cost-benefit analyses and how the analyses were conducted please see Huijser et al. (2009). It is also important to know that the costs and benefits are expressed in 2007 US$. Since the costs associated with deer-vehicle collisions and with mitigation measures change continuously and can even vary substantially depending on the geographic region, the cost-benefit analyses should be regarded as indicative. The researchers would also like to point out that the cost-benefit analyses does not include all parameters that should be considered when making a decision on the implementation of potential mitigation measures. The researchers strongly advise to use the cost-benefit analyses as a decision support tool but also urge users to recognize that it is only one of the factors that may or should be considered in the decision making process.

6. RECOMMENDATIONS

6.1. Introduction

The current situation includes a wildlife fence and wildlife jump-outs on the east side of the road. In the context of reducing wildlife-vehicle collisions it is not advisable to only have a wildlife fence on one side of a highway. In addition, should a highway section be fenced (on both sides of the road), safe wildlife crossing opportunities should be an integral part of the mitigation package.

6.2. Distance between Safe Crossing Opportunities

When wildlife fencing is installed alongside a road, the barrier effect of the road corridor is increased. Depending on the species concerned, a wildlife fence may be an absolute or a nearly complete barrier. Such barriers in the landscape are to be avoided as they isolate animal populations, and smaller and more isolated populations have reduced population survival probability. Therefore, when a wildlife fence is installed, safe crossing opportunities for wildlife should normally be provided for as well. This section discusses the distance between safe crossing opportunities.

The spacing of safe crossing opportunities for wildlife can be calculated in more than one way and is dependent on the goals one may have. Examples of possible goals are:

- Provide permeability under or over the road for ecosystem processes, including but not restricted to animal movements. Ecosystem processes include not only biological processes, but also physical processes (e.g. water flow).
- Allowing a wide variety of species to change their spatial distribution drastically, for example in response to climate change.
- Maintaining or improving the population viability of selected species based on their current spatial distribution. This includes striving for larger populations with a certain degree of connectivity between populations (allowing for successful dispersal movements).
- Providing the opportunity for individuals (and populations) to continue seasonal migration movements (e.g. elk).
- Allowing individuals, regardless of the species, that have their home ranges on both sides of the highway to continue to use these areas. This may result in a road corridor that is permeable for wildlife, at least to a certain degree, at least for the individuals that live close to the road.

A further complication is that individuals that disperse, that display seasonal migration, or that live in the immediate vicinity of a road may display differences in behavior with regard to where and how they move through the landscape, how they respond to roads, traffic, and associated barriers (e.g. wildlife fencing), and their willingness to use safe crossing opportunities. For example, dispersing individuals may come from remote areas, they may not move through habitat that we may expect them to be in, they typically travel long distances, much further and quicker compared to resident individuals, but successful dispersers may also stay away from roads and traffic, and other types of human disturbance. Safe crossing opportunities may not be encountered by dispersing individuals as they are new to the area and are not familiar with their location, and when confronted with a road or associated wildlife fence they may return or change the direction of their movement before they encounter and use a safe crossing opportunity. Furthermore, if dispersing individuals do encounter a safe crossing opportunity, they may be more hesitant to use them compared to resident individuals that not only know about their location, but that also have had time to learn that it is safe to use them. Since dispersal can be a relatively rare phenomenon, one may not be able to afford a dispersing individual to fail. Therefore, despite the fact that dispersers travel much further than resident individuals, designing safe crossing opportunities for dispersers does not automatically mean that one can allow for a greater distance between safe crossing opportunities.

Full scale population viability analyses can be very helpful to compare the effectiveness of different configurations of safe crossing opportunities. Another approach is to base the spacing of safe crossing opportunities based on the size of the home range of the target species (Table 4, Figure 12).

Table 4. Home range size and diameter estimates for the selected ungulate and carnivore species. The estimates relate to female individuals where possible, and local or regional data weighed relatively heavily in the final estimation of the home range size.

Species	**Home range (ha) and diameter (m)**	**Source(s)**
White-tailed deer (*Odocoileus virginianus)*	70 ha 944 m	70.5 ha for adult females in summer (Leach & Edge, 1994), <80 in summer (Mundinger, 1981), 60-70 ha for females in summer (review in Mackie et al. 1998), 89 ha (range 17-221 ha) for females in summer and 115 ha (range 19-309 ha) in winter (review in Mysterud et al., 2001)
Mule deer (*Odocoileus hemionus)*	300 ha 1,955 m	301 ha on average for males and females in winter (D'Eon & Serrouya, 2005), 90-320 ha for adult females in summer and 80-500 ha in winter (review in Mackie et al. 1998), 617 ha (range 25-4,400 ha) for females in summer and 1,267 ha (range 32-9,070 ha) in winter (review in Mysterud et al., 2001)
Elk (*Cervus canadensis*)	5,000 ha 7,981 m	3,769 ha (range 820-9,520 ha) for females in summer and 181 ha (range 152-210 ha) in winter (review in Mysterud et al., 2001), 5,296 ha for adult females in summer and 10,104 ha in winter (Anderson et al., 2005), 8,360-15,720 ha for elk populations (Van Dyke et al., 1998)
Moose (*Alces alces)*	2,500 ha 5,643 m	2,612 ha (range 210-10,300 ha) for females in summer and 2,089 ha (range 200-11,300 ha) in winter (review in Mysterud et al., 2001)
Bighorn sheep (*Ovis canadensis*)	900 ha 3,386 m	541 ha for females (review in Demarchi et al., 2000), 920 ha (range 650-1,140 ha) for females in summer and 893 (range 880-1,320 ha) in winter (review in Mysterud et al., 2001), 640-3,290 ha (review in Demarchi et al., 2000)
Black bear (*Ursus americanus)*	4,000 ha 7,138 m	1,960 ha for females (Young & Ruff 1982), 5,960 ha (range 2,300-16,000 ha) for adult females (McCoy, 2005)
Grizzly bear (*Ursus arctos*)	25,000 ha 17,846 m	22,700 ha (range 3,500-88,400 ha) for adult females (Gibeau et al., 2001), 28,500 ha (112-482 ha) for adult females (Servheen, 1983)

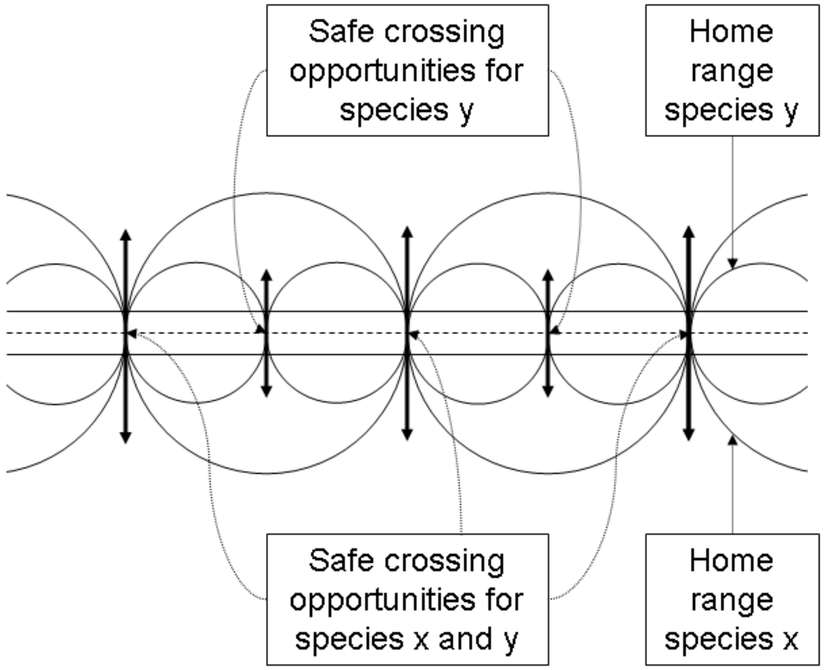

Figure 12. Schematic representation of home ranges for two theoretical species projected on a road and the distance between safe crossing opportunities (distance is equal to the diameter of their home range). In this case it was assumed that the center of an animal's home range would be on the road.

Yet another reference for the spacing between safe crossing opportunities is to evaluate what has been done elsewhere.

Table 5. The number of wildlife crossing structures per road length unit (mi or km) along different road sections in North America.

Location	Wildlife crossing structures (n)	Road length (mi (km))	Number of wildlife crossing structures per mi (per km)	Source
US Hwy 93, Flathead Indian Reservation, Montana, USA	41	56 (90)	0.7 (0.5)	Huijser et al., 2013
I-75 (Alligator Alley) in south Florida, USA	24	40 (64)	0.6 (0.4)	Foster & Humphrey, 1995
Trans-Canada Highway in Banff National Park in Alberta, Canada (phase 1, 2 and 3A)	24	28 (45)	0.9 (0.5)	Clevenger *et al.* 2002
State Route 260 in Arizona, USA	17	19 (31)	0.9 (0.5)	Dodd *et al.* (2006)

The authors of this report would like to emphasize that the approaches described above do not necessarily result in viable populations for every species of interest, and that not every individual that approaches the road and associated wildlife fence, will encounter and use a safe crossing opportunity. In addition, the approach described above is not necessarily the only approach or the approach that addresses the barrier effect of the road corridor and associated fencing sufficiently for all species concerned. However, the authors do think that the approach based on home range size of the target species is consistent, practical, based on the available data (or lack thereof), and likely to result in considerable permeability of the road corridor and associated wildlife fencing for a wide array of species.

6.3. Safe Crossing Opportunity Types

The authors of this report distinguished between six different types of safe crossing opportunities for potential implementation on and along the roads in the study area (Table 6). Note that there are other types of crossing structures, e.g. for arboreal species, amphibians, but these are not included in this report because most of these species are able to crawl through the wildlife fence. In addition, the six types of crossing structures listed are likely to be also used by e.g. amphibians, reptiles, (semi-)arboreal species, and small mammals, given certain environmental conditions or modifications. For example, if wet habitat is present or created on or nearby an overpass or underpass, amphibians and other semi-aquatic species are more likely to use the crossing opportunity. Similarly, aquatic or semi-aquatic species are likely to use a crossing opportunity if the underpass is combined with a stream or river crossing. Stream characteristics and stream dynamics must be carefully studied to ensure that the conditions inside the crossing structure are and remain similar to that of the stream up- and downstream of the structure. Such parameters include e.g. water velocity, variability in water velocity, erosion of substrate inside the crossing structure, or up- and downstream of the structure, and the implications of high and low water events, including debris and potential maintenance issues. If terrestrial animals are to use the underpass as well, a minimum path width of 0.5 m is recommended for small and medium mammals, and 2-3 m for large mammals (Clevenger & Huijser, 2011). Furthermore, small mammals increase their use of wildlife underpasses and overpasses if cover (e.g. tree stumps, branches and rocks) is provided for continuous travel through or over the crossing structure. Nonetheless, one may choose to provide additional safe crossing opportunities specifically designed for e.g. amphibians, reptiles, semi-arboreal species, and small mammals (soil and air humidity, cover, woody vegetation that spans across or under the road or canopy connectors such as ropes or other material) (e.g. Kruidering et al. 2005).

While Table 6 classifies crossing structures based on their type and dimensions, there is no generally agreed upon definition of different types of crossing structures. One may also choose to modify the dimensions of an underpass based on the species of interest and the physical environment at the location of the underpass.

Table 7 provides an overview of the suitability of the six different types of safe crossing opportunities for the species of interest. When evaluating the suitability, the authors assumed no human co-use of the crossing opportunities. The suitability of the different types of safe crossing opportunities is not only influenced by the size of the species and their habitat, but also by behavior. Most animal detection systems only detect large mammals and are therefore by definition not suitable for medium and small species. Because the suitability of the different safe crossing opportunities depends on the species, and large landscape connectors (e.g. tunneling or elevated road sections) are rare, providing a variety of different types of safe crossing opportunities generally provides habitat connectivity for more species than implementing only one type of crossing structure, even if that structure is relatively large.

Should at grade crossing opportunities be implemented in combination with wildlife fencing, extreme care must be taken to discourage wildlife from wandering off in between the fences in the fenced road corridor. Bringing the fence close to the road at these locations, with or without the use of boulder fields may help, and electric mats embedded in the road surface and adjacent shoulder, may also be considered to discourage animals from walking off to the sides on the road. Nonetheless, such at grade crossing opportunities should be seen as experimental and their effectiveness should be carefully evaluated before implementing them on large scale, and they are less suitable with increasing traffic volume.

Table 6. Dimensions of the safe crossing opportunities recommended for implementation on or along the roads in the study area.

Safe Crossing Opportunity	Dimensions (as seen by the animals)		Safe Crossing Opportunity	Dimensions (as seen by the animals)
Wildlife overpass	50 m wide		Medium mammal underpasses	0.8-3 m wide, 0.5-2.5 m high
Open span bridge	12 m wide, ≥5 m high		Small-medium mammal pipes	0.3-0.6 m in diameter
Large mammal underpass	7-8 m wide, 4-5 m high		Animal Detection system	n/a

Table 7. Suitability of different types of mitigation measures for selected species. ● Recommended/Optimum solution; ⭘ Possible if adapted to local conditions; ⊗ Not recommended; ? Unknown, more data are required; — Not applicable (Clevenger & Huijser, 2011; Clevenger, unpublished data).

	Wildlife overpass	Open span bridge	Large mammal underpass	Medium mammal underpass	Small-medium mammal underpass	Animal detection system
Ungulates						
Deer sp.	●	●	●	⊗	⊗	●
Elk	●	●	⭘	⊗	⊗	●
Moose	●	●	⭘	⊗	⊗	●
Bison	●	●	?	⊗	⊗	●
Bighorn sheep	●	●	⭘	⊗	⊗	●
Carnivores						
Black bear	●	●	●	⊗	⊗	●
Grizzly bear	●	⭘	⭘	⊗	⊗	●

6.4. Recommendations

Below are the pros and cons for several options for mitigation packages. The pros and cons start with statements related to whether or the two major objectives would be met when implementation a mitigation package:

Package	Pros	Cons
No change	No change is "easiest" option; no new negotiations or agreements with stakeholders are required. No change does not require additional funds for mitigation measures.	Objective not met: There continue to be relatively high numbers of wildlife-vehicle collisions with large mammals that pose a substantial threat to human safety. Objective not met: Wildlife movements continue to be hindered along the transportation corridor and the existing fence on the east side of the highway.

Reduce night time posted speed limit from 55 mi/h to 45 mi/h for the entire road section between Jackson and Gros Ventre Jct. This would be consistent with the posted speed limit in and adjacent to Park lands around the Gros Ventre River and further north. Also consider **reducing the day time speed limit** to 45 mi/h, consistent with the highway north of the Gros Ventre River.	It is uncertain if a reduction of "posted speed limit" also results in a reduction of the actual "operating speed" of the vehicles, especially if the road design continues to allow for faster speeds. The researchers did not have access to the data from Grand Teton National Park about the potential effectiveness and the extent of the effectiveness of having reduced the posted speed limit to 45 mi/h on Park lands. Reduction of night time posted speed limit to around 55 mi/h may reduce the number of large mammal-vehicle collisions by about 9% (CDOT, 2012). However, here the posted speed limit would be reduced from 55 mi/h to 45 mi/h. This adds to the unpredictability of the effectiveness of the measure, though it is likely limited. Relatively inexpensive.	Objective likely not (fully) met: There continue to be relatively high numbers of wildlife-vehicle collisions with large mammals that pose a substantial threat to human safety. Objective not met: Wildlife movements continue to be hindered along the transportation corridor and the existing fence on the east side of the highway.
For the road section south of the Fish Hatchery, **move the fence on the east side of the road further to the east** to allow for a greater distance between the road corridor and the fence (e.g. a minimum distance of 40-60 m (131-197 ft)), similar to north of the Fish Hatchery. In addition consider **redesigning the pull-out with the information panels** so that elk are less afraid of the site and they can see no people or predators are hiding there.	Relatively inexpensive. No new negotiations or agreements with stakeholders are required. This measure is likely to cause less panic among the elk when they are looking for a jump-out south of the Fish Hatchery. Thus this is likely to allow for a quicker entry into the National Elk Refuge, and fewer wildlife-vehicle collisions (the magnitude of the reduction is unknown)	Objective likely not (fully) met: There continue to be relatively high numbers of wildlife-vehicle collisions with large mammals that pose a substantial threat to human safety. However, the measure may reduce panic among elk though and reduce the likelihood that animals run back west across the road. Objective not met: Wildlife movements continue to be hindered along the transportation corridor and the

		existing fence on the east side of the highway. This results in a reduction of winter habitat in the fenced area of the wildlife refuge. However, if elk are avoiding the first 50-100 m adjacent to the road as it is (because the elk may not want to be close to the transportation corridor), the effective loss of winter habitat may be negligible, at least for the elk. On the other hand, the avoidance of the area near the road may be non-existent or substantially less during the night. This would mean that relocating the fence may still affect forging opportunities for elk.
Wildlife fencing and jump-outs on west side road between Jackson and Gros Ventre River (to supplement the existing wildlife fence and jump-outs on the east side of the highway). Access roads should be equipped with **wildlife guards** (about 90% effective for large ungulates) or **electric mats or concrete** (effective for all large mammal species). Minimize (e.g. through bundling) the number of access points.	Relatively inexpensive. Objective met: Is likely to substantially reduce collisions with large mammals (80-100%) (review in Huijser et al., 2009).	Objective not met: The transportation corridor and associated fences will likely result in a near absolute barrier for large mammals on the west side of the National Elk Refuge. There will be substantial problems with elk trying to access the National Elk Refuge moving (or being moved) from the west to the east in the fall and early winter. The result on the near absolute barrier is unknown, but increased presence on private land (including in the town of Jackson) is possible. Note that the researchers strongly advise against increasing the barrier effect of the highway and traffic without providing for safe and

		effective crossing opportunities for wildlife. There may be objections against wildlife fencing, limiting or bundling the number of human access points, and the perceived or real dangers associated with wildlife guards or electric mats or concrete.
Wildlife fencing and jump-outs on west side road between Jackson and Gros Ventre River (to supplement the existing wildlife fence and jump-outs on the east side of the highway), and **at grade crossing opportunities** in selected areas. At grade crossing opportunities would primarily consist of a gap in the fence on opposite sides of the road (e.g. 25-100 wide), perhaps about 0.6-0.9 at grade crossing opportunities per mile. The at-grade crossing opportunities should have measures in place (e.g. **electric mats** (note: speedrite 6000 energizers use about the same amount of power as a 60 watt light bulb (Pers. Com. Brad Truelove, Lampman Wildlife Services) that encourage animals to cross the road and not wander off into the fenced right-of-way. **Animal detection systems**, ideally in combination with a **mandatory reduction of the speed limit**, installed at the fence gaps are optional. Animal detection system may increase the effectiveness of the mitigation measures in	Objective (partially) met: Is likely to substantially reduce collisions with large mammals (40-100%) (highly variable) (review in Huijser et al., 2009). Objective (partially met): There will likely be easier access (compared to the current situation) for elk trying to access the National Elk Refuge moving (or being moved) from the west to the east in the fall and early winter. Relatively inexpensive. If the gaps (at grade crossing opportunities) are closed with a fence, one way wildlife (e.g. elk) traffic may still be possible if the gap is not closed on the west side and the gap is closed on the east side, but wildlife jump-outs are present on the east side too. These would allow west to east wildlife (e.g. elk) movements when the east gap is closed for east to west wildlife movements.	At grade crossing opportunities still expose the public and the animals to potential collisions. Traffic volume is at the high end or above of what would be considered suitable for at grade crossing opportunities with or without an animal detection system. The risk of rear-end collisions increases when drivers need to reduce vehicle speed abruptly and traffic volume is high. If an animal detection system is included in the mitigation measure package, there are relatively high risks of technological and management problems. If the crossing areas are lighted it may cause animals to avoid the crossing area. Light pollution may also occur, though there are ways to concentrate the light on the crossing area and minimize light pollution in the wider area. In addition, green lights (Poot et al., 2008) may be used that may be better accepted by wildlife than white or orange lights.

reducing wildlife-vehicle collisions, but they should be considered experimental as they are often associated with technical and management problems). The crossings may also be **lighted** (e.g. green colored lights may cause less disturbance to wildlife than white or orange colored lights) to increase the visibility of wildlife to drivers. Note: The gaps in the fence may be closed at times when elk are not allowed to leave the National Elk Refuge. When elk herds are hazed off private lands further west the gaps may be temporarily opened to haze the elk onto the refuge. Access roads should be equipped with **wildlife guards** (about 90% effective for large ungulates) or **electric mats or concrete** (effective for all large mammal species). Minimize (e.g. through bundling) the number of access points.		The effectiveness of at grade crossing opportunities, with or without an animal detection system is highly variable and potentially far less effective than wildlife fencing in combination with wildlife underpasses and/or overpasses. The gaps are either open or closed to all species for which the fence is a barrier. However, one way wildlife traffic may be possible if there are also wildlife jump-outs installed at the gap on the east side of the road. There may be objections against wildlife fencing, limiting or bundling the number of human access points, and the perceived or real dangers associated with wildlife guards or electric mats or concrete. Seasonal closures of crossing opportunities outside of the (fall) migration season may result in late comers concentrating on the west side of the fence, and an increased likelihood for these animals to end up in the fenced road corridor as the breach the fence or associated barriers. Note that from an ecological perspective it is best to not have seasonal closures for wildlife crossing opportunities.
Wildlife fencing and jump-outs on west side road between Jackson and Gros Ventre River (to supplement	Objective met: Is likely to substantially reduce collisions with large mammals (80-	Relatively expensive. Required substantial digging and soil disturbance for the width of the road corridor.

the existing wildlife fence and jump-outs on the east side of the highway), and **wildlife underpasses and/or wildlife overpasses** in selected areas. A **wildlife underpass at the Fish Hatchery** and a **wildlife overpass in the flats south of the Gros Ventre River** would be the minimal, but more crossing opportunities (**perhaps additional at grade crossing opportunities east of Gros Ventre Butte**) for large mammals would be better considering the road length is over 6 mi (Flat Creek Bridge – Gros Ventre River), and the existing practice of installing wildlife crossing opportunities at about 0.6-0.9 per mile road length. Note that the existing bridge at Flat Creek is not suitable for large mammals (marsh and open water). The Gros Ventre River bridge may or may not be suitable for large ungulates during certain times of the year. There is currently a peak in wildlife vehicle collisions at and around the Gros Ventre bridge, suggesting that a substantial number of animals choose to cross the highway at grade rather than under the bridge. At this time it is unclear whether fencing would result in more animals moving under Gros Ventre bridge. A wildlife overpass south of the Gros Ventre river would be located in relatively flat terrain. Therefore the approach of the overpass for	100%) (review in Huijser et al., 2009). Objective likely met: Wildlife movements are less likely to be hindered because of a wildlife overpass (level with the surrounding landscape). An underpass at the Fish Hatchery may or may not receive substantial use by elk; the steep slope and reduced sight distance on the west side of the highway may be a problem. That is one of the reasons why additional at grade crossing opportunities may be required as alternatively crossing opportunities. In the Rocky Mountains wildlife underpasses are not always used as much by elk as researchers or practitioners hope. The type of underpass, the dimensions, the location in the landscape in relation to where elk move, and the topography and vegetation all appear to play some role. Even some wildlife overpasses may not be used by elk as expected, potentially because of steep approaches (elk cannot see the other side of the overpass), and the lack of a visual screen on the overpass to block the sight of traffic and headlights. An overpass with an approach that is level with the surrounding open and flat terrain may function much better than an underpass or an overpass with a slope and reduced sight distance for the animals. In addition, one of the other target species close	Note that Grand Teton National Park would like the slopes to be gentle (not too steep) so that there is a more natural feel to the lowered road. Note that the footprint of the work should not be bigger than absolutely necessary and that re-vegetation with native species and weed management is essential. No or reduced view of the Teton Range for people traveling on the road for 1 mile or so (road is lowered for the wildlife overpass). Lowered road section must be wide enough to allow for snow to be "stored" during the winter months. Sufficient drainage must be in place to avoid water on the road when the snow starts melting. There may be objections against wildlife fencing, limiting or bundling the number of human access points, and the perceived or real dangers associated with wildlife guards or electric mats or concrete. Seasonal closures of crossing opportunities outside of the (fall) migration season may result in late comers concentrating on the west side of the fence, and an increased likelihood for these animals to end up in the fenced road corridor as the breach the fence or associated barriers. Note that from an ecological perspective it is best to not have seasonal closures for

wildlife should be flat as well. This then suggests lowering the road, perhaps for 1 mile or so, allowing for an overpass that is completely level with the surrounding landscape and that allows for long sight distances for the animals that move through this open area dominated by grasses, herbs and sagebrush. Note: The underpass, overpass, and gaps in the fence may be closed at times when elk are not allowed to leave the National Elk Refuge. When elk herds are hazed off private lands further west the gaps may be temporarily opened to haze the elk onto the refuge. Access roads should be equipped with **wildlife guards** (about 90% effective for large ungulates) or **electric mats or concrete** (effective for all large mammal species). Minimize (e.g. through bundling) the number of access points.	to the river is moose, and moose have a strong preference for overpasses compared to underpasses in the Rocky Mountains. Reduced visual impact of road, traffic and wildlife fencing for people and wildlife for the 1 mile section where the road is lowered (from the perspective of wildlife and people that are away from the road).	wildlife crossing opportunities.

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