Highway Mitigation Opportunities for Wildlife in Jackson Hole, Wyoming

by

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16. Abstract

This report documents the following types of information for highway sections in Jackson Hole, WY, USA: 1. Where the highway segments cut across important wildlife habitat and corridors based on existing maps and local knowledge and experience, 2. Where concentrations of wildlife-vehicle collisions occur based on carcass removal data over the last 10 years, 3. Where concentrations of wildlife occur based on observations by Wyoming Game & Fish Department and by the public. In addition, the report contains 1. Cost-benefit analyses for different types and combinations of mitigation measures for the road sections concerned, 2. Recommendations for potential future mitigation measures for selected mitigation emphasis sites, 3. A review of different types and combinations of mitigation measures that allow for a substantial reduction in wildlife-vehicle collisions and that also provide safe crossing opportunities for wildlife, and a section with the answers to three commonly asked questions about wildlife mitigation measures.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Most of the highway segments in Jackson Hole are likely to be reconstructed, either in the near future or further out. This study aimed to identify and prioritize highway segments in Jackson Hole that may require mitigation for wildlife. This report documents the following types of information:

- Where the highway segments cut across important wildlife habitat and corridors based on existing maps and local knowledge and experience.

  The highway segments cut across important mule deer, elk, and moose migration routes and streams important to Yellowstone cutthroat.

- Where concentrations of wildlife-vehicle collisions occur based on carcass removal data from the last 10 years.

  The carcass removal data related mostly to mule deer (77%), elk (12%) and moose (9%). The data were used to identify "mortality clusters" which consisted of the "worst 20%" of all 0.1 mi road units where road kill had been reported from and the adjacent 0.1 mi units, as long as these fell within the "worst 40%" of all 0.1 mi road units. The road section with the highest concentration of wildlife-vehicle collisions was on Broadway in the town of Jackson.

- Where concentrations of wildlife occur based on observations by Wyoming Game & Fish Department and by the public.

  These observations were similar to the carcass removal data but appear to have a bias towards moose, black bear and other "interesting" species rather than the most common species. These observations also included species with smaller body size. The highest concentration of wildlife observations by the public was along Hwy 390 near the Jct with Hwy 22. This cluster was dominated by moose observations.

- Cost-benefit analyses were conducted to investigate what the costs associated with wildlife-vehicle collisions were along the different road sections in Jackson Hole and how these costs may be mitigated through different types of mitigation measures such as wildlife fencing with crossing structures and animal detection systems.

  All highway segments had road sections where the threshold values for either all or some of the four mitigation measures were (nearly) met or exceeded. 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 road section with the highest costs associated with wildlife-vehicle collisions was along Hwy 22 (around mi reference posts 1.0-2.0) near the Jct with Hwy 191 in Jackson.

- Recommendations were formulated for potential future mitigation measures for selected mitigation emphasis sites along the road sections in Jackson Hole.

Information on important wildlife habitat and corridors, wildlife-vehicle collisions, wildlife observations was integrated to selected road sections (mitigation emphasis sites) that were visited by stakeholders. The stakeholders evaluated and ranked the selected sites with regard to the local and regional conservation value, suitability for the implementation of mitigation measures (based on topography, land use and other parameters), and land security for wildlife. The information was summarized in a table that allows policy makers and planners to see what road sections may have the highest ranking for implementing potential future mitigation measures and for which parameters a site may have particularly high or low rankings. Thus it allows for informed discussion when deciding on potential mitigation measures for a site.

- A review of different types and combinations of mitigation measures that allow for a substantial reduction in wildlife-vehicle collisions and that also provide safe crossing opportunities for wildlife.

  This review provides background information on different types and combinations of wildlife mitigation measures, particularly wildlife fencing, wildlife underpasses and overpasses and animal detection systems. In addition mitigation measures are recommended for the different mitigation emphasis sites and for a location along Broadway in Jackson. Finally a discussion is included on the pros and cons of combining human use and wildlife use of crossing structures.

- A section with the answers to three commonly asked questions about wildlife mitigation measures.

  This section explains that wildlife fencing along roads is not bad for wildlife but that the fencing helps reduce direct road mortality and helps funnel wildlife to safe crossing opportunities. In addition, it shows that wildlife do use wildlife crossing structures, often in high numbers, and that there is no evidence that predators wait for prey at wildlife underpasses and overpasses.

1. INTRODUCTION

1.1. Project Goals and Objectives

This study aims to identify and prioritize highway segments in Jackson Hole that may require mitigation for wildlife. The highway segments cut across important wildlife habitat and corridors. This not only results in wildlife-vehicle collisions but also in reduced connectivity across the landscape for wildlife. Most of the highway segments are likely to be reconstructed, either in the near future or further out. The reconstruction of the highway segments may involve more and wider lanes, wider shoulders and wider clear zones. Wider roads, higher traffic volume, and higher vehicle speeds lead to increased impact on wildlife, including their habitat and movements across the landscape. While it has been found that widening lanes and shoulders on rural highways leads to roads that are overall safer, it also is associated with an increase wildlife-vehicle collisions (Vokurka & Young, 2008).

The specific objectives of this project are to:

- Identify and prioritize highway segments that may require mitigation measures aimed at reducing wildlife-vehicle collisions and providing safe crossing opportunities for wildlife based on:
    - Existing crash and carcass data;
    - Existing observation data of wildlife seen alive on and along the highway segments, and;
    - Existing maps and local knowledge and experience of important wildlife habitat and corridors bisected by the highways.
- Recommend mitigation measures for wildlife at the selected locations.
- Conduct cost-benefit analyses for a range of mitigation measures for the selected highway segments.

The crash and carcass data emphasize the highway segments where mitigation measures may be required to improve human safety and reduce wildlife mortality. The observation data on animals seen alive and along the highway segments emphasize where mitigation measures may be required to reduce the barrier effect of the highway segments. The same applies to the maps and local knowledge and experience of important wildlife habitat and corridors.

The species concerned, the nature of the terrain, and the land security (potential for development) all influenced the prioritization of the highway segments that may require mitigation measures. Cost-benefit analyses allow for insight in the financial aspects of wildlife-vehicle collisions and mitigation measures and are useful in the potential future decision process whether to implement mitigation measures.

1.2. Study Area

The project focused on the following highway segments in Jackson Hole (see also Figure 1):

- U.S. Highway 26/89/189/191. From Hoback Junction (south end) to the South Park Loop Road (north end), about 7.5 mi (12.0 km) in length.
- Wyoming Highway 22 (WY Hwy 22). From its junction with Highway 26/89/189/191 in Jackson (east end) to Fish Creek bridge in Wilson (west end), about 5.4 mi (8.7 km) in length.
- Wyoming Highway 390 (WY Hwy 390). From its junction with WY Hwy 22 (south end) to the boundary of Grand Teton National Park at Range Road (north end), about 7.6 mi (12.2 km) in length.

In addition, for the identification and prioritization based on crash and carcass data, the research team also included:

- U.S. Highway 26/89/189/191. From South Park Loop Road (south end) to the junction with WY Hwy 22 (north end), approximately 4.4 mi (7.0 km) in length.
- U.S. Hwy 26/89/189/191. From junction with WY Hwy 22 (south end) through the town of Jackson to Gros Ventre Junction, approximately 8.3 mi (13.3 km) in length.

These two additions for the crash and carcass data analyses effectively resulted in the inclusion of Highway 26/89/189/191 from Hoback Junction (south end) to Gros Ventre Junction (north end).

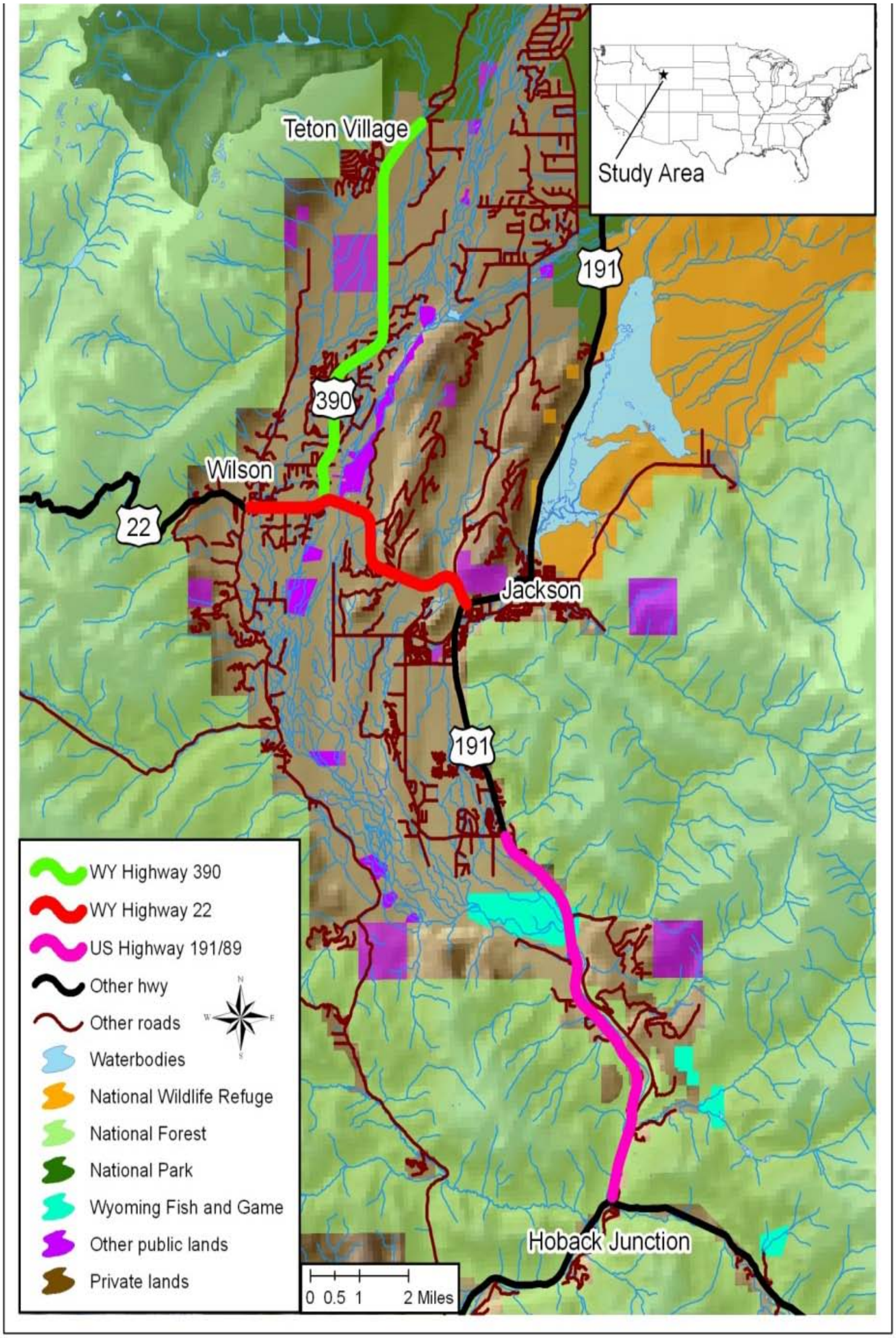

Figure 1: Jackson Hole Highways project area map with three highway segments of greatest interest highlighted.

2. WILDLIFE CORRIDORS AND ECOLOGICAL CONNECTIVITY

2.1.1. Overview

Roads constitute one of the greatest impacts to landscape connectivity and the maintenance of biodiversity. Public roads have direct ecological effects on an estimated 15-20 percent of the area of the U.S. with the ‘road-effect zone’ extending hundreds of meters from the road itself (Forman, 2000). These effects include habitat loss, degradation and fragmentation; direct wildlife mortality; and road avoidance behaviors by wildlife (Andrews, 1990; Bennett, 1991; Forman & Alexander, 1998). Further, wildlife-vehicle collisions affect the safety of drivers; nation-wide, animal-vehicle collisions are estimated at 1-2 million annually (Huijser et al., 2007).

Adverse road effects are amplified with increasing road size (Fahrig et al., 1995, Lovallo & Anderson, 1996), speed limits (Gunther, 2000), and traffic volume (Seiler, 2003; Waller & Servheen, 2005). For every kilometer (0.62 mile) of highway construction, an estimated 644 hectares (1,591 acres) of land is converted from its original vegetative cover or made available for further development, resulting in a significant loss of habitat to wildlife (Wolf, 1981).

Wildlife populations using areas adjacent to roads face increased mortality risk due to collisions with vehicles (Mumme et al., 2000). A national study identified 21 federally listed threatened or endangered animals in the U.S. for which road mortality is among the major threats to the survival of the species (Huijser et al., 2007). One of the species, Canada lynx, is present in the mountains surrounding the Jackson Hole study area.

In some areas of the United States, roads are an obstacle to maintaining ecological connectivity and may pose a threat to the long-term persistence of key wildlife populations (Noss et al., 1996; Sweanor et al., 2000; Gibbs & Shriver, 2002; Epps et al., 2005), and may significantly affect wildlife population demographics (Gibbs & Steen, 2005). The habitat fragmentation effects of roads can isolate wildlife populations unwilling or unable to cross roads (Wayne et al., 1992; Gerlach, 2000), while increased noise, pollution, and edge effects can make habitat less favorable for many species (Chomitz & Gray, 1996).

Population densities for large mammals tend to be lower within 100-200 meters of roads (Lyon et al., 1996; Yost & Wright, 2001; Rowland et al., 2000; Chruszcz et al., 2003). However, recent research describes the attraction to roads by prey (i.e., moose, elk) as a means of seeking refuge from predators (i.e., grizzly bears, wolves) which are less likely to remain near high human activity areas such as highways (Berger, 2007; Muhly et al., 2011).

2.1.2. Migration

Migration, at its simplest, and perhaps in broadest terms, has been defined as “the act of moving from one spatial unit to another” (Baker, 1978). This wildlife movement helps meet a suite of animals’ needs (Dingle, 1996):

- Daily movement (e.g., food, water, security)
- Seasonal environmental change (e.g., snowfall, high temperatures, lack of resources)
- Annual movement (e.g., winter range to summer range)
- Reproduction (e.g., access to leks, spawning grounds)

- Natural disturbance avoidance (e.g., wildfire, flood)
- Anthropogenic disturbance avoidance (e.g., land use development, roads)
- Dispersal (i.e. to find unoccupied habitat or mates)
- Gene Flow (i.e., long term fitness)

Migration within the Jackson Hole project area helps animals, such as deer, elk, and pronghorn adjust for daily, seasonal and annual needs. In the Greater Yellowstone Area, vertical migrations are common where animals travel to low elevations during the winter months and return to high elevations during the summer months. It has been estimated that 75% of the long distance migrations of elk, bison and pronghorn in the Greater Yellowstone have already been lost (Berger, 2004). Safe passage between seasonal ranges is important for the continued persistence of vital wildlife populations in the Jackson Hole project area. Barriers, such as high traffic highways, can act as major impediments to migration success. Mitigating such barriers is crucial in maintaining healthy numbers of migrating species.

2.1.3. Climate Change

Climate change adds to the cumulative impacts on natural systems and wildlife populations by exacerbating the negative effects of habitat loss, degradation, and fragmentation. Local climate disruptions are changing long-term patterns of fire, drought, and flood, as well as seasonal patterns of precipitation and temperature. To adapt and survive, many wildlife species will need to adjust their home ranges and movement patterns. In many cases, fragmentation will impede such adaptation, potentially resulting in isolated wildlife populations that will be highly vulnerable to extirpation or extinction.

Scientific reviews of the best strategies to protect biodiversity highlight the importance of maintaining landscape connectivity to assure species can move in reaction to climate induced changes (Madley et al., 2009). Further, upon a review of 25 years of peer-reviewed articles, the most oft cited recommendation to protect biodiversity in the face of climate change was to increase connectivity (Heller & Zavelata, 2009). To bolster this argument, Gilbert-Norton et al. (2010), in their review of empirical studies of corridors, found that corridors increase movement between habitat patches by approximately 50% compared to patches that are not connected with corridors.

Maintaining permeable highways will allow animals to find refuge by moving away from habitats that have experienced change and toward habitats that contain the same conditions to which they are adapted. Thus, conserving corridors is not only strategic and climate smart, but a proven method of allowing wildlife to move in response to environmental change. Since highway infrastructure and its mitigation is designed to exist for many decades into the future, increasing permeability today increases the probability for animals to successfully adjust to changing environmental conditions far in to the future.

2.1.4. Selection of Mitigation Emphasis Sites Based on Wildlife Connectivity

"Serve the United States by ensuring a fast, safe, efficient, accessible and convenient transportation system that meets our vital national interests and enhances the quality of life of the American people, today and into the future."

Mission statement of the U.S Department of Transportation

Most highway wildlife mitigation is focused on providing for the safety of motorists, that is, addressing problematic wildlife-vehicle collisions areas along highways. As a result, most data collected by transportation agencies are reports on collisions with large mammals, primarily ungulates – deer, elk, and moose. Since the mission of the federal and state highway agencies focuses on speed, safety and efficiency, the need to provide for the conservation of wildlife is often an ancillary focus to their primary mission.

However, much progress has been made in the past decade as state departments of transportation consider and incorporate ecological connectivity into highway projects. For example, the I-90 Snoqualmie Pass East Project, an expansion of an interstate highway in the Cascade Mountains by the Washington State DOT, has included a desired ecological condition that "requires reducing risks of road-related mortality of wildlife, improving the permeability of the highway for all organisms, and providing for the long-term sustainability of populations in the area". (Clevenger et al., 2008). The Western Governors' Association launched its Wildlife Corridors Initiative in 2007 led at that time by its Chair, former Wyoming Governor Dave Freudenthal. They dedicated a working group to develop new policies to address transportation infrastructure impacting habitat connectivity (Western Governors' Association, 2008) in the 19 western states as part of the Initiative. At the same time, the Wyoming Department of Transportation (WYDOT) has been successfully mitigating for wildlife's needs with projects at Nugget Canyon on US Highway 30, at Togwotee Pass on U.S Highway 26-287 and it has recently awarded a contract to build wildlife overpasses and underpasses on US 191 north of Pinedale, WY. These multiple efforts are demonstrating that the design and implementation of safe passage for wildlife is no longer solely a motorist safety issue or simply a wildlife mortality issue, but increasingly, highway projects are incorporating concerns for a broader array of species, for maintaining habitat connectivity and providing for the long-term persistence of wildlife populations.

The Jackson Hole Highways project did not use wildlife-vehicle collision data as the single consideration to select mitigation emphasis sites. It also used available data and maps for wildlife migration, sightings of wildlife adjacent to roads, and other related information to aid in the selection of wildlife mitigation emphasis sites (MESs). Thus, this project has evaluated wildlife conservation needs on par with wildlife-vehicle collision data.

Spatially explicit information on the following species was available to incorporate into the consideration for locating MESs for each of the three highway segments in the study area:

- Moose, elk and deer migration routes (corridors) that cross the highway segments
- Potential cutthroat trout spawning streams that pass under the highways
- Known bald eagle nest areas within 400 meters of the highway
- A regional wolverine connectivity study that identified a potential corridor that crosses US Highway 191/89 in the study area.

This information was compiled in GIS format by the Conservation Research Center for the Jackson Hole Conservation Alliance and is available on its website (URL: http://www.jhalliance.org/mapsNRO.htm). In the compilation, data was drawn from a variety of sources:

- Elk migration routes: Wyoming Game and Fish Department (WYGF) and Wyoming Open Spaces Initiative (WOSI)
- Mule deer migration routes: WYGF, WOSI and Conservation Research Center
- Moose migration routes: WYGF and WOSI data
- Bald Eagle data: WYGF data
- Yellowstone Cutthroat Trout data: USGS Interagency Yellowstone Cutthroat Trout Coordination Group and WYGF data

The ungulate migration routes were also detailed in a study of Greater Yellowstone migrations that wasn't part of the Jackson Hole Conservation Alliance's synthesis (Lyons, 2005).

A wolverine dispersal corridor that crosses US 191/89 was identified via an ongoing research project using a circuit theory model for connectivity (McRae et al., 2008) based on wolverine habitat and genetic data (Robert Inman, Wildlife Conservation Society, personal communication). The final wolverine maps are being prepared for publication in a peer-reviewed journal and therefore could not be published in this report. Other carnivore (grizzly bear, black bear, mountain lion, lynx) movement or dispersal corridors were not available for this study. Some wildlife species' habitat and migration information was available for Teton County (bighorn sheep, mountain goat, sage grouse,, trumpeter swan) but their key habitat was not located adjacent to or crossing a highway segment.

All of the aforementioned spatially explicit wildlife information was incorporated into composite maps for each of the highway segments in the study area (Figures 3, 4 and 5). Various colored lines on each of the maps represent where a migration or dispersal corridor crossed a highway segment, a potential cutthroat trout spawning water body passed under the highway, and/or a known eagle nesting site was within 400 meters of a highway segment (as an example, Figure 2 shows mule deer and moose migration route crossings bisected by WY Highway 390 and Figure 5 presents these same crossings in a much simpler format that is used for all three highway segments). Figures 3, 4 and 5 represent a summary of locations where key wildlife connectivity and important habitat is impacted by the Jackson Hole highway segments and could be addressed via highway-wildlife mitigation.

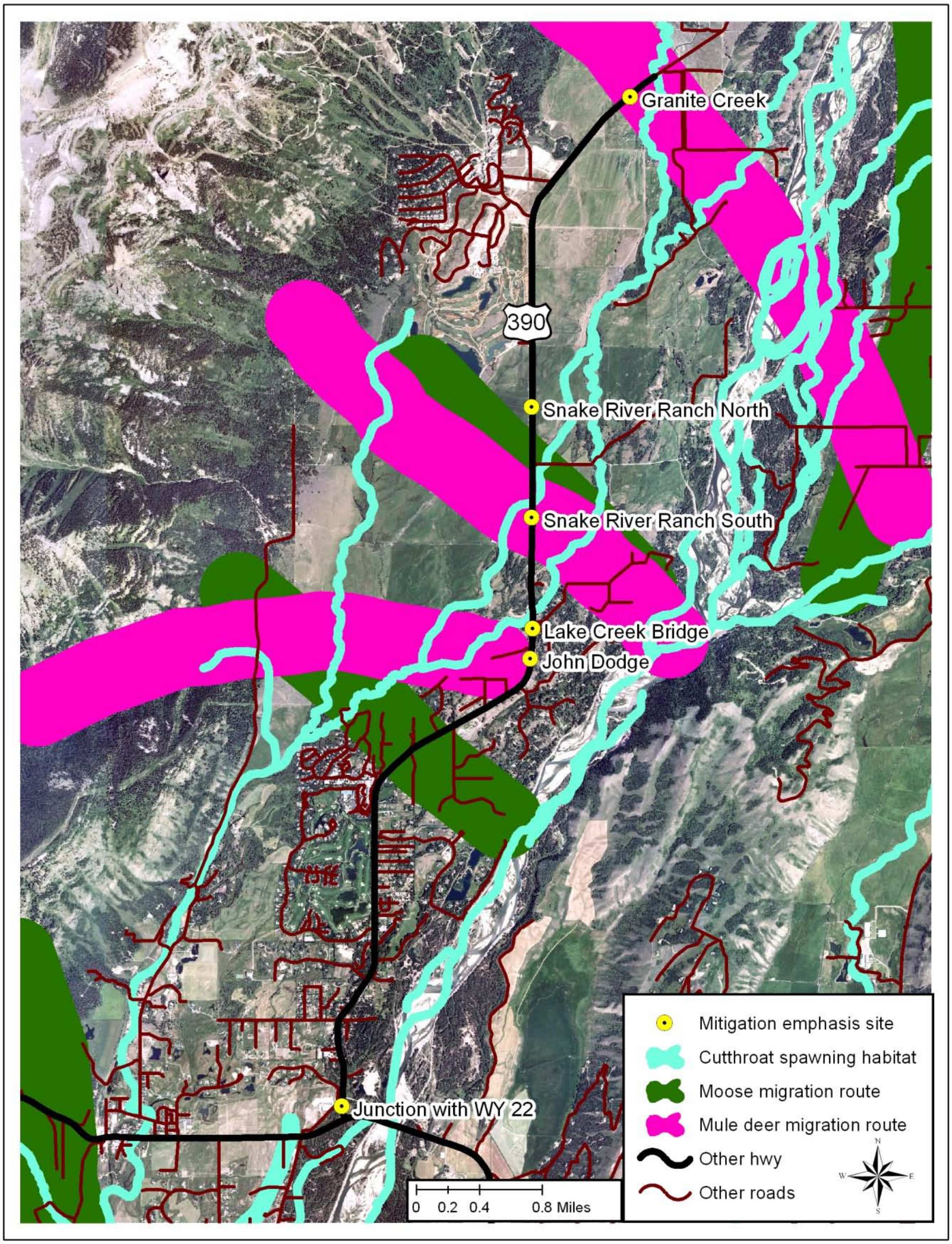

Figure 2: Example of ungulate migration routes crossing WY Highway 390 in Jackson Hole Highways project area.

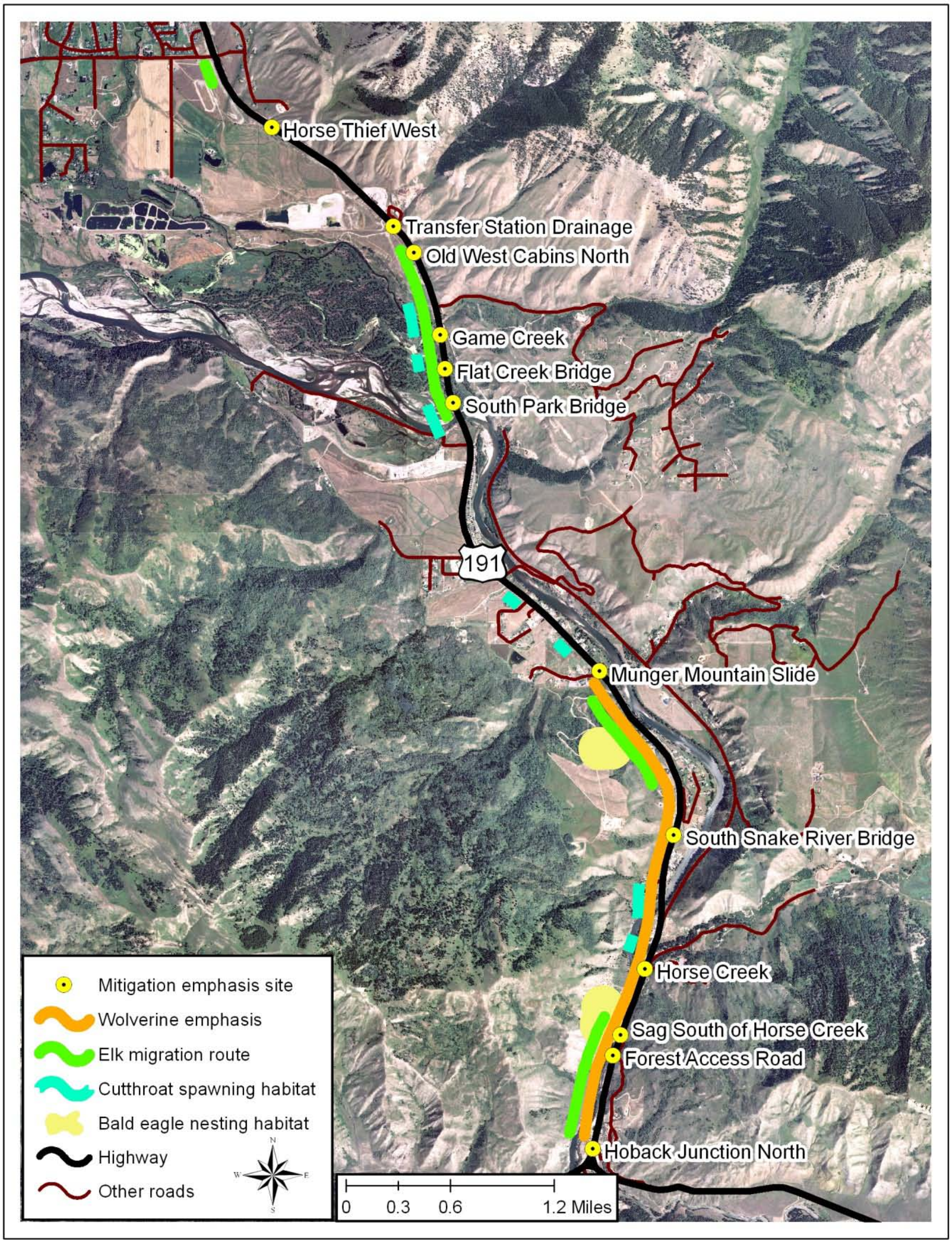

Figure 3: Wildlife migration route crossings and other important habitat considerations across, under or adjacent to the segment of US Highway 191/89 in Jackson Hole Highways project area.

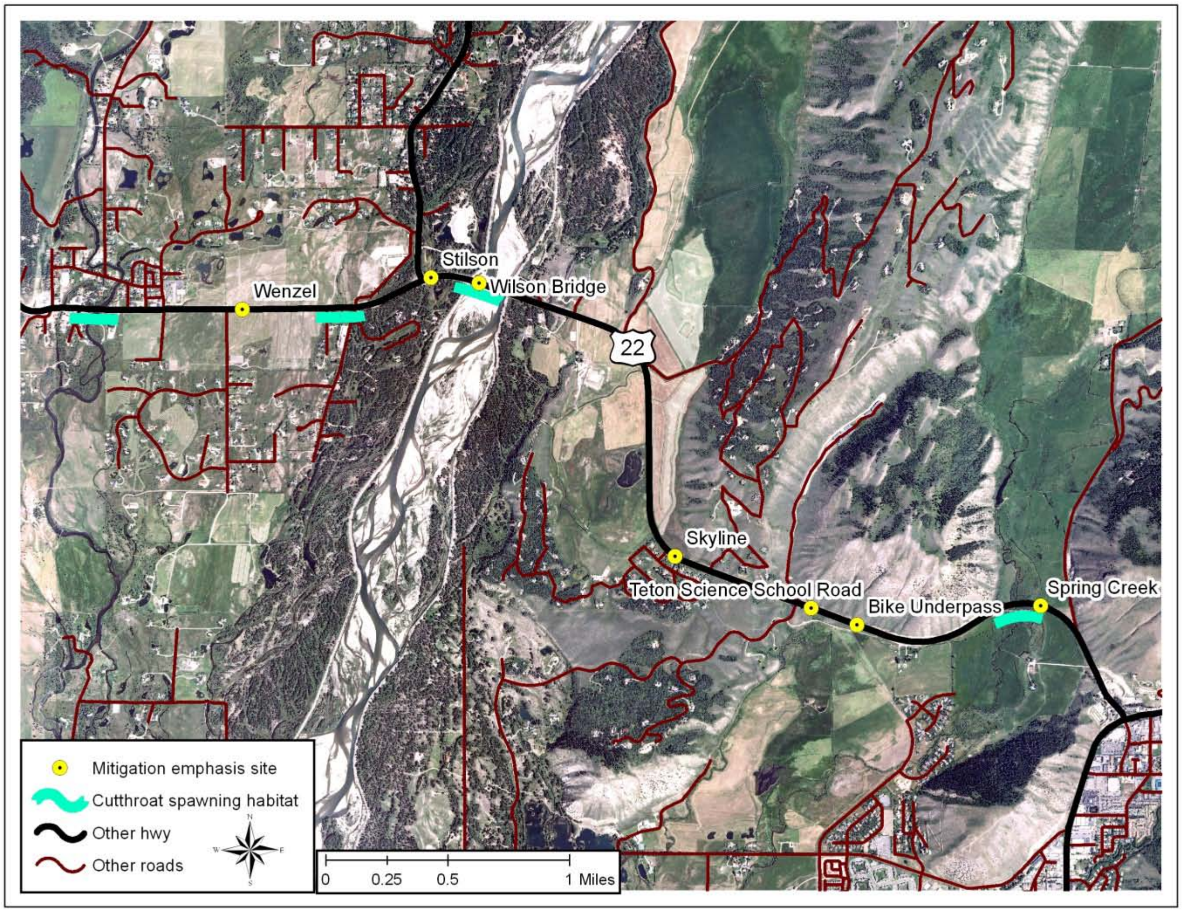

Figure 4: Potential Yellowstone cutthroat trout spawning streams flowing under the segment of WY Highway 22 in the Jackson Hole Highways project area. No key terrestrial migration routes or other important habitats were identified for this segment.

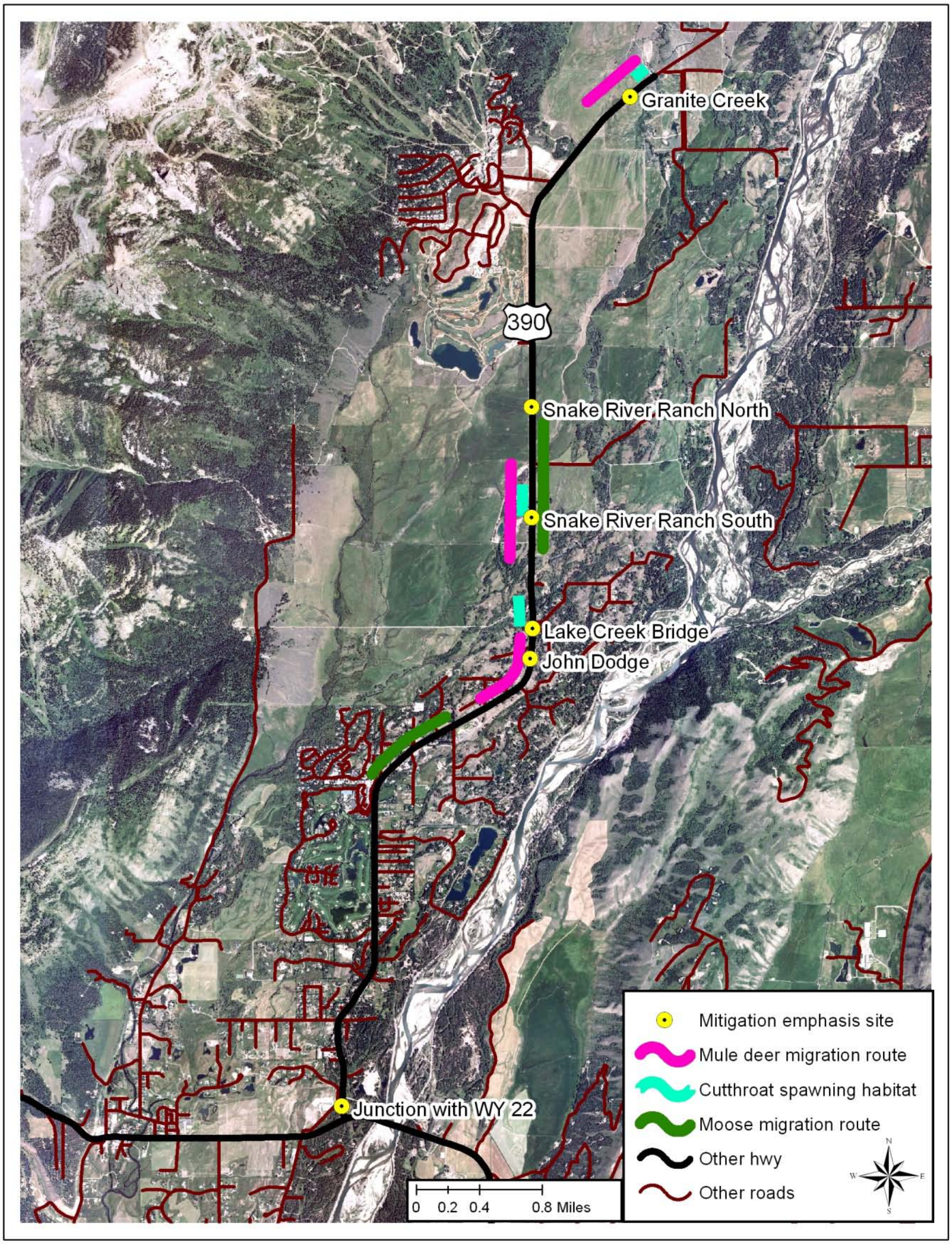

Figure 5: Wildlife migration route crossings and other important habitat considerations across, under or adjacent to the segment of WY Highway 390 in Jackson Hole Highways project area.

3. WILDLIFE-VEHICLE COLLISION AREAS

3.1. Introduction

Wildlife-vehicle collision data were used to identify and prioritize highway segments that have a concentration of wildlife-vehicle collisions. These locations may require mitigation measures to reduce wildlife-vehicle collisions in order to increase human safety and reduce direct road mortality of wildlife.

3.2. Methodology

There were two types of wildlife-vehicle collision data available to the research team; crash data and carcass data. These two datasets are discussed in the following sections.

3.2.1. Crash data

Crash data are collected by the Wyoming Highway Patrol and maintained by the Wyoming Department of Transportation. The crash data for the different highway segments were all between 1 January 2001 and 31 December 2010 and they were collected to the nearest 0.1 mi (160.9 m).

The data are presented for the following highway segments:

- U.S. Hwy 191 south. From Hoback Jct (south end) to Jct with Hwy 22 in Jackson (north end).
- U.S. Hwy 191 north. From Jct with Hwy 22 in Jackson (south end) to Gros Ventre Jct (north end).
- WY Hwy 22. From Jct with Hwy 191 in Jackson (east end) to Fish Creek bridge in Wilson (west end).
- WY Highway 390. From Jct with Hwy 22 (south end) to the boundary of Grand Teton National Park at Range Rd (north end).

The most frequently recorded wildlife species group in the crash data was deer (*Odocoileus* spp.) (white-tailed deer (*Odocoileus virginianus*) and mule deer (*Odocoileus hemionus*) combined (Figure 6). The data collectors did not distinguish between these two species. Elk (*Cervus canadensis*) and moose (*Alces alces*) were hit less frequently.

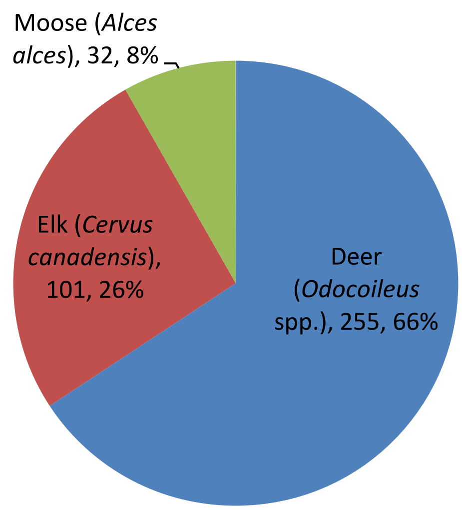

Figure 6: The number (N_{total} = 388) and the percentage of different species recorded as crash data for all four highway segments combined between 1 January 2001 and 31 December 2010.

3.2.2. Carcass data

Carcass removal data are collected and maintained by the Wyoming Department of Transportation. The crash data for the different highway segments were for different time periods (indicated below), and they were collected to the nearest 1.0 mi (1.609 km).

- U.S. Hwy 191 south: 26 October 1999 – 29 March 2011.
- U.S. Hwy 191 north: 3 February 2003 – 18 February 2011.
- WY Hwy 22: 6 January 1996 – 11 March 2011.
- WY Highway 390: 24 October 2003 – 16 January 2011.

The years for which carcass data were available for all four highway segments were selected from the database (1 January 2004 – 31 December 2010). The most frequently recorded wildlife species in the carcass data was mule deer (*Odocoileus hemionus*), followed by elk (*Cervus canadensis*) and moose (*Alces alces*) (Figure 7). The species grouped in the "other" category are listed in Table 1)

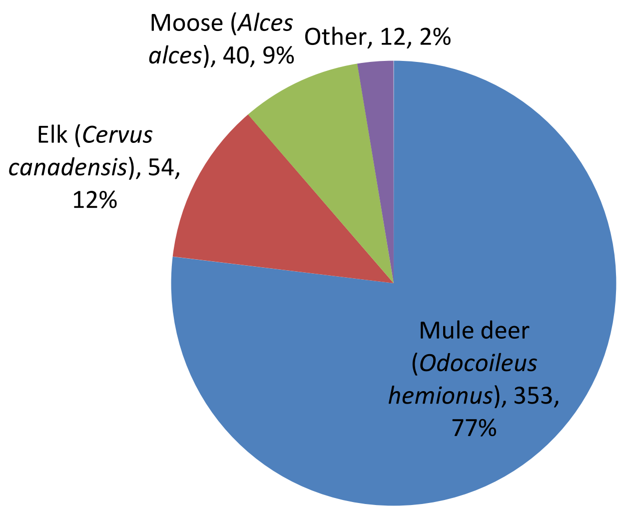

Figure 7: The number (N_{total} = 459) and the percentage of different species recorded as carcass data for all four highway segments combined between 1 January 2004 and 31 December 2010.

Table 1: The number and percentage of the species grouped in the "other" category of Figure 7.

Species	**N**	**%**
White-tailed deer (*Odocoileus virginianus*)	9	1.96
Pronghorn (*Antilocapra americana*)	2	0.44
Deer (*Odocoileus* spp.)	1	0.22

3.2.3. Identification Mortality Clusters

The spatial resolution of the crash data was far greater (0.1 mi (160.9 m)) than that for carcass data (1.0 mi (1.609 m). Therefore the research team based the identification and prioritization of the highway segments with a high concentration of wildlife-vehicle collisions on crash data rather than carcass data.

The procedure for the identification and prioritization of highway segments with a concentration of wildlife-vehicle collisions was as follows:

- The number of recorded wildlife-vehicle crashes was summed for each road length unit (see Appendix A). A road length unit was 0.1 mi (160.9 m) long. Observations at a 0.1 mi marker were assigned to a road length unit that extended from the 0.1 mi marker concerned through the following 0.1 mi marker. For example, an observation at mi marker 146.3 was assigned to road length unit 146.3-146.4.
- No distinction was made between the different species that were present in the database; all species were weighted equally. The number of observations in each 0.1 mi (160.9 m) road length unit reflects the total number of reported wildlife road mortality observations based on the crash data.

- For each 0.1 mi (160.9 m) long road length unit, a "wildlife road mortality value" was calculated by taking the sum of the unit concerned and its two neighboring units. For example, if adjacent 0.1 mi long units had the following number of observations: 0, 1, 3, 2, 4, 2, 0, the "wildlife road mortality value" for these 0.1 mi units was (?+1), 4, 6, 9, 8, 6, (2+?) (see also Appendix A). Thus the "wildlife road mortality value" for each 0.1 mi long road unit was related to the number of crash observations in a 0.3 mi long road section. This procedure recognized that an observation may have actually occurred in the neighboring 0.1 mi (potential spatial errors or spatial imprecision of observers) and it provided for a variable with values with a smoother transition between adjacent 0.1 mi long road units as the "wildlife road mortality value" for each 0.1 mi long unit was also influenced by its two neighboring units.
- Six categories of the "wildlife road mortality values" were distinguished for the 0.1 mi (160.9 m) long road units. The cut-off levels for these categories were determined using the following procedure:
    - 0.1 mi units with a "0" wildlife road mortality value were classified as "absent" (Table 2).
    - The remaining 0.1 mi units had a wildlife road mortality value of 1 or greater and the researchers calculated the 20, 40, 60 and 80 percentiles and classified each of the 0.1 mi units as one of the following: "very low" (>0-20%), "low" (20-40%), "medium" (40-60%), "high" (60-80%), and "very high" (80-100%) (Table 2).

Table 2. Cutoff levels of "wildlife road mortality values" for the four highway segments combined in Jackson Hole.

Absent	Very low	Low	Medium	High	Very high
0	>0-0.33	>0.33-0.50	>0.50-1.00	>1.00- 2.00	>2.00-8.00

The researchers identified "mortality clusters" by marking all 0.1 mi road units categorized as "very high" (see Appendix A). If a 0.1 mi road unit marked as "very high" had adjacent units that were classified as "high", these units were marked as well (see Appendix A). The "marking" on either side of a 0.1 mi road unit classified as "very high" stopped when a 0.1 mi road unit occurred that was classified as "medium" or lower. If a 0.1 mi road unit classified as "high" was not adjacent to a 0.1 mi road unit classified as "very high" it was not included in any of the mortality clusters. Thus, "mortality clusters" consisted of the "worst 20%" of all 0.1 mi road units (excluding the 0.1 mi road units that were classified as "absent") and the adjacent 0.1 mi units, as long as these fell within the "worst 40%" (excluding the 0.1 mi road units that were classified as "absent") (see Appendix A). Note that the mortality clusters were based on a 10 year long time period (2001 through 2010). The location of 10 year mortality clusters is likely more robust than mortality clusters based on only one or a few years.

Note that this procedure assumes that the search and reporting effort for crashes involving wildlife is similar for all road segments concerned. It is also important to realize that the procedure to identify mortality clusters is simply based on identifying the highway segments that have the highest frequency of wildlife-vehicle crashes. The mortality clusters that are identified do not necessarily meet a national standard or norm. The procedure described above only identifies the road sections with most wildlife vehicle collisions for the highway segments analyzed. Wildlife vehicle collisions also occur outside of the mortality clusters, but less frequently.

3.2.4. Prioritizing Mortality Clusters

For each mortality cluster the researchers summed the wildlife road mortality values. This number was divided by the number of 0.1 mi units of the mortality cluster concerned, standardizing a measure for the number of road killed wildlife. The resulting "ranking value" allowed for a direct comparison of the severity of the mortality clusters (see Appendix A). The higher the ranking value, the greater the number of road killed wildlife in a cluster standardized per 0.1 mi road length unit.

3.2.5. Buffer Zones, Gaps, and Mitigation Zones

For each mortality cluster the researchers calculated the percentage of each species based on the underlying wildlife road mortality observations. These data showed the researchers what species potential mitigation measures should be designed for based on the carcass data.

If wildlife road mortality in the mortality clusters is reduced through the installation of e.g. wildlife fencing and safe crossing opportunities for wildlife, wildlife that is attracted to the right-of-way vegetation or that wants to cross the highway may still gain access to the highway at fence ends. Such behavior may result in a change in location of wildlife-vehicle collisions rather than a substantial reduction in wildlife-vehicle collisions. Therefore wildlife fencing and safe crossing opportunities should have buffer zones with wildlife fencing that extend beyond the actual location of the mortality clusters. The researchers set the buffer zones at 0.62 mi (1 km) from each end of a mortality cluster. The researchers estimate that this distance is substantial enough to be a discouragement to most large ungulates that approach the road at a mortality cluster to travel a fence end rather than using safe crossing opportunities within the fenced road sections.

3.3. Results

The mortality clusters and buffer zones for the four highway segments are shown in Figure 8-11. The mortality clusters are concentrated on Hwy 191 south of Jackson, with additional clusters along Hwy 191 in and north of Jackson, and along Hwy 22 and Hwy 390. The prioritization of the mortality clusters (ranking value), the mi markers, and the species recorded in the mortality clusters are summarized in Table 3. Interestingly, the highest ranking mortality cluster is located along Hwy 191 in the town of Jackson just north of the Jct with Hwy 22. The crashes are primarily with deer (especially mule deer (based on the carcass data)) and elk (*Cervus Canadensis*), and to a lesser extent with moose (*Alces alces*).

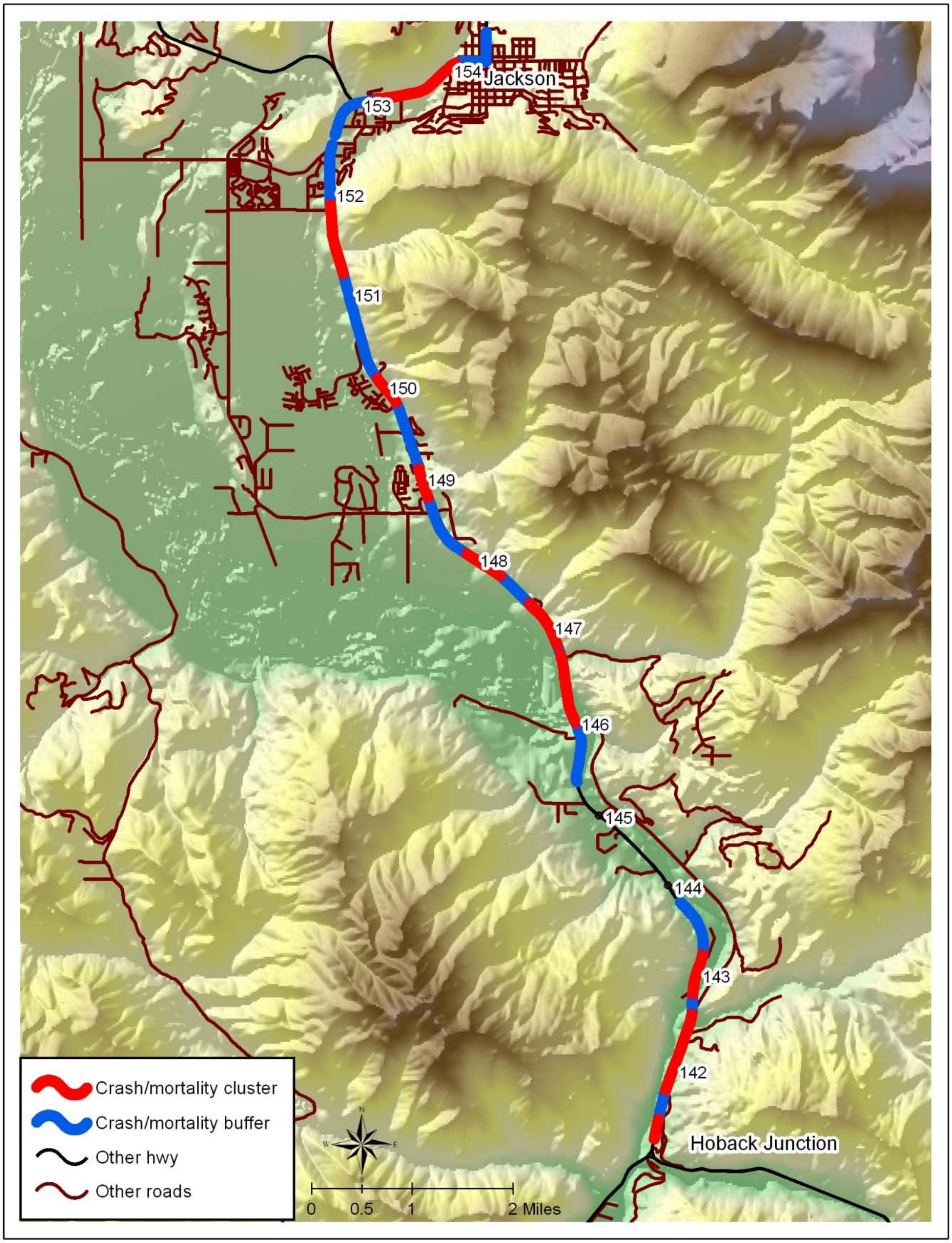

Figure 8: The mortality clusters and buffer zones along Hwy 191 from Hoback Jct and Jackson based on crash data (2001 through 2010).

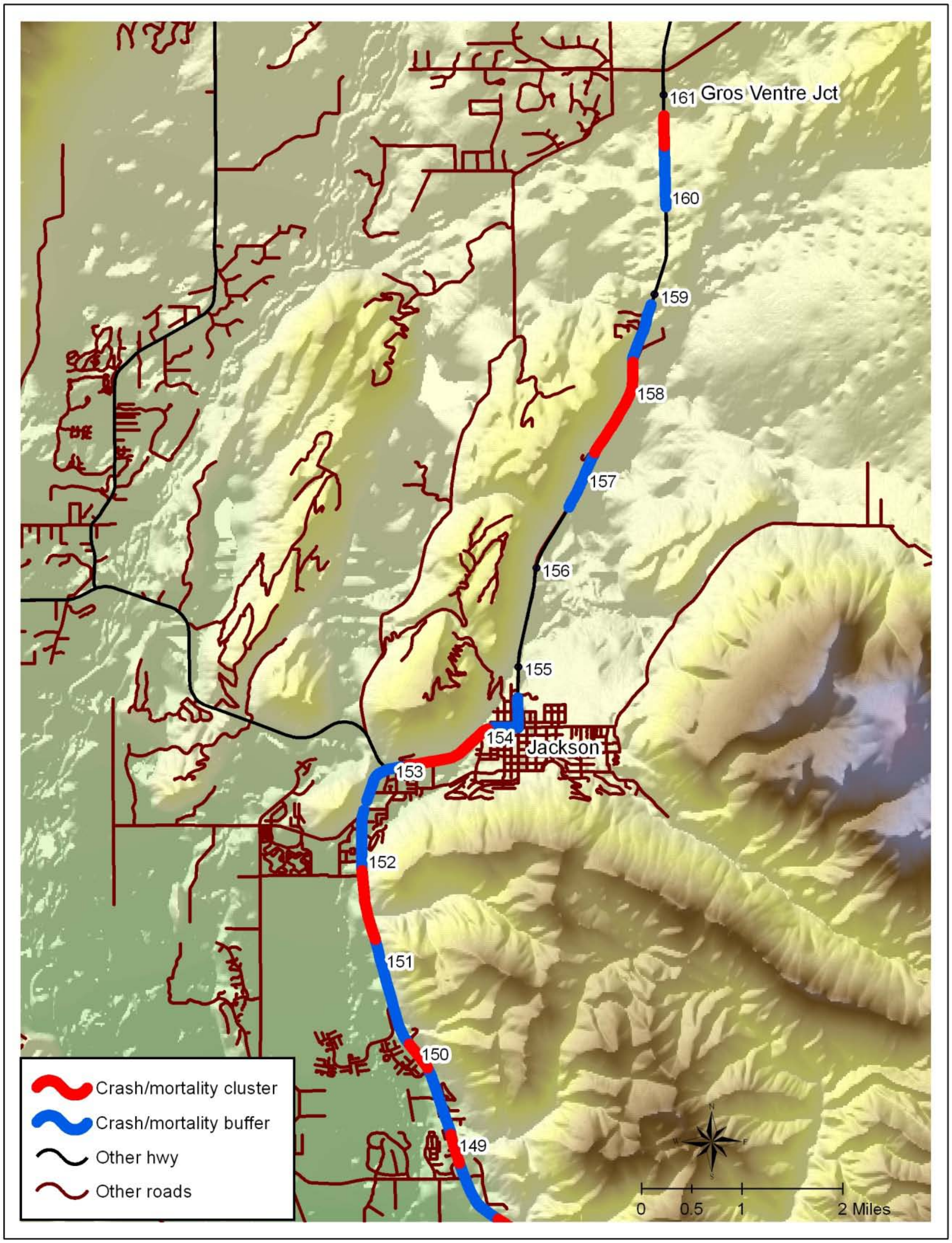

Figure 9: The mortality clusters and buffer zones along Hwy 191 from South Park loop Rd and Gros Ventre Jct based on crash data (2001 through 2010).

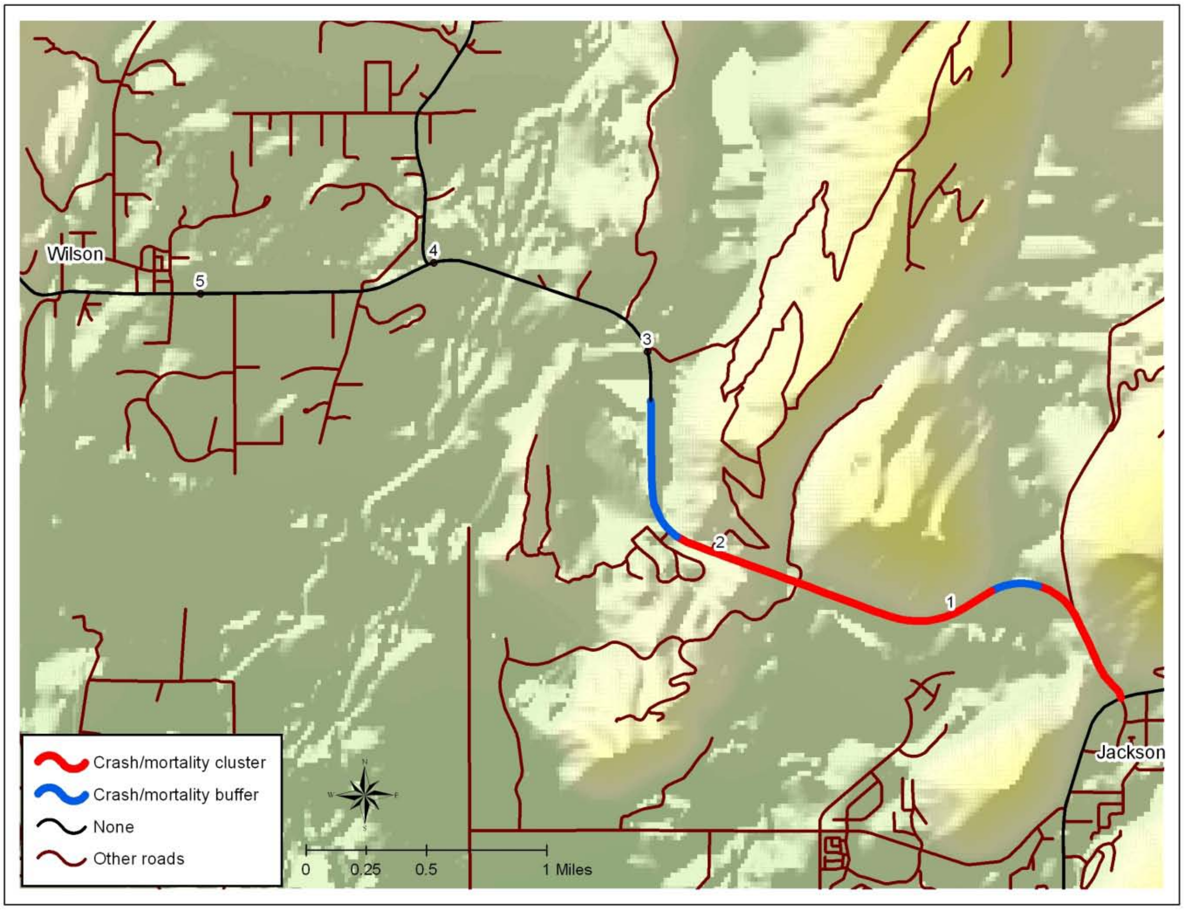

Figure 10: The mortality clusters and buffer zones along Hwy 22 from Jackson to Wilson based on crash data (2001 through 2010).

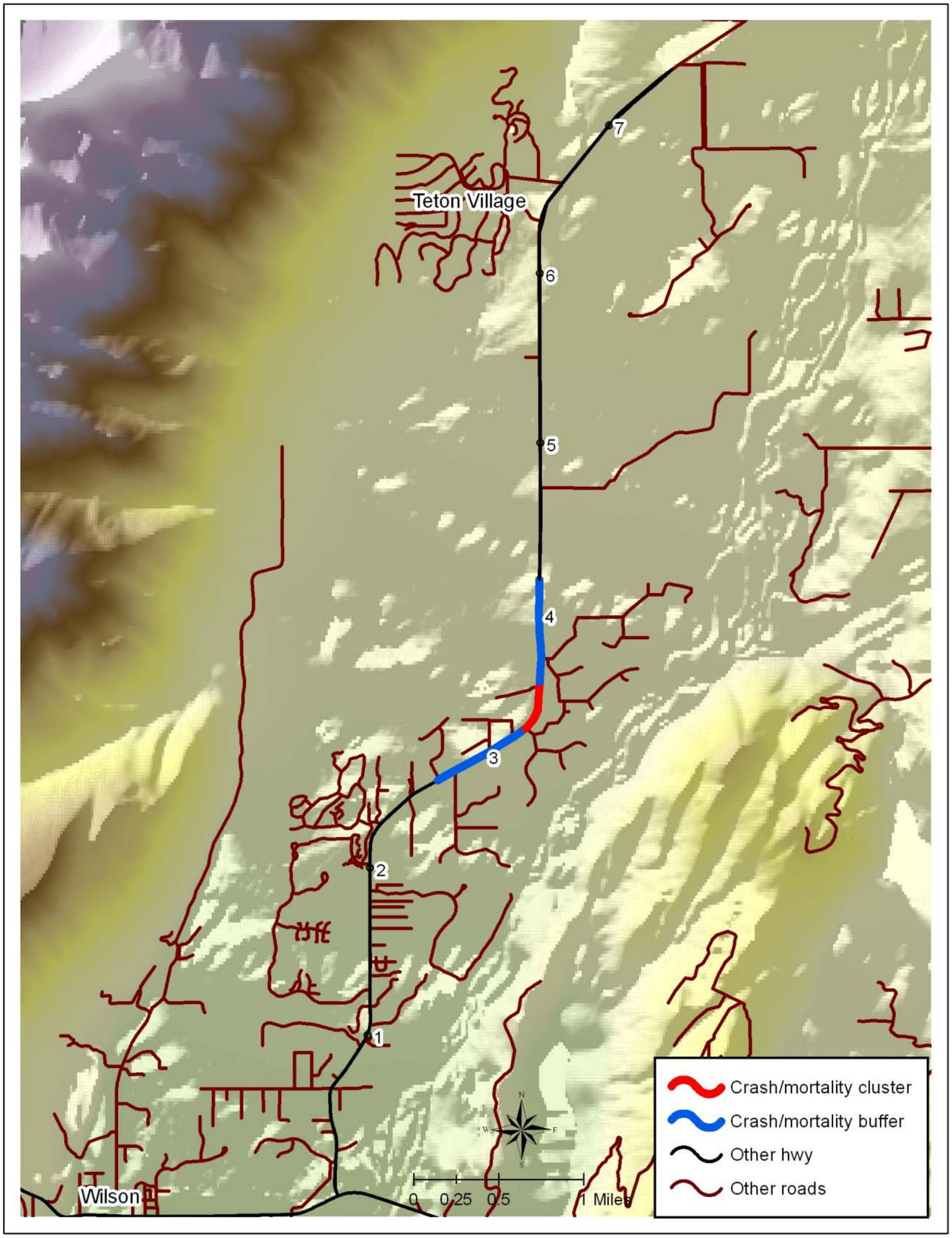

Figure 11: The mortality clusters and buffer zones along Hwy 390 from the Jct with Hwy 22 and the boundary of Grand Teton National Park based on crash data (2001 through 2010).

Table 3. The mortality clusters along the four highway segments in Jackson Hole and the number and percentage of the species recorded in each mortality cluster between 2001 and 2010. Note: When translating the mi markers into the road length units concerned, simply add 0.1 mi to the upper mi marker. For example: mortality cluster 141.4-141.5 relates to the highway segment 141.4-141.6.

Hwy	Mi Markers	Ranking Cluster	Species	N	%
191	141.4-141.5	13	Deer (*Odocoileus* spp.)	5	100.00
191	141.9-142.6	12	Deer (*Odocoileus* spp.)	15	83.33
			Elk (*Cervus canadensis*)	3	16.67
191	142.9-143.2	8	Deer (*Odocoileus* spp.)	9	100.00
191	146.1-146.7	9	Deer (*Odocoileus* spp.)	11	73.33
			Elk (*Cervus canadensis*)	4	26.67
191	146.9-147.3	14	Elk (*Cervus canadensis*)	9	90.00
			Deer (*Odocoileus* spp.)	1	10.00
191	147.8-148.1	10	Deer (*Odocoileus* spp.)	4	50.00
			Elk (*Cervus canadensis*)	4	50.00
191	148.9-149.1	6	Deer (*Odocoileus* spp.)	7	87.50
			Elk (*Cervus canadensis*)	1	12.50
191	149.9-150.1	3	Deer (*Odocoileus* spp.)	9	90.00
			Moose (Alces alces)	1	10.00
191	151.3-151.9	5	Deer (*Odocoileus* spp.)	13	68.42
			Elk (*Cervus canadensis*)	4	21.05
			Moose (Alces alces)	2	10.53
191	153.3-154.1	1	Deer (*Odocoileus* spp.)	48	100.00
191	157.4-158.3	4	Deer (*Odocoileus* spp.)	17	56.67
			Elk (*Cervus canadensis*)	13	43.33
191	160.6-160.8	11	Deer (*Odocoileus* spp.)	3	50.00
			Moose (Alces alces)	3	50.00
22	0.1-0.2	16	Deer (*Odocoileus* spp.)	4	100.00
22	0.4-0.6	7	Deer (*Odocoileus* spp.)	7	100.00
22	0.9-2.2	2	Elk (*Cervus canadensis*)	30	58.82
			Deer (*Odocoileus* spp.)	17	33.33
			Moose (Alces alces)	4	7.84
390	3.3-3.6	15	Deer (*Odocoileus* spp.)	4	57.14
			Moose (Alces alces)	2	28.57
			Elk (*Cervus canadensis*)	1	14.29

4. OBSERVATIONS BY WYOMING GAME & FISH DEPARTMENT

4.1. Introduction

Wyoming Game & Fish Department maintains a database on wildlife observations. The researchers used this database to investigate which species are frequently observed on or near the highways. These data help identify locations where safe crossing opportunities may have to be provided for and for which species.

4.2. Methods

4.2.1. Data Selection

Observations from the Wyoming Game & Fish Department were only available for the southern segment of Hwy 191 between Hoback Jct and the southern edge of Jackson. The observations were made between 29 December 1978 and 3 March 2011. The researchers selected observations as follows:

- Only observations that fell within 200 m from Hwy 191 were included (both sides of the road combined into a 400 m wide zone). By only selecting observations close to the road the data were more likely to indicate where animals may cross the road or be potentially interested in crossing.
- Only mammal species that were greater or equal to the body size of red fox (*Vulpes vulpes*) were included as smaller animal species are unlikely to experience wildlife fencing as a barrier.
- Observations of road killed animals were deleted. The location of wildlife-vehicle collisions was probably better captured already through crash and carcass data (though only crash data were used, see previous chapter). The data from Wyoming Game & Fish Department were primarily used to investigate potential other locations where animals may either cross the road successfully or come close to the road, potentially indicating suitable locations for safe crossing opportunities.

The most frequently recorded wildlife species in the selected data was mule deer (*Odocoileus hemionus*), followed by elk (*Cervus canadensis*), moose (*Alces alces*) and white-tailed deer (Figure 12). The species grouped in the "other" category are listed in Table 4)

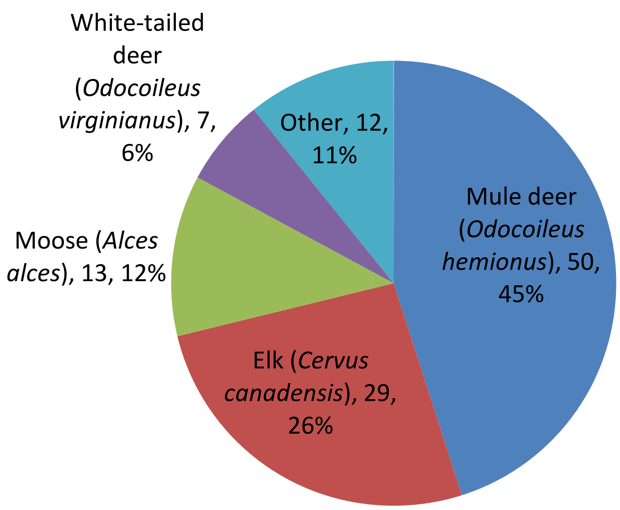

Figure 12: The number (N_{total} = 111) and the percentage of different species recorded in the Wyoming Game & Fish Department data for Hwy 191 between Hoback Jct and the southern edge of Jackson (December 1978 through March 2011).

Table 4: The number and percentage of the species grouped in the "other" category of Figure 7.

Species	N	%
Black bear (*Ursus americanus*)	5	4.50
Pronghorn (*Antilocapra americana*)	4	3.60
Mountain lion (*Felis concolor*)	2	1.80
Bighorn sheep (*Ovis canadensis*)	1	0.90

4.2.2. Identification and Prioritization Observation Clusters

The procedure to identify and prioritize highway segments that have a concentration of wildlife observations was similar to that in the previous chapter, calculating "wildlife observation values" rather than "wildlife road mortality values". The cut-off levels for the observation categories are shown in Table 4.

Table 5. Cutoff levels of "wildlife observation values" for the observation data from Wyoming Game & Fish Department for the southern segment of Hwy 191 between Hoback Jct and the southern edge of Jackson.

Absent	Very low	Low	Medium	High	Very high
0	>0-0.32	>0.32-0.66	>0.66-1.32	>1.32- 1.66	>1.66-4.33

4.3. Results

The wildlife observation clusters for the southern segment of Hwy 191 are shown in Figure 13. The prioritization of the wildlife observation clusters (ranking value), the mi markers, and the species recorded in the clusters are summarized in Table 6.

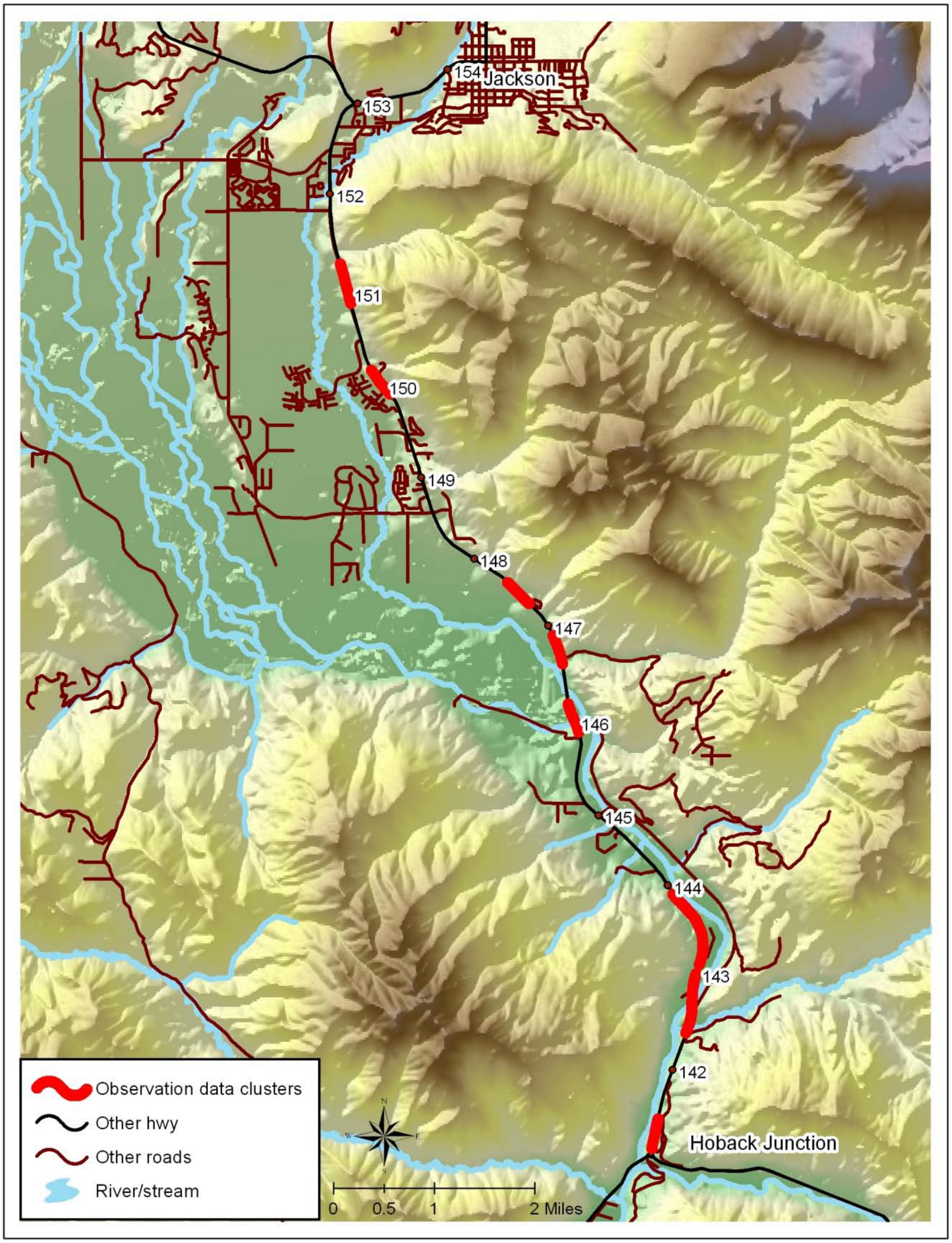

Figure 13: The wildlife observation clusters along Hwy 191 between Hoback Jct and Jackson based on Wyoming Game & Fish Department data (December 1978 through March 2011).

Table 6. The wildlife observation clusters along Hwy 191 between Hoback Jct and Jackson based on Wyoming Game & Fish Department data (December 1978 through March 2011) and the number and percentage of the species recorded in each observation cluster. Note: When translating the mi markers into the road length units concerned, simply add 0.1 mi to the upper mi marker. For example: mortality cluster 141.3-141.5 relates to the highway segment 141.3-141.6.

Hwy	Mi Markers	Ranking Cluster	Species	N	%
191	141.3-141.5	7	Mule deer (*Odocoileus hemionus*)	2	66.67
			Elk (*Cervus canadensis*)	1	33.33
191	142.5-143.0	5	Mule deer (*Odocoileus hemionus*)	5	45.45
			Elk (*Cervus canadensis*)	5	45.45
			Moose (*Alces alces*)	1	9.09
191	143.2-143.9	3	Mule deer (*Odocoileus hemionus*)	9	45.00
			Elk (*Cervus canadensis*)	5	25.00
			White-tailed deer (*Odocoileus virginianus*)	3	15.00
			Moose (*Alces alces*)	2	10.00
			Mountain lion (*Felis concolor*)	1	5.00
191	145.9-146.2	1	Mule deer (*Odocoileus hemionus*)	5	38.46
			Elk (*Cervus canadensis*)	4	30.77
			White-tailed deer (*Odocoileus virginianus*)	2	15.38
			Moose (*Alces alces*)	1	7.69
			Pronghorn (*Antilocapra americana*)	1	7.69
191	146.7-146.9	6	Elk (*Cervus canadensis*)	2	40.00
			White-tailed deer (*Odocoileus virginianus*)	2	40.00
			Pronghorn (*Antilocapra americana*)	1	20.00
191	147.4-147.6	2	Black bear (*Ursus americanus*)	5	55.56
			Mule deer (*Odocoileus hemionus*)	2	22.22
			Elk (*Cervus canadensis*)	2	22.22
191	150.0-150.2	4	Mule deer (*Odocoileus hemionus*)	4	50.00
			Moose (*Alces alces*)	3	37.50
			Mountain lion (*Felis concolor*)	1	12.50
191	151.0-151.3	5	Mule deer (*Odocoileus hemionus*)	3	42.86
			Elk (*Cervus canadensis*)	3	42.86
			Moose (*Alces alces*)	1	14.29

5. OBSERVATIONS BY THE PUBLIC

5.1. Introduction

Nature Mapping Jackson Hole (http://www.naturemappingjh.org) coordinates the collection of wildlife observations by the public in the Jackson Hole area. The public can enter observations of wildlife in a database. These data include observations on and along highways. These data help identify locations where safe crossing opportunities may have to be provided for and for which species.

5.2. Methods

5.2.1. Data Selection

Observations from the Nature Mapping Jackson Hole project were available along all four highway segments. The observations were made between 21 August 2009 and 14 May 2011. The researchers selected observations as follows:

- Only observations that fell within 200 m from the four highway segments were included (both sides of the road combined into a 400 m wide zone). By only selecting observations close to the road the data were more likely to indicate where animals may cross the road or be potentially interested in crossing.
- Only mammal species that were greater or equal to the body size of red fox (*Vulpes vulpes*) were included as smaller animal species are unlikely to experience wildlife fencing as a barrier.
- Observations of road killed animals were deleted. The location of wildlife-vehicle collisions was probably better captured already through crash and carcass data (though only crash data were used, see previous chapter). The data from Nature Mapping Jackson Hole were primarily used to investigate potential other locations where animals may either cross the road successfully or come close to the road, potentially indicating suitable locations for safe crossing opportunities.

The most frequently recorded wildlife species in the selected data was mule deer (*Odocoileus hemionus*), followed by elk (*Cervus canadensis*), moose (*Alces alces*) and white-tailed deer (Figure 12). The species grouped in the "other" category are listed in Table 4)

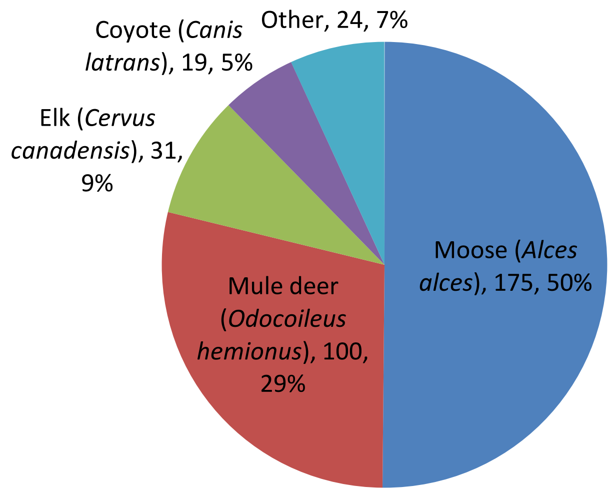

Figure 14: The number (N_{total} = 349) and the percentage of different species recorded in the Nature Mapping Jackson Hole for the four highway segments in Jackson Hole (21 August 2009 and 14 May 2011).

Table 7: The number and percentage of the species grouped in the "other" category of Figure 14.

Species	N	%
Red fox (*Vulpes vulpes*)	14	4.01
White-tailed deer (*Odocoileus virginianus*)	6	1.72
Pronghorn (*Antilocapra americana*)	3	0.86
American badger (*Taxidea taxus*)	1	0.29

5.2.1. Identification and Prioritization Observation Clusters

The procedure to identify and prioritize highway segments that have a concentration of wildlife observations was similar to that in the previous two chapters, calculating "wildlife observation values" rather than "wildlife road mortality values". The cut-off levels for the observation categories are shown in Table 8.

Table 8. Cutoff levels of "wildlife observation values" for the observation data from Nature Mapping Jackson Hole for the four highway segments in Jackson Hole.

Absent	Very low	Low	Medium	High	Very high
0	>0-0.32	>0.32-0.66	>0.66-1.32	>1.32- 2.19	>2.19-12.67

5.3. Results

The wildlife observation clusters for four highway segments are shown in Figure 15-19. The prioritization of the wildlife observation clusters (ranking value), the mi markers, and the species recorded in the clusters are summarized in Table 9.

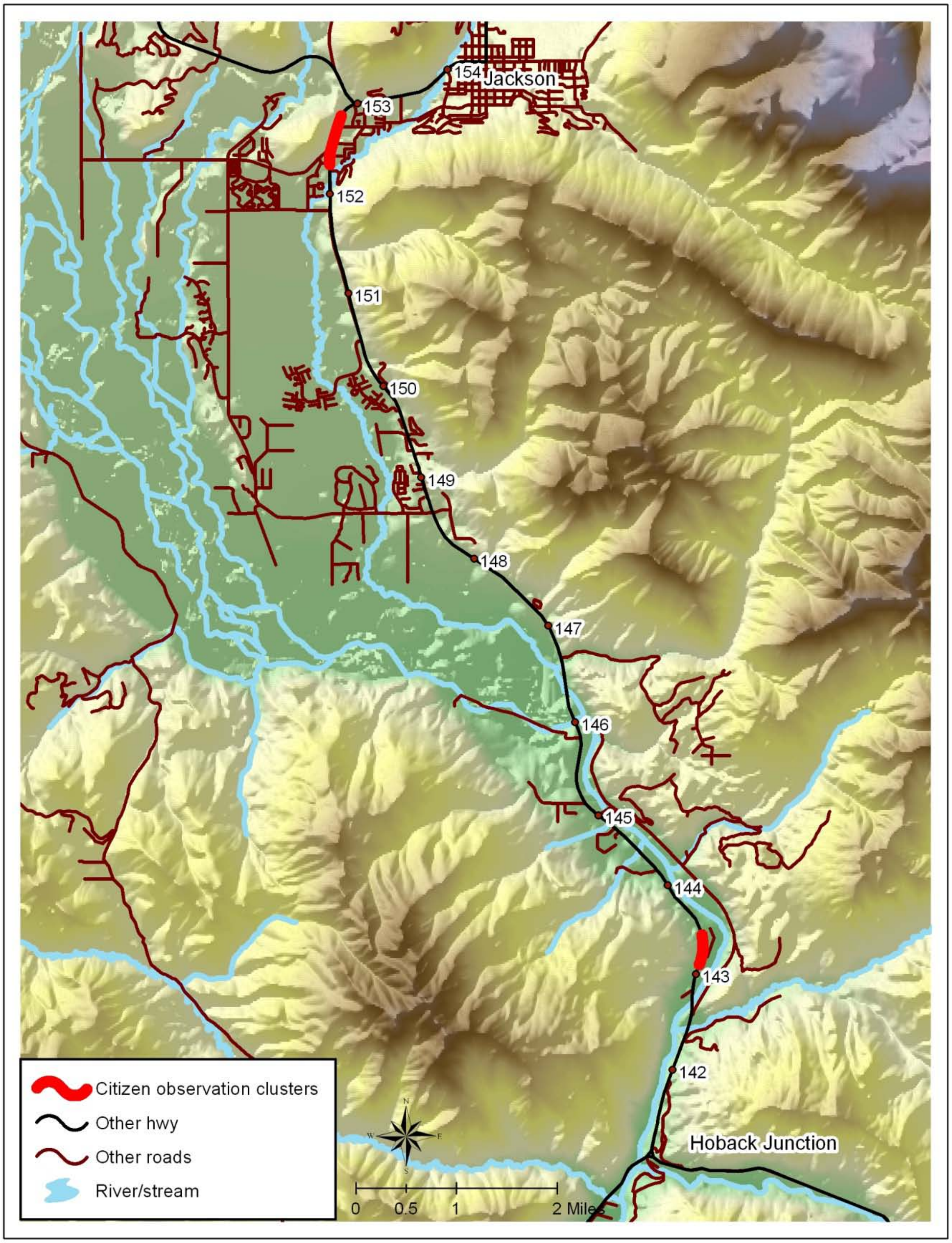

Figure 15: The wildlife observation clusters along the southern segment of Hwy 191 between Hoback Jct and Jackson based on Nature Mapping Jackson Hole data (12 August 2009 through 14 May 2011).

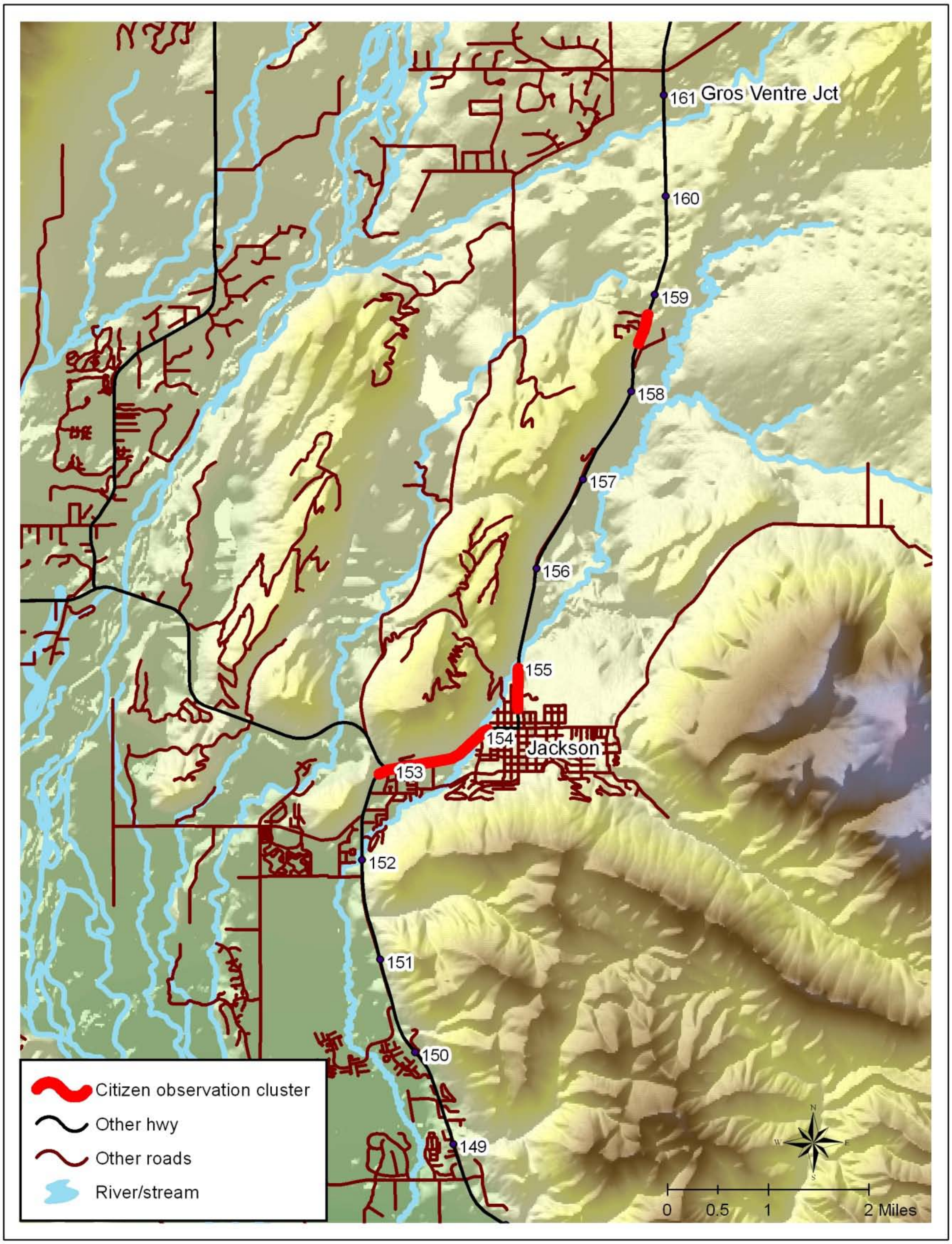

Figure 16: The wildlife observation clusters along the northern segment of Hwy 191 between Jackson and Gros Ventre Jct based on Nature Mapping Jackson Hole data (12 August 2009 through 14 May 2011).

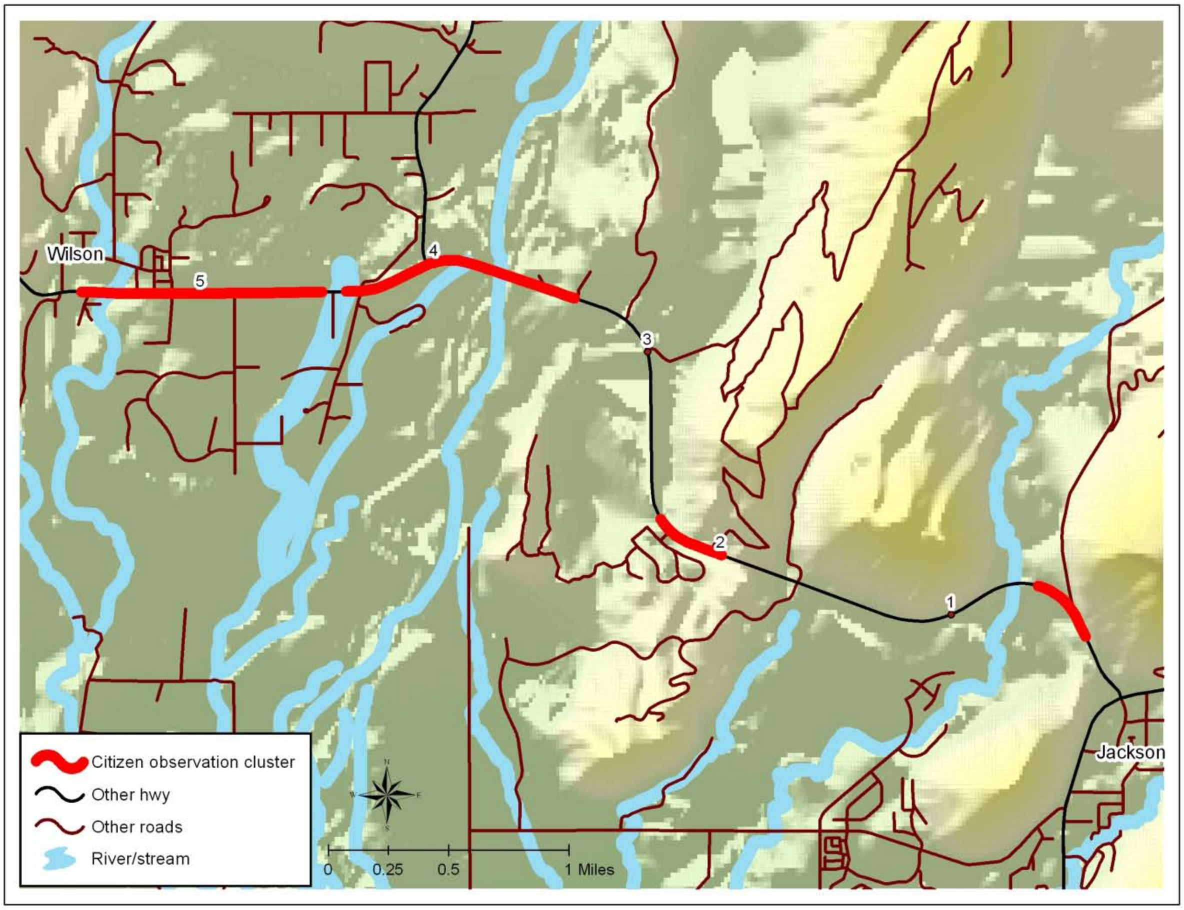

Figure 17: The wildlife observation clusters along Hwy 22 between Jackson and Wilson based on Nature Mapping Jackson Hole data (12 August 2009 through 14 May 2011).

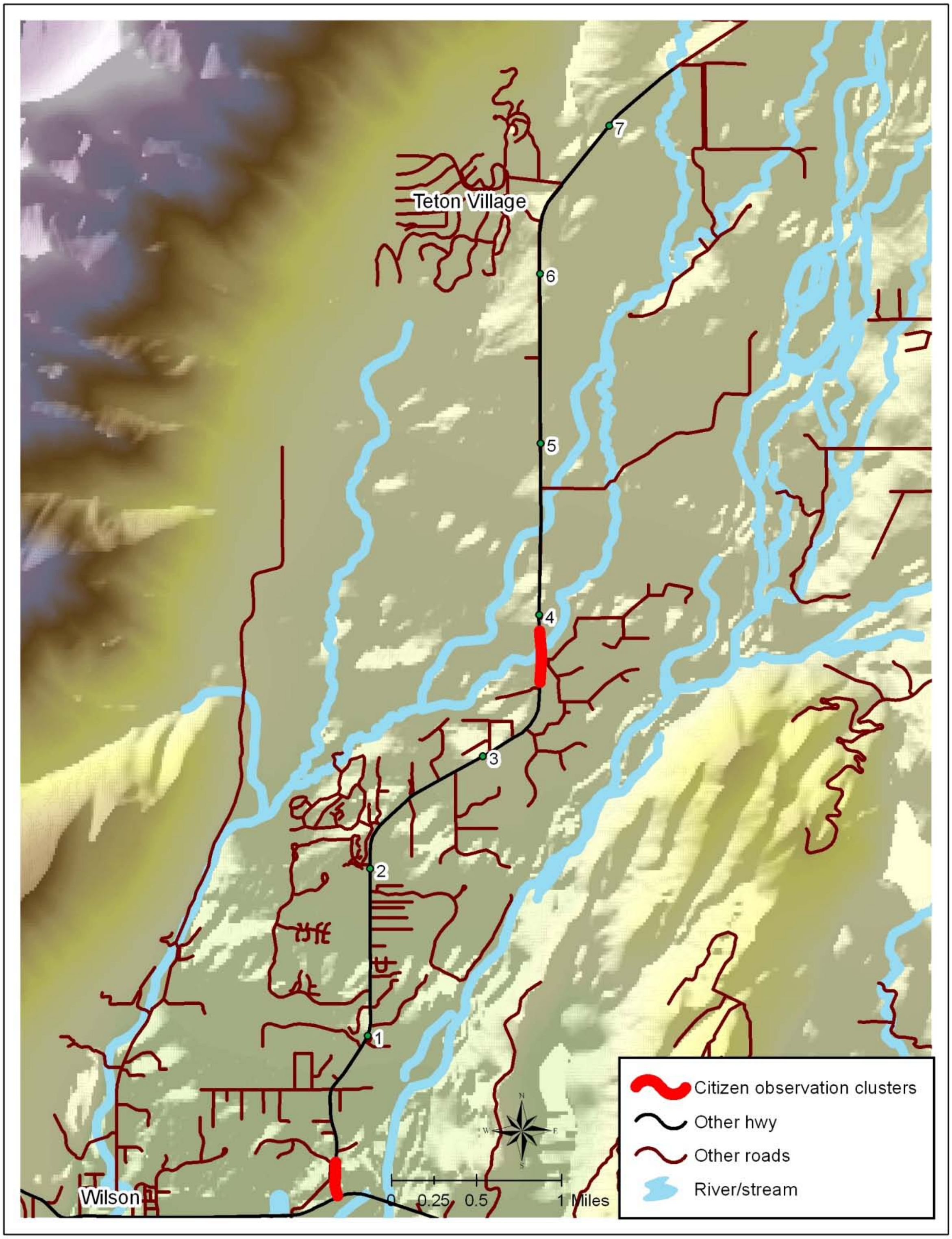

Figure 18: The wildlife observation clusters along Hwy 390 between the Jct with Hwy 22 and the boundary of Grand Teton National Park based on Nature Mapping Jackson Hole data (12 August 2009 through 14 May 2011).

Table 9. The wildlife observation clusters along the four highway segments in the Jackson Hole area based on Nature Mapping Jackson Hole data (12 August 2009 through 14 May 2011) and the number and percentage of the species recorded in each observation cluster. Note: When translating the mi markers into the road length units concerned, simply add 0.1 mi to the upper mi marker. For example: mortality cluster 143.2-143.4 relates to the highway segment 143.2-143.5.

Hwy	Mi Markers	Ranking Cluster	Species	N	%
191	143.2-143.4	11	White-tailed deer (*Odocoileus virginianus*)	3	75.00
			Mule deer (*Odocoileus hemionus*)	1	25.00
191	152.4-152.8	10	Mule deer (*Odocoileus hemionus*)	8	88.89
			Badger (*Taxidea taxus*)	1	11.11
191	153.0-154.1	9	Mule deer (*Odocoileus hemionus*)	24	88.89
			Moose (*Alces alces*)	2	7.41
			Elk (*Cervus canadensis*)	1	3.70
191	154.7-155.0	6	Moose (*Alces alces*)	6	50.00
			Mule deer (*Odocoileus hemionus*)	6	50.00
191	158.6-158.8	7	Mule deer (*Odocoileus hemionus*)	4	57.14
			Moose (*Alces alces*)	3	42.86
22	0.4-0.6	8	Mule deer (*Odocoileus hemionus*)	6	100.00
22	2.1-2.3	3	Moose (*Alces alces*)	10	62.50
			Red fox (*Vulpes vulpes*)	3	18.75
			Elk (*Cervus canadensis*)	2	12.50
			Coyote (*Canis latrans*)	1	6.25
22	3.5-4.4	2	Moose (*Alces alces*)	60	90.91
			Elk (*Cervus canadensis*)	5	7.58
			Coyote (*Canis latrans*)	1	1.52
22	4.6-5.5	5	Moose (*Alces alces*)	28	62.22
			Red fox (*Vulpes vulpes*)	7	15.56
			Coyote (*Canis latrans*)	7	15.56
			Elk (*Cervus canadensis*)	2	4.44
			White-tailed deer (*Odocoileus virginianus*)	1	2.22
390	0.0-0.2	1	Moose (*Alces alces*)	25	92.59
			Elk (*Cervus canadensis*)	2	7.41
390	3.7-3.9	4	Mule deer (*Odocoileus hemionus*)	9	64.29
			Moose (*Alces alces*)	4	28.57
			Red fox (*Vulpes vulpes*)	1	7.14

6. COST-BENEFIT ANALYSIS MITIGATION MEASURES

6.1. 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.

6.2. 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 ten year period (2001-2010) 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.

6.3. Results

Figures 19 through 21 show for which road sections the number of recorded deer carcasses was high enough to meet or exceed thresholds for the implementation of four different types of mitigation measures. All highway segments had road sections where the threshold values for either all or some of the four mitigation measures were (nearly) met or exceeded.

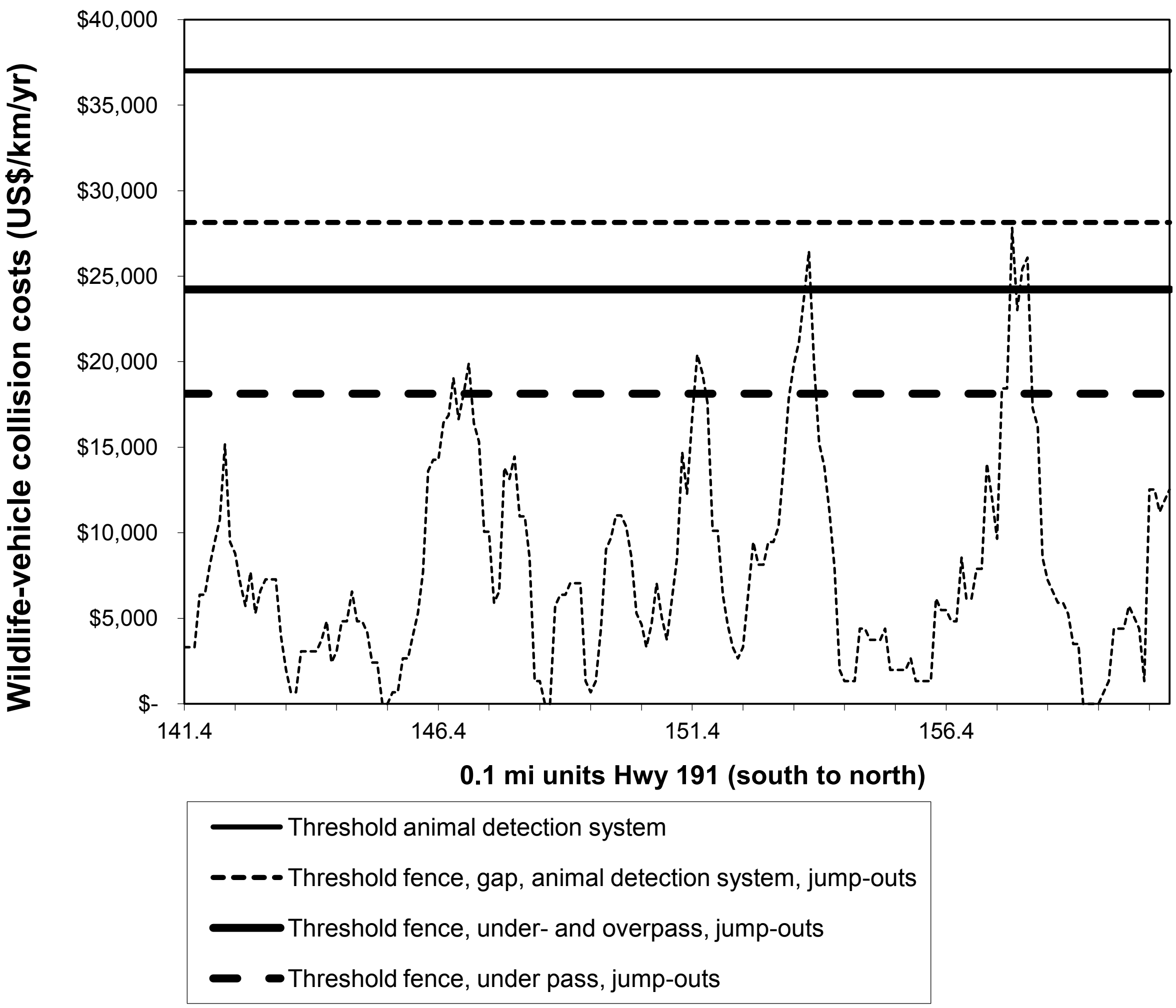

Figure 19: Hwy 191 from Hoback Jct (south end, left side of graph) to Gros Ventre Jct (north end, right side of graph). The costs (in 2007 US$) associated with ungulate-vehicle collisions per year (annual average based on crash data 2001-2010), and the threshold values (at 3% discount rate) that need 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.

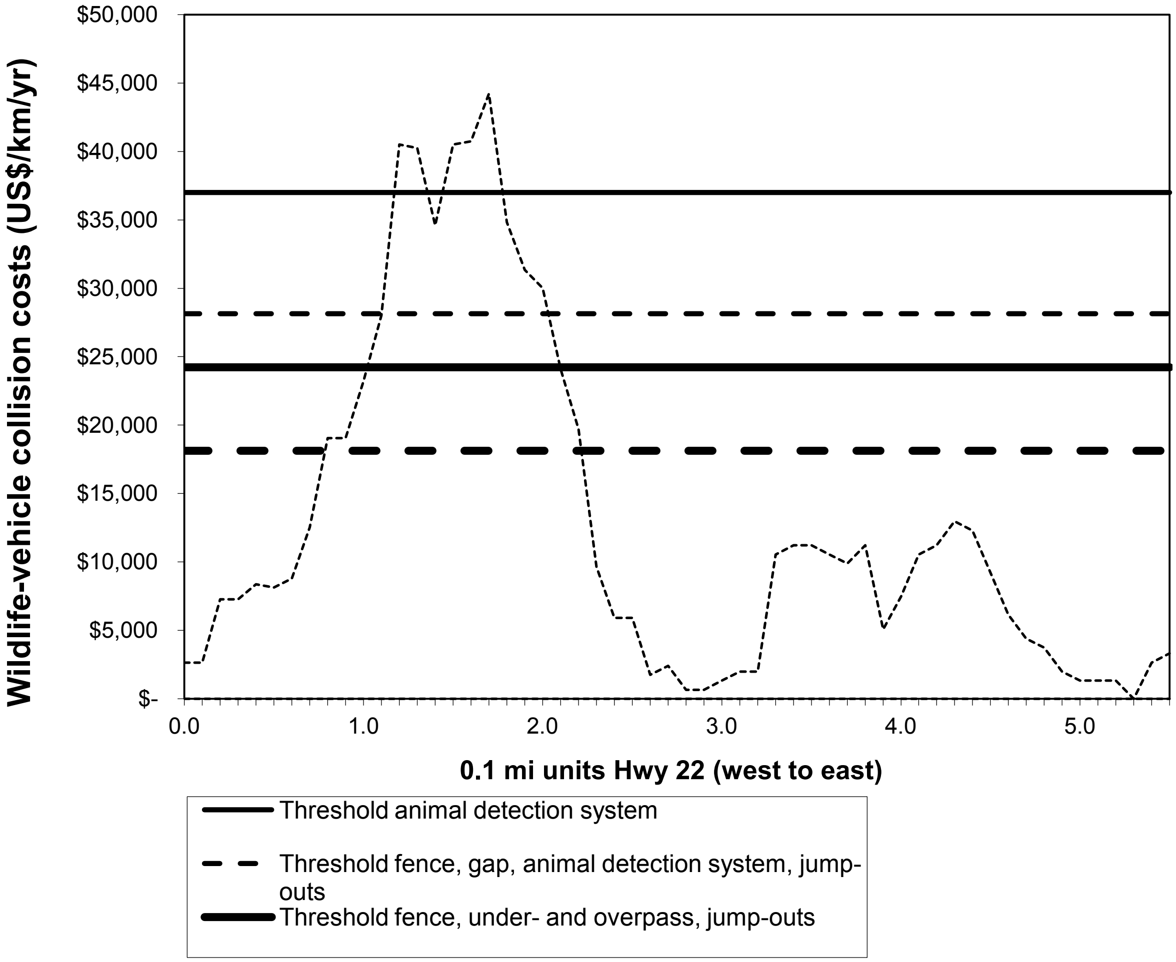

Figure 20: Hwy 22 from Jct with Hwy 191 in Jackson (east end, left side of graph) to Wilson (west end, right side of graph). The costs (in 2007 US$) associated with ungulate-vehicle collisions per year (annual average based on crash data 2001-2010), and the threshold values (at 3% discount rate) that 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.

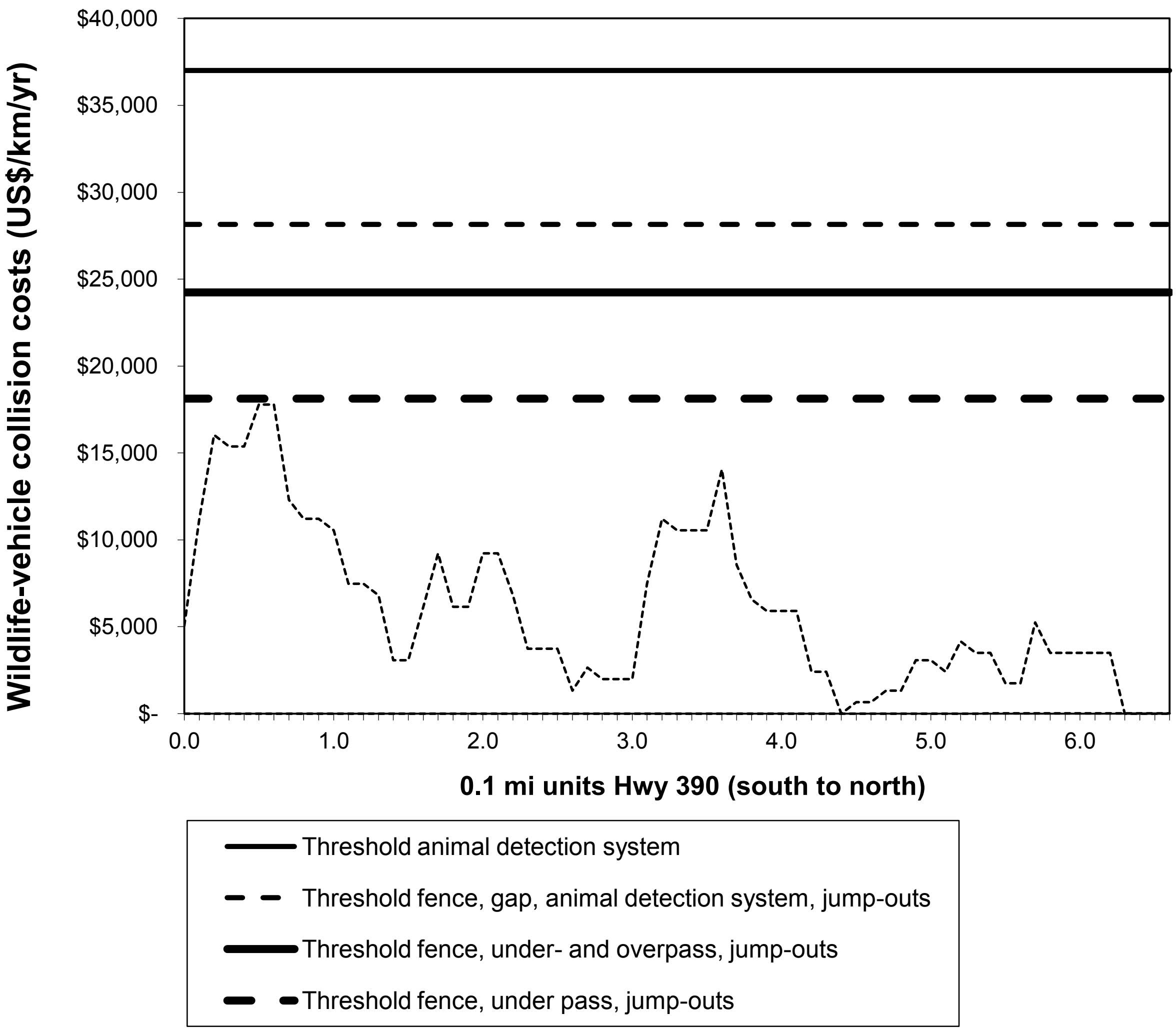

Figure 21: Hwy 390 from Jct with Hwy 22 (south end, left side of graph) to boundary with Grand Teton National Park (north end, right side of graph). The costs (in 2007 US$) associated with ungulate-vehicle collisions per year (annual average based on crash data 2001-2010), and the threshold values (at 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.

6.4. Discussion and Conclusions

All highway segments had road sections where the threshold values for either all or some of the four mitigation measures were (nearly) met or exceeded. 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 crash data rather than carcass data, mainly because of the lack of spatial precision of the carcass 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 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.

7. MITIGATION EMPHASIS SITES

7.1. Locations of Mitigation Emphasis Sites

The purpose of this project was to locate areas along the three highway segments in the study area that are important for wildlife's needs; such as wildlife movement corridors, winter or summer range for ungulates, nesting sites for bald eagles and potential spawning streams for cutthroat trout. Data was gathered from a variety of sources and mitigation emphasis site (MES) locations were selected based on where the highway segments passed through (bisected) wildlife corridors or important seasonal ranges of ungulates. Additional importance was given to the location if it also had a stream or river under the highway that had the potential for spawning cutthroat trout or a nesting area for bald eagles. This portion of the MES selection process was completed using GIS mapping (Figures 22, 23 and 24).

Each MES was then tested for its inclusion into the study via a field review on 29-30 June 2011. A technical advisory team (Appendix D) went to each site and either 1) agreed to retain the MES in the report, 2) move the MES's location slightly up or down the highway (one to two tenths of a mile), 3) strike the MES from consideration, or 4) add new MESs. Three sites were moved slightly to improve their capacity for mitigation, one MES was dropped from consideration and one MES was added (Snake River Ranch was made in to two distinct locations: Snake River Ranch North and Snake River Ranch South on WY 390). At the end of the field review 25 MES were adopted, evaluated and reviewed by the technical advisory team. Twelve MESs are located along US Highway 191/89 south of the town of Jackson where the five lane highway transitions to two lanes and proceeds to Hoback Junction. This highway segment is currently having an environmental review conducted by the WY Department of Transportation as it selects an alternative to add additional traffic lanes and straighten this section. It also is currently considering wildlife mitigation options to promote wildlife connectivity and reduce wildlife-vehicle collisions. Seven MESs were selected and evaluated on WY Highway 22 from its junction with US 191/89 in Jackson running west and ending at the Fish Creek bridge on the east side of Wilson, WY. The third highway segment, WY 390, had 6 MESs along its route from the junction with WY 22 north to the southern border of Grand Teton National Park.

7.2. Methods for Prioritizing Mitigation Emphasis Sites

A ranking system was developed to help highway managers prioritize MES locations most important for wildlife mitigation for the three highway segments. The values are relative to each other throughout the study area, not just for the particular road segment where the MES is located. Values for three of the six categories at each MES were reached by consensus during the field review by the technical advisory team: regional conservation value, local conservation value, and mitigation options. Values for the other three categories were derived from data (highway mortality and citizen observations of live wildlife) or from land plat maps for land security. They were judged on a relative numerical scale from zero (no value) to five (very high value). Six categories were delineated to capture values important for setting MES priorities:

1. The local conservation value sought to capture the importance of maintaining connectivity for the seasonal movement of local herds of ungulates, fish passage, and other related fine scale opportunities for wildlife. For example, since there is a Wyoming

Game and Fish elk winter feeding ground in the project area, many ungulates are moving in the fall from their summer range at higher elevations in the adjacent mountains down in to the valley where the feeding ground is located. This necessitates high numbers of individuals moving across the highways.

2. The regional wildlife category sought to value a MES for its importance in maintaining connectivity at a regional scale. This relates especially to large mammals that have low population density (e.g. grizzly bears, wolverines), but it could also relate to the impoartnce of corridors for more common species. Success for some of these species may be measured by safe passage at highway crossings at very low rates; since effective population levels are so low. For example, it has been estimated that effective population sizes for wolverine in the Northern Rocky Mountain states is 35 (Schwartz, et al. 2009), indicating maintaining low highway mortality rates is important for maintaining viable populations of this rare carnivore.
3. Transportation mitigation option values were based on opportunities presented at the MES by its geographical setting and features (i.e, stream crossing, terrain, slope stability), the difficulty or ease for the placement and design of infrastructure (i.e., underpass, overpass), the age, condition and appropriate size of existing infrastructure (i.e., culverts, bridges) and other physical, biological and social (i.e., recreational trails) features. The value for each MES represents the relative ease or difficulty presented to the technical advisory team during its field visit on 29-30 June 2011. Geotechnical information and other engineering studies were not available during the development of these values in the field.
4. The values for highway mortality were based on Table 2 in Chapter 3 (see also Appendix A).
5. Citizen observations were based on Table 8 in Chapter 5 (see also Appendix C).
6. Land security was the category that evaluated the condition of the lands directly adjacent to the MES. Investing in highway infrastructure that provides safe passage for wildlife is often an expensive undertaking that could cost a million dollars or more. Therefore, assuring that the lands that provide access and egress to the crossing will not be developed for commercial, residential or industrial purposes is an important consideration for setting mitigation priorities. Such development on lands adjacent to the MES could impede or create a barrier to wildlife movement and reduce the effectiveness of the mitigation measures. Land security values were developed using Geographical Information System (GIS) information made available to the public by Teton County, Wyoming (URL: http://www2.tetonwyo.org/mapserver/). Teton County has GIS maps for land ownership and conservation easements; the GIS was built and is continuing to be maintained by Greenwood Mapping, Inc. for the county. To develop land security values, the Teton County GIS information was layered with the highway segments and the MES locations. Values for land security were then developed based on land ownership, existing conservation easement information, and land development attributes on both sides of the highway at each MES (Figures X, Y and Z). The highest value (5) was very secure and the lowest value (1) had development on lands on both sides of the highway at the MES location:

   5 - Public lands (federal, state, county) or private lands with a conservation easement on both sides of MES

4 - Public lands or conservation easement on one side of MES, open space on the other (with unsecured easements)

3 - Open space lands on both sides, but unsecured conservation easements for these private lands

2 - Housing development or industrial/commercial site on one side, open space on other side (with unsecured easements)

1 - Housing development or industrial/commercial sites on both sides of highway at MES

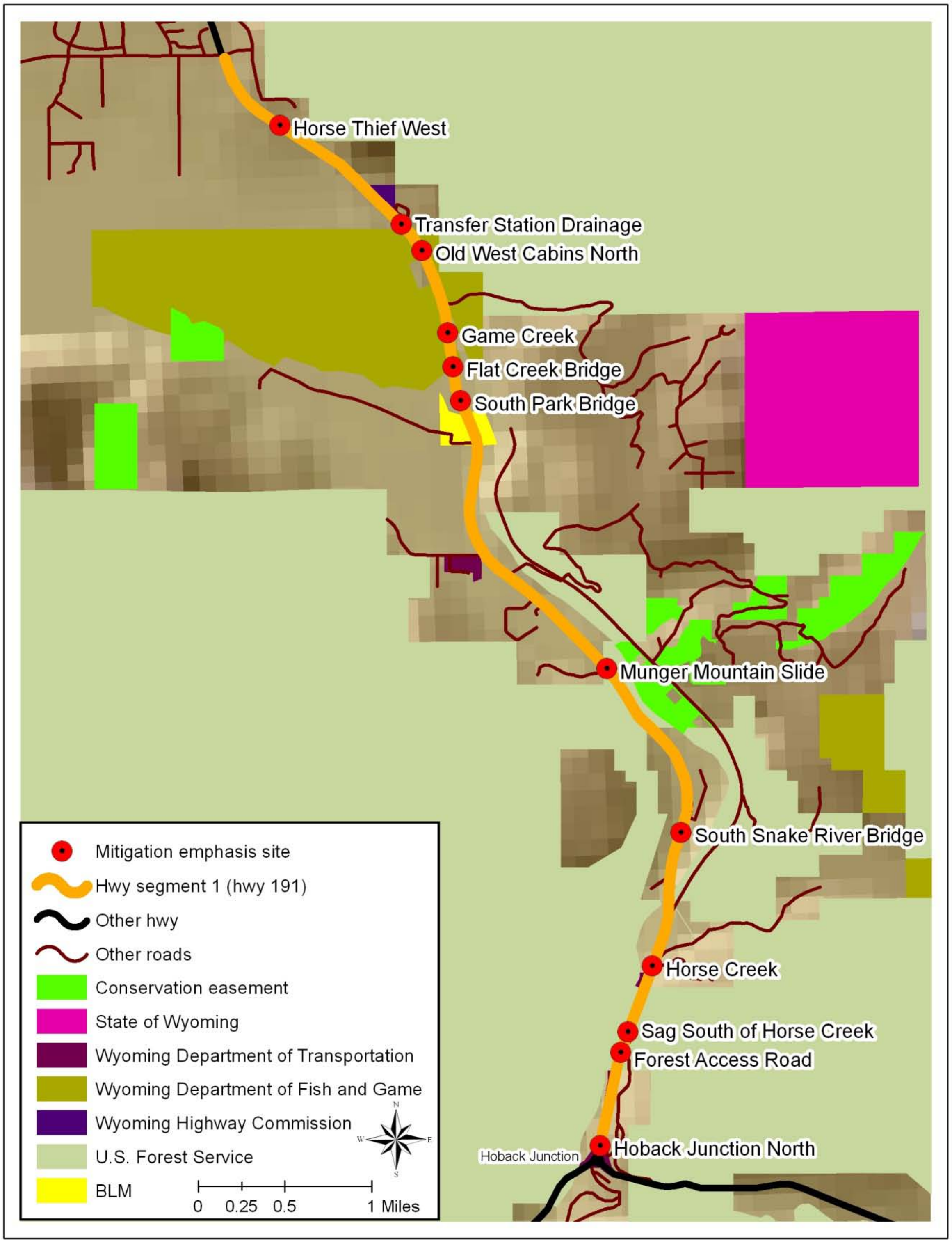

Figure 22: Land ownership and conservation easements along US Highway 191/89 from south of Jackson, WY to Hoback Junction.

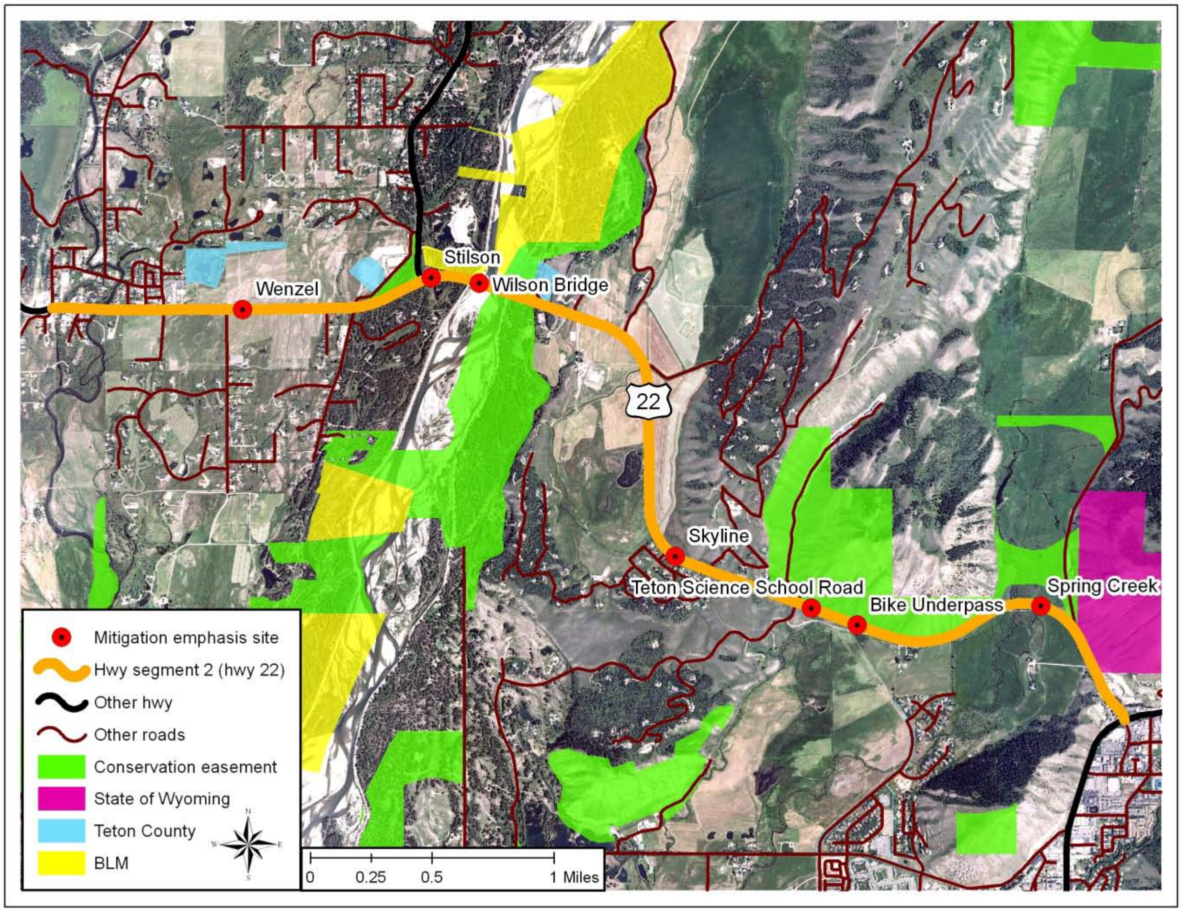

Figure 23: Land ownership and conservation easements along WY Highway 22 between Jackson and Wilson, WY.

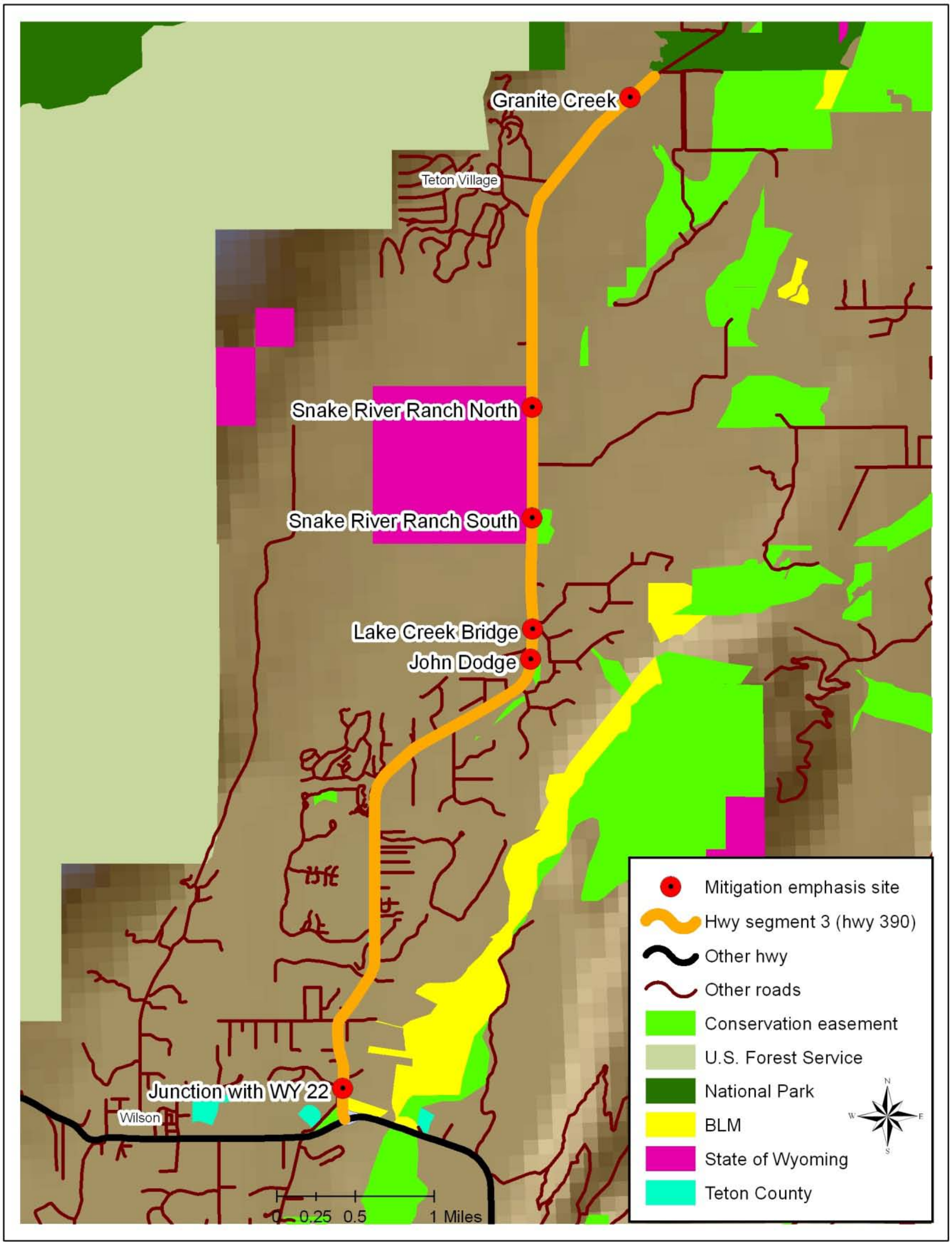

Figure 24: Land ownership and conservation easements along WY Highway 390 from the junction with WY 22 to the border of Grand Teton National Park

7.3. Results of Mitigation Emphasis Site Prioritization

The values for the six categories were combined to give each MES an average value. This result allows each MES to be quantitatively compared to other potential mitigation sites for each of the three highway segments in the study area (Table 10).

The highest ranking MES of the twelve locations on US191/89 south of Jackson, WY was Flat Creek Bridge (4.3) followed by Old West Cabins North (4.0). Next with high average values were three MES with the same average value (3.8) – Horse Creek, South Snake River Bridge and South Park Bridge. Game Creek has an average value of 3.7, the six other MES on this highway segment had average values of 3.5 or lower.

Of the seven MESs on WY Highway 22 between Jackson and Wilson, WY, two were tied with the highest average value for this highway segment (4.0) – Teton Science School Road and Skyline Road. Close behind in average value was Stilson (3.9). During the field review the Technical Advisory Team noted that the Stilson MES's transportation mitigation options value of 3 could improve to a 4. To improve mitigation options, the current location of the intersection of WY 390 with WY 22 would need to be re-aligned. WY 390 would be re-routed to follow the current road to the transit parking lot that then intersects with WY 22 (to the west of the current alignment). If this re-alignment would prove to be viable, the Stilson MES's overall average value would increase to 4.1, resulting in being the highest priority for this highway segment.

The six MESs on WY Hwy 390 had relatively low average values (3.3 or less) except for two. The highest average value was at the Junction with WY Hwy 22 (4.5) and the other was Snake River Ranch South (3.7). The Junction with WY Hwy 22 MES had the highest average value of any of the 22 MESs in the study area with a rating of 5 in four different categories – local conservation value, regional conservation value, citizen observations and land security.

Table 10: Priority values for each mitigation emphasis site for highway segments of US191/89, WY22 and WY390 in Jackson Hole, Wyoming (from 0 (no value) to 5 (very high value)).

SITE NAME	LOCATION: MILE POST	LOCAL CONSERVATION VALUE	REGIONAL CONSERVATION SIGNIFICANCE	TRANSPORTATION MITIGATION OPTIONS	HIGHWAY MORTALITY[1]	CITIZEN OBSERVATIONS	LAND SECURITY[2]	AVERAGE
Jackson South - US 191/89								
Hoback Junction North	141.0	5	5	1	no data	no data	3	3.5
Forest Access Road	141.6	5	5	3	1	0	5	3.2
Sag South of Horse Creek	141.8	5	5	4	0	0	5	3.2
Horse Creek	142.2	5	5	5	4	0	4	3.8
South Snake River Bridge	143.0	5	5	5	5	0	3	3.8
Munger Mountain Slide	144.1	5	5	4	3	0	3	3.3
South Park Bridge	146.0	5	5	4.5	3	2	3	3.8
Flat Creek Bridge	146.2	5	5	5	4	2	5	4.3
Game Creek	146.4	5	5	2 [3]	5	0	5	3.7
Old West Cabins North	146.9	5	5	2	4	4	4	4.0
Transfer Station Drainage	147.2	5	5	3	4	2	2	3.5
Horse Thief West	148.0	5	2.5	4	5	0	3	3.3
WY 22								
Spring Creek	0.7	3	3	4	3	3	3	3.2
Bike Underpass	1.5	3	3	4	5	4	4	3.8
Teton Science School Road	1.7	4	3	4	5	4	4	4.0
Skyline	2.3	5	5	3	3	5	3	4.0
Wilson Bridge	3.9	5	5	4	0	5	3	3.7
Stilson	4.1	4	4.5	3 [4]	3	5	4	3.9
Wenzel	4.9	3	3	5 [5]	3	4	3	3.5
WY 390								
Junction with WY 22	0.2	5	5	4	3	5	5	4.5
John Dodge	3.6	4	4	1	4	3	2	3.0
Lake Creek Bridge	3.8	4	4	1	3	5	2	3.2
Snake River Ranch South	4.5	5	5	4	0	3	5	3.7
Snake River Ranch North	5.2	5	4	4	1	2	4	3.3
Granite Creek	7.4	5	3	1	no data	no data	3	3.0

[1] This value relates to the tenth of a mile specified by mile post location (column C), value could be significantly different in previous or next tenth of a mile section.
[2] This value relates to land security immediately adjacent to the mile post location (column C), value could be significantly different in previous or next tenth of a mile section.

[3] This value is for the situation at present, if restriction to motorized traffic or rerouting (crossing upstream) occurs, the value could improve to 4.

[4] This value is for the present location of the intersection of WY390 with WY 22, if WY 390 was re-aligned to follow current road to transit parking lot that then intersects with WY 22 (to the west of the current alignment), this re-alignment would improve potential mitigation to a 4.

[5] Due to the flat terrain at this MES it would be very costly for large underpasses that would require raising the road prism; therefore, this value is for mitigation for small to medium mammals to pass under the existing road bed via culverts.

Table 11: Focal species at each mitigation emphasis site of highway segments US 191/89, WY 22 and WY 390 in Jackson Hole, Wyoming.

SITE NAME	LOCATION: MILE POST	FOCAL SPECIES (crash data)	FOCAL SPECIES (live observations)	FOCAL SPECIES (local knowledge and experience)
Jackson South - US 191/89				
Hoback Junction North	141.0	no data	no data	Deer/Elk/Carnivores
Forest Access Road	141.6	Deer/Elk/Carnivores	Mule deer	Deer/Elk/Carnivores
Sag South of Horse Creek	141.8	Deer/Elk/Carnivores	Mule deer	Deer/Elk/Moose/ Carnivores (Canada lynx/Mountain lion/Black bear/Grizzly bear)
Horse Creek	142.2	Deer/Carnivores	Mule deer	Deer/Elk/Carnivores
South Snake River Bridge	143.0	Deer	Mule deer, Pronhorn	Moose/Elk/Cougar
Munger Mountain Slide	144.1	Deer/Elk	Mule deer	
South Park Bridge	146.0	Deer/Elk	Pronghorn, Mule Deer, Elk	Moose/Elk/Cougar
Flat Creek Bridge	146.2	Deer/Elk	White-tailed deer/Elk/Mule deer	
Game Creek	146.4	Deer/Elk	Elk, Mule deer/White-tailed deer	Elk/Deer/Moose
Old West Cabins North	146.9	Elk/Deer	Mule deer/ Elk	Elk/Deer
Transfer Station Drainage	147.2	Elk/Deer	Mule deer/ Elk	Elk/Deer
Horse Thief West	148.0	Elk/Deer	Mule deer	Elk/Deer
WY 22				
Spring Creek	0.7	Elk/Deer	Mule deer/Elk/Coyote	Deer
Bike Underpass	1.5	Elk/Deer	Mule deer/Moose/Elk	Deer/Elk
Teton Science School Road	1.7	Elk/Deer/Moose	Mule deer/Moose/Elk	Deer/Elk/Moose
Skyline	2.3	Elk/Deer	Moose/Elk/Red Fox/Coyote	Moose/Elk
Wilson Bridge	3.9	Deer/Moose	Moose/Elk/Coyote	Moose/Elk/Bear/Elk
Stilson	4.1	Deer/Moose	Moose/Elk/Coyote	Moose/Elk/Bear
Wenzel	4.9	Deer	Moose/Elk/Coyote/Red fox	Moose/Elk
WY 390				
Junction with WY 22	0.2	Deer/Moose	Moose/Elk	Moose/Elk
John Dodge	3.6	Deer/Moose/Elk	Mule deer/Moose/Elk/Red fox	Deer/Elk/Moose
Lake Creek Bridge	3.8	Deer/Elk/Moose	Mule deer/Moose/Elk/Red fox	Deer/Moose
Snake River Ranch South	4.5	Deer	Moose/Elk/Mule deer	Moose/Elk
Snake River Ranch North	5.2	Elk/Deer	Mule deer/Coyote/Red fox	Elk
Granite Creek	7.4	No data	No data	Deer/Elk

8. WILDLIFE MITIGATION RECOMMENDATIONS

8.1. Recommended Mitigation Measures

Although there have been many mitigation measures suggested to reduce wildlife-vehicle collisions (WVCs), only a few of measures have the potential to substantially reduce WVCs (Huijser et al. 2008a, Clevenger & Huijser 2011). Only wildlife fencing and animal detection systems have shown to be able to reduce WVCs with large mammals substantially (>80%). It is important to note however, that animal detection systems should still be considered experimental whereas the estimate for the effectiveness of wildlife fencing in combination with wildlife underpasses and overpasses is much more robust. Large boulders in the right-of-way as an alternative to wildlife fencing appear to have potential as a barrier to ungulates and may be an alternative to wildlife fencing. However, this measure should also still be considered experimental and would be mostly targeted at ungulates rather than other species groups. For a summary of the pros and cons of selected mitigation measures, including wildlife fencing, animal detection systems and large boulders in the right-of-way, see Table 12.

Closing and removing the road, or tunneling or elevating the road over long sections (e.g. hundreds of meters to tens of kilometers) are more effective in reducing WVCs that the measures described above. In addition, they allow for better habitat connectivity. However, road closure and road removal are considered unacceptable, and tunneling or elevating the road is extremely costly and are typically only an option if the nature of the terrain, the physical environment, requires it. Therefore the authors of the report did not include road closure and removal or tunneling or elevating the road in the recommendations.

Using less sodium chloride or replacing sodium chloride with alternative deicing or anti-icing substances may substantially reduce the time certain species, e.g. bighorn sheep, spent on or alongside the road. However, such alternative substances may have other negative side effects and their implementation should also be considered experimental. The effectiveness of other mitigation measures in reducing WVCs is relatively low (<50%), impractical, not applicable, or unknown (Huijser et al. 2008a).

Roadway lighting can increase the visibility of wildlife to drivers. However, data suggest that roadway lighting may also keep animals away from the road (e.g. Huijser 2000). Therefore roadway lighting should be seen as a measure to reduce wildlife-vehicle collisions but it should not be implemented at locations where wildlife crossings are encouraged.

The authors of this report would like to emphasize that, although speed reduction and the enforcement of speed limits have important safety benefits, WVCs are unlikely to be substantially reduced as a result of increased speed management efforts. For a summary of the pros and cons of a reduction of the maximum speed limit, see Table 12.

Table 12. Pros and cons of selected mitigation measures.

Mitigation measure	**Pros**	**Cons**
Wildlife fencing	87% reduction in WVCs expected when combined with wildlife underpasses and overpasses.	Barrier for wildlife; combine with safe crossing opportunities. Affects landscape aesthetics and sense of connectedness of the drivers to the surrounding areas. Potential animal intrusions at access roads/points, and fence ends. Potential mortality source for certain species under certain conditions (e.g. grouse, bighorn sheep). May provide drivers with a sense of security that may lead to higher speeds. Excluding r-o-w vegetation may lead to displacement or population reduction in species that depend on r-o-w vegetation (e.g. white-tailed deer, elk).
Large boulders	Substantial reduction in WVCs for most ungulates expected (e.g. deer, elk, and moose, but not for e.g. bighorn sheep and mountain goat). Not a barrier for species that can climb over the boulders. Less effect on landscape aesthetics than wildlife fencing	Not all species protected against WVCs. Barrier for most ungulates; combine with safe crossing opportunities. Potential animal intrusions at access roads/points, and end of boulder rows. Excluding r-o-w vegetation may lead to displacement or population reduction in species that depend on r-o-w vegetation (e.g. white-tailed deer, elk). Experimental measure.
Maximum speed limit reduction (including speed reduction during the night only, e.g. 70 km/h)	Local drivers (frequent visitors) may "learn" to respond to the maximum speed limit reduction (rather than respond to the design speed) with massive and consistent speed enforcement.	Lowering speed limit may lead to increased speed dispersion and higher crash rates. Design speed will make drivers, especially infrequent visitors, want to drive the perceived save speed, which is at least 90 km/h, probably even higher. Enforcing maximum speed limits substantially lower than the design speed will likely be experienced as "unjust". Massive and consistent speed enforcement may need to be automated, which may conflict with policy or law. Experimental measure.
Animal detection	87% reduction in WVCs for large mammals expected, but this estimate in WVC reduction	Not suitable for very high traffic volumes.

systems	may change substantially as more data become available. Have the potential to provide wildlife with safe crossing opportunities anywhere along the mitigated roadway, in contrast to underpasses and overpasses which are typically limited in number and width. Are less restrictive to wildlife movement than fencing or crossing structures. They allow animals to continue to use existing paths to the road or to change them over time No road work or traffic control needed for installation (in contrast to wildlife underpasses and overpasses). Likely to be less expensive than wildlife crossing structures, especially once they are mass produced Can be installed over long road sections (multiple km) or at gaps in fence. This measure is somewhat mobile (except for foundations) and can be used at other locations should animals start crossing somewhere else.	Detects large animals only. Animals are allowed to cross at grade; the design of the measure allows drivers to still be exposed to risk. The number of at grade crossings may not be sufficient to ensure long term population viability for all species. When combined with wildlife fencing, wildlife is directed to road at fence ends or at gaps, and this may cause road managing agencies to be liable in case of a collision, especially if the animal detection system may not have been working properly. Species that depend on r-o-w vegetation may use the at grade crossing to access that vegetation and end up in between the fences. This may be mitigated by boulder fields in r-o-w and electric mats on road, which may only function in summer. Some of the systems are not operational during the day. Curves, drops and rises in the right-of-way, access roads, pedestrians, winter conditions (including snow spray from snow plow and snow accumulation, can cause problems with the installation, maintenance and operation. The presence of poles and equipment in the right-of-way is a potential hazard to vehicles that run off the road. Animal detection systems can be aesthetically displeasing. Experimental measure.
Wildlife underpasses and overpasses	87% reduction in WVCs expected when combined with wildlife fencing. Well used by a wide variety of species. Can provide cover (e.g., vegetation, living trees, tree stumps) and natural substrate (e.g., sand, water) allowing better continuity of habitat than e.g. at grade crossing opportunities. Likely to have greater longevity and lower maintenance and monitoring costs than e.g. animal detection systems	The number, type, and dimensions of crossing opportunities may not be sufficient to ensure long term population viability for all species. This measure requires substantial road work and traffic control. This measure is not mobile.

Wildlife fencing and the use of large boulders in the right-of-way increase the barrier effect of the road. These measures should typically only be used if safe crossing opportunities for wildlife are also provided for. Such crossing opportunities can consist of at grade crossings at a gap in the barrier, with or without additional warning signals for drivers (e.g. animal detection systems), or wildlife underpasses and overpasses.

The authors of this report consider animal detection systems and wildlife fencing (Figure 25 and 26), in combination with wildlife underpasses and overpasses, to be the primary recommended mitigation measures for the reduction of WVCs along the highways in Jackson Hole. However, animal detection systems should still be considered experimental whereas the performance estimates for wildlife fencing and underpasses and overpasses are much more robust. Also, care must be taken to reduce false detections, for example if pedestrians are present in the right-of-way, and animal detection systems are less effective if a high percentage of the traffic is not local or if drivers are unlikely to respond to warning signals (perhaps drivers of large vehicles are less likely to reduce speed than drivers of small vehicles). The authors of this report also consider public information and education, experiments with alternatives to road salt, and experiments with large boulders in the right-of-way (Figure 27) mitigation measures to have potential for reducing WVCs. However, these mitigation measures are classified as either "supportive" (secondary measures) or experimental.

Figure 25. A 2.4 m high fence with buried apron along the Trans-Canada Highway in Banff National Park (Phase 3-A) (© Tony Clevenger).

Figure 26. A 2.4 m high wildlife fence along the 2-lane US Highway 93 on the Flathead Reservation in Montana, USA (© Marcel Huijser).

Figure 27. Large boulders placed in the right-of-way as a barrier to elk and deer along State Route 260 in Arizona, USA (© Marcel Huijser).

While wildlife fencing is typically placed at the edge of the right-of-way or at least outside the clear zone, wildlife fencing typically angles towards the road at wildlife overpasses or underpasses to minimize the length (= road width) of these crossing structures. If needed, e.g. at "at grade" crossing opportunities (e.g. gap in fence with an animal detection system, fence ends) a fence that comes close to the road may have to be combined with a guard rail or concrete barrier for safety reasons (Figure 28). Alternatively, rocks may be installed to form a boulder field to stimulate ungulates in crossing the road rather than wandering off in the right-of-way and getting trapped in between the wildlife fencing (Figure 29). Wildlife guards have also been used on major roads at fence ends (Figure 30).

Figure 28. Fence end brought close to the road with a concrete barrier for safety along Hwy 93S in Banff National Park, just west of Castle Jct (© Marcel Huijser).

Figure 29. The Boulder Field at the Fence End at Dead Man's Flats Along the Trans Canada Highway East of Canmore, Alberta, Canada (© Bruce Leeson).

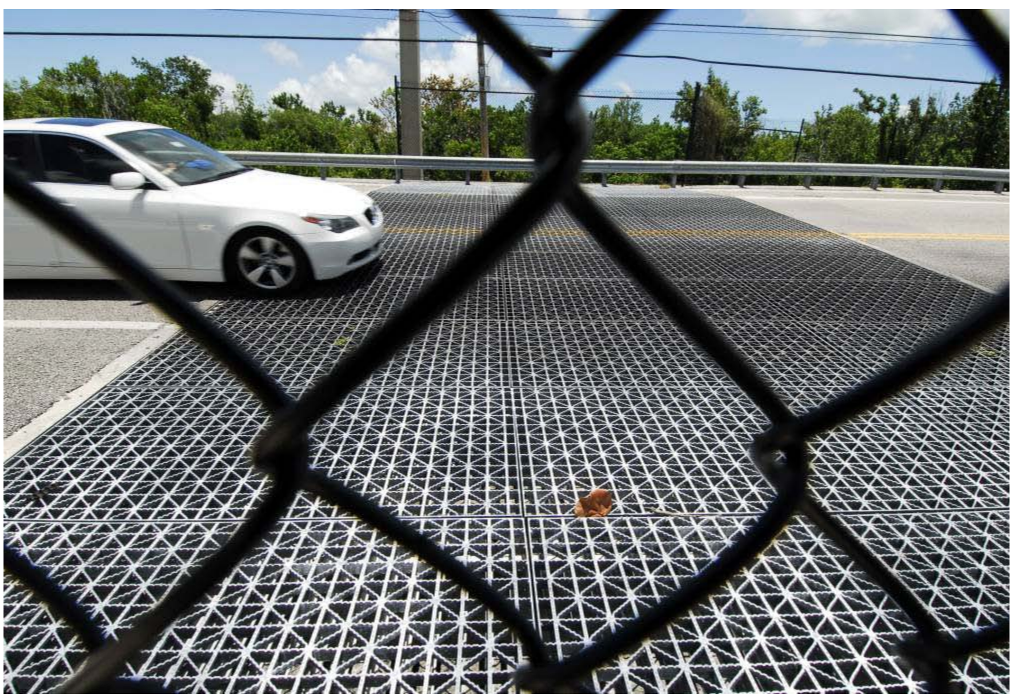

Figure 30. Wildlife guard at a fence end on the 2-lane US Hwy 1 on Big Pine Key, Florida, USA (© Marcel Huijser).

Animals may end up in between fences or other barriers placed along the transportation corridor posing a safety risk and exposing the species concerned to road mortality. Therefore, absolute barriers, such as wildlife fencing, should typically be accompanied with escape opportunities for animals that have ended up in between the fences (Reed et al. 1974, Ludwig & Bremicker 1983, Feldhamer et al. 1986, Bissonette & Hammer 2000). Jump-outs or "escape ramps" are sloping mounds of soil placed against a backing material on the right-of-way side of the fence (Figure 31 through 33). The highway fence is tied in to the edges of the jump-out. Jump-outs are designed to allow animals caught in between the fences to jump out of the right-of-way. At the same time, jump-outs should not allow animals to jump into the right-of-way area. Little is known about the appropriate height for jump-outs. The appropriate height of jump-outs is likely dependent on the main species of interest and the terrain (e.g. up-slope or down-slope), but they are typically 1.6-2.4 m in height.

Figure 31. A jump-out along a 2.4 m (8 ft) high fence along US 93 in Montana, USA (© Marcel Huijser).

Figure 32. A jump-out along a 2.4 m (8 ft) high fence along US 93 in Montana, USA (© Marcel Huijser).

Figure 33. A jump-out along a 2.4 m (8 ft) high fence with smooth metal to prevent bears from climbing the jump-out the wrong way. Along the Trans Canada Highway, Lake Louise area, Banff National Park, Canada (© Marcel Huijser).

Fences intersect with access roads, and access points for e.g. hikers. Depending on the traffic volume and purpose of the road, wildlife guards (Figure 34-35) or gates (Figure 36 and 37) can be installed at access roads. In addition, access points for people, e.g. hikers, can be provided for (Figure 38 and 39).

Figure 34. A wildlife guard at an access road of the 2-lane US Highway 93 on the Flathead Reservation in Montana, USA (© Marcel Huijser).

Figure 35. A wildlife guard at an access road of the 2-lane US Highway 1 on Big Pine Key, Florida, USA (© Marcel Huijser).

Figure 36. A gate at an access road of the 2-lane US Highway 93 on the Flathead Reservation in Montana, USA (© Marcel Huijser).

Figure 37. A gate at an access road of the 2-lane US Highway 1 on Big Pine Key, Florida, USA (© Marcel Huijser).

Figure 38: Swing gate in fence (spring loaded) allowing access for people, also when there is snow on the ground, along the Trans-Canada Highway in Banff National Park, Alberta, Canada (© Adam Ford, TCH research project / WTI-MSU).

Figure 39: Access point for people along US93, south of Missoula, Montana, USA (© Marcel Huijser). This type of gate may be a barrier for ungulates.

8.2. 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 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. big horn sheep, white-tailed deer).
- 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, and 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 be far away from the areas where one is used to seeing them, 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 in 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. For this report the authors choose a simpler approach. For selected ungulate and carnivore species the diameter of their home ranges were estimated (Tables 13 and 14).

The distance between safe crossing opportunities was set to be equal to the diameter of the home range of the species concerned (Figure 40). This allowed individuals that have the center of their home range on the road to have access to at least one safe crossing opportunity. However, individuals that may have had their home range on both sides of the road do not necessarily have access to a safe crossing opportunity (Figure 41). Finally, this approach assumed homogenous habitat and distribution of the individuals and circular home ranges, while in reality habitat and habitat quality may vary greatly, causing variations in density of individuals and irregular shapes home ranges.

The authors of this report would like to emphasize that this approach does 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 chosen 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.

Table 13. Home range size and diameter estimates for selected 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)
Focal species		
Fisher (*Martes pennanti*)	75,000 ha 23,885 m	47,700 ha for females for females, 219,000 ha for males (Weir & Corbould, 2010)
Wolverine (*Gulo gulo)*	20,000 ha 15,962 m	16,700 ha (range 7,600-26,900 ha) for females (Banci & Harestad, 1990), 10,500 for adult females (Whitman et al., 1986), 38,800 for females (review in Lindstedt et al., 1986), 32,500-40,500 ha for females (Krebs et al., 2007)
Bobcat (*Lynx rufus)*	2,500 ha 5,643 m	1,780 ha for adult female (Knowles, 1985), 1,930 ha for females (review in Lindstedt et al., 1986), 3,120 ha for females (Litvaitis et al., 1986)
Canada lynx (*Lynx canadensis)*	15,000 ha 13,823 m	2,800 ha (range 1,110-4,950 ha) for adults (Brand et al., 1976), 9,000 ha (range 5,800-12,100 ha for adult females (Squires & Laurion, 2000), 20,600 ha (range 7,700-40,800 ha) for females (Apps, 2000)
Cougar (*Puma concolor)*	4,000 ha 7,138 m	3,500 ha (range 1,900-5,100 ha) for adult females in summer and 2,600 ha (range 1,400-4,300 ha) in winter (Spreadbury et al., 1996), 6,730 ha for females (review in Lindstedt et al., 1986), 9,700 ha (range 3,900-22,700 ha) for adult females in summer and 8,700 (range 3,100-23,900 ha) in winter (Ross & Jalkotzy, 1992)
Red fox (*Vulpes vulpes*)	1,500 ha 4,371 m	1,611 ha (range 277-3,420 ha) (Jones & Theberge, 1982), 350 ha (Frey & Conover, 2006)
Coyote (*Canis latrans)*	2,500 ha 5,643 m	1,130 ha (range 280-3,200 ha) (Gese et al., 1988), 2,010 ha (range 1,600-2,420 ha) for females (review in Lindstedt et al., 1986), 2,420 ha (range 880-5,460 ha) for adult females (Andelt & Gipson, 1979), 3,186 ha (range 670-9,140 ha) for females (review in Laundré & Keller, 1984)
Wolf (*Canis lupus*)	50,000 ha 25,238 m	6,250 ha (range 700-6,800 ha) (review in Lindstedt et al., 1986). 73,900 ha (Latham, 2009)
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)

Table 14. Home range size and diameter estimates for the selected ungulate 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)
Selected other species		
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)
Mountain goat (*Oreamnos americanus*)	300 ha 1,955 m	280 ha for adult males, 480 ha for adult females (Singer & Doherty, 1985)
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)

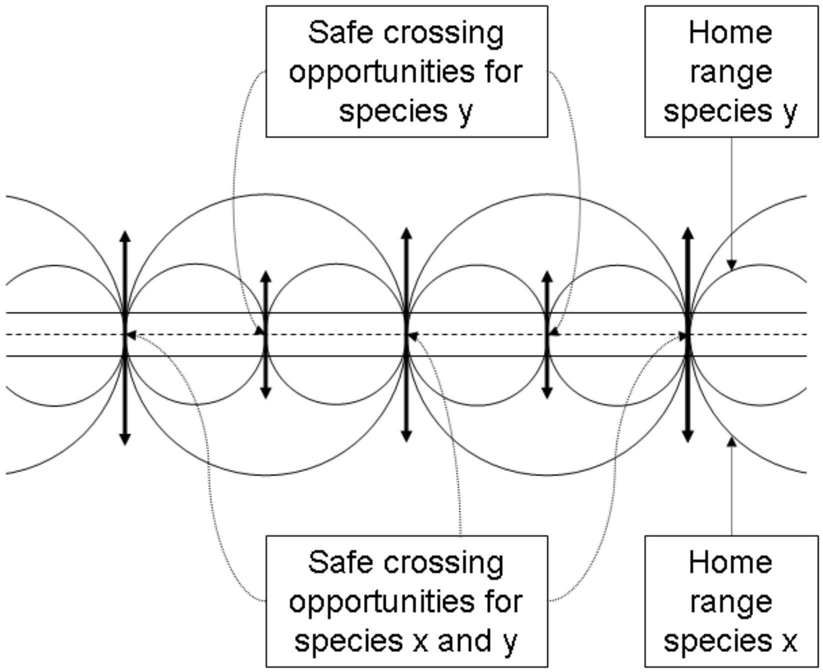

Figure 40. Schematic representation of home ranges for two theoretical species projected on a road and the distance between safe crossing opportunities (distance is equal to the diameter of their home range).

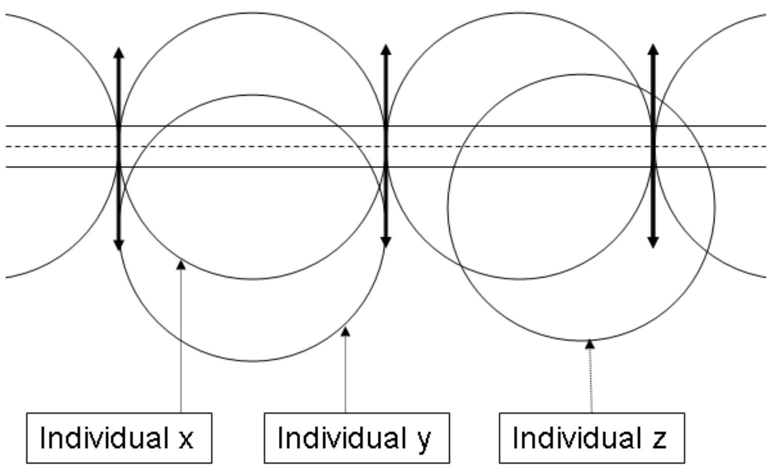

Figure 41. Schematic representation of home range for an individual (x) that has the center of its home range on the center of the road (access to two safe crossing opportunities), an individual (y) that has the center of its home range slightly off the center of the road exactly in between two safe crossing opportunities (no access to safe crossing opportunities), and an individual (z) that has the center of its home range slightly off the center of the road but not exactly in between two safe crossing opportunities (access to one safe crossing opportunity).

8.3. Safe Crossing Opportunity Types

The authors of this report distinguished six different types of safe crossing opportunities for potential implementation on and along the roads in the study area (Table 15) (Figure 42 through 50). 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 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. 1995).

While Table 15 classifies crossing structures based on their 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 16 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 an electric mat (ElectroMAT™, ElectroBraid™) that is embedded in the road surface, or laid on top of the road, may also be considered to discourage animals from walking off to the sides on the roadway (ElectroBraid 2008a). Reports on the manufacturer’s website suggest that the electric matt holds up when exposed to snowplows and that it can function throughout the winter (ElectroBraid 2008b). Nonetheless, such at grade crossing opportunities should be seen as experimental and their effectiveness should be carefully evaluated before implementing them on large scale.

Table 15. 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

Figure 42. Red Earth overpass on the Trans-Canada Highway (© Tony Clevenger).

Figure 43. Wildlife overpass ("Schwarzgraben") across a 2-lane road (B31) in southern Germany (© Edgar van der Grift).

Figure 44. An open span bridge along the 2-lane US Highway 93 on the Flathead Reservation in Montana, USA (across Spring Creek, south of Ravalli) (© Marcel Huijser).

Figure 45. A large mammal underpass (7-8 m wide, 4-5 m high) along the 2-lane US Highway 93 on the Flathead Reservation in Montana, USA (south of Ravalli) (© Marcel Huijser).

Figure 46. A medium mammal box culvert (1.2 m wide, 1.8 m high) along the 2-lane US Highway 93 on the Flathead Reservation in Montana, USA (south of Ravalli) (© Marcel Huijser).

Figure 47. A medium mammal culvert (2 m wide, 1.5 m high) along the 2-lane US Highway 93 on the Flathead Reservation in Montana, USA (south of Ravalli) (© Marcel Huijser).

Figure 48. A small-medium mammal pipe ("badger pipe") in The Netherlands (© Marcel Huijser).

Figure 49. An animal detection system (infrared break-the-beam system manufactured by Calonder Energy, Switzerland) at a gap in a wildlife fence near 't Harde, The Netherlands (© Marcel Huijser).

Figure 50. An animal detection system (microwave radio signal break-the-beam system manufactured by Sensor Technologies & Systems, Scottsdale, AZ) installed along a 1 mile (1,609 m) section of US Hwy 191 between Big Sky and West Yellowstone in Yellowstone National Park (© Marcel Huijser).

Table 16. 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	●	●	○	⊗	⊗	●
Mountain goat	●	●	○	⊗	⊗	●
Bighorn sheep	●	●	○	⊗	⊗	●
Carnivores						
Wolverine	●	?	?	?	⊗	⊗
Bobcat	●	●	●	●	●	⊗
Canada lynx	●	?	?	?	⊗	⊗
Cougar	●	●	●	⊗	⊗	⊗
Coyote	●	●	●	●	●	⊗
Wolf	●	●	○	⊗	⊗	⊗
Black bear	●	●	●	⊗	⊗	●
Grizzly bear	●	○	○	⊗	⊗	●
Additional						
Pine marten	●	○	○	●	●	⊗
Porcupine	●	●	●	?	?	⊗
Snowshoe hare	●	●	●	?	?	⊗
Striped skunk	●	●	●	●	●	⊗
Beaver	⊗	○	○	○	⊗	⊗
Hoary marmot	●	●	●	●	●	⊗
Badger	●	●	●	?	?	⊗
Red fox	●	●	●	●	●	⊗

8.4. Site Specific Recommendations for Mitigation Measures

The site specific recommendations for the mitigation emphasis sites are summarized in Table 17.

Table 17. Site specific recommendations for mitigation measures.

Site name	Location (mi reference post)	Animal behavior (comments from field evaluation group)	Recommendation	Comments
Jackson South - US 191/89				
Hoback Junction North	141.0		Consider an overpass, or an underpass.	Potentially unstable soils
Forest Access Road	141.6		Consider an underpass.	Potentially unstable soils
Sag South of Horse Creek	141.8		Install underpass.	
Horse Creek	142.2		Existing culvert (fully inundated, fast flowing creek), consider a second culvert (dry) that would run parallel on the south side of the creek.	Keep underpass relatively small (discourage potential use by grizzly bears because of adjacent houses and campground).
South Snake River Bridge	143.0		Existing bridge, perhaps create or expand dry flat crossing areas on both sides of river if possible.	North and south bank are both relatively steep.
Munger Mountain Slide	144.1		Install an underpass.	

South Park Bridge	146.0	Potential for deer, elk, moose, and black bear movements.	Existing bridge, perhaps create dry flat crossing area on south side of river if possible.	North bank has flat area, south side has steep bank. Human use (take out for boats and rafts) is currently high on the north bank but may be moved to south bank.
Flat Creek Bridge	146.2	Potential for deer, elk and moose movements.	Existing bridge, perhaps expand dry flat crossing areas on both sides of creek if possible.	Currently, the embankments are very steep. At high water passage may be difficult for ungulates.
Game Creek	146.4	Elk migrate to and from feeding grounds on west side of highway.	Install two underpasses (1 for Henry's Rd, one for Hwy 191). Consider an overpass across both roads (substantial soil movement).	Access to Henry's Rd may change (perhaps re-route Henry's Rd further to the east), allowing for a direct approach to Hwy 191 with an underpass.
Old West Cabins North	146.9	Elk migrate to and from feeding grounds on west side of highway.	Consider underpass or overpass depending on land use.	Potential or likely human generated disturbance from houses and shooting range may need to be addressed or potential mitigation location may have to be abandoned.
Transfer Station Drainage	147.2	Elk migrate to and from feeding grounds on west side of highway.	Consider an underpass.	Terrain may be challenging for an underpass.

Horse Thief West	148.0	Elk migrate to and from feeding grounds on west side of highway.	Install underpass (substantial soil removal required), or potentially an overpass.	This is the mitigation location that is furthest north on Hwy 191 north and would need to serve animal movements from further north.
WY 22				
Spring Creek	0.7	Potential use by deer.	Existing bridge, consider installing an very wide underpass (wide meandering creek with dry areas).	Ideally roadbed should be higher to allow for a higher underpass.
Bike Underpass	1.5	Seasonal movements of deer and elk.	Consider an overpass just to the west (rise on either side of highway)	
Teton Science School Road	1.7	Seasonal movements of deer and elk.	Existing culvert. Expand height and width of possible.	
Skyline	2.3	Seasonal movements of deer and elk.	Consider an underpass.	Direct animal movements away from area with houses.
Wilson Bridge	3.9	Potential for moose, elk, black bear, grizzly bear movements.	Consider expanding the bridge to incorporate dry bank or create one or more underpasses further west in the marshes and wet forests.	

Stilson	4.1	Potential for moose, elk, black bear, grizzly bear movements.	Consider rerouting Hwy 390 further west (west of forested area along Beckley Park Way). Install one or more underpasses along Hwy 22 to allow for north-south movements.	If re-routing of Hwy 390 takes place, the forested area enclosed by Hwy 22, Hwy 390 and Beckley Park Way would no longer be isolated and mitigation of Hwy 390 may be avoided along this road section.
Wenzel	4.9	Red fox and similar sized species	Install one or more small pipes under Hwy 22.	
WY 390				
Junction with WY 22	0.2	Potential for moose, elk, black bear, grizzly bear movements.	Consider rerouting Hwy 390 further west (west of forested area along Beckley Park Way). Install one or more underpasses along Hwy 22 to allow for north-south movements.	If re-routing of Hwy 390 takes place, the forested area enclosed by Hwy 22, Hwy 390 and Beckley Park Way would no longer be isolated and mitigation of Hwy 390 (e.g. traffic calming) may be avoided along this road section.
John Dodge	3.6	Mule deer, moose, elk.	Consider at grade solutions. Consider continuous fencing if Lake Creek bridge can be made passable by large ungulates.	
Lake Creek Bridge	3.8	Mule deer, moose, elk.	Existing bridge. Height is too low to allow for the crossing of large ungulates. This location may not be feasible as a safe crossing opportunity for large mammals.	Increasing the height of the bridge will affect the sight distance for drivers.

Snake River Ranch South	4.5	Elk. No recent observations of pronghorn in this area.	Consider an overpass (underpass may be more difficult in the flat wet terrain).	Allows for movements between the Snake River and the mountains to the west.
Snake River Ranch North	5.2	Elk. No recent observations of pronghorn in this area.	Consider an overpass (underpass may be more difficult in the flat wet terrain).	Allows for movements between the Snake River and the mountains to the west.
Granite Creek	7.4		Existing culverts. No change required for large mammals.	Considering the adjacent National Park and lower vehicle speeds (Park Entrance booth) mitigation may not be required. Consider mitigation for fish passage though.

In addition to the mitigation emphasis sites along the three road segments highlighted in Chapter 1, the researchers also formulated possible mitigation measures for Broadway through the town of Jackson. This road section, specifically between mile reference posts 153.3-154.1, has the highest concentration of reported large mammal carcasses among the road sections analyzed in and around Jackson (see Chapter 3 Table 9). While the reported carcasses related to "deer" only, the observations by the public showed that in addition to mule deer, moose and elk have also been observed along this road section (Chapter 5 Table 9).

The landscape on the northwest side of Broadway is characterized by a steep open slope that comes down to the road. The landscape on the southeast side of the road has a narrow strip of development, mostly businesses, and riparian habitat along a stream that crosses Broadway at the northeast end (Figure 51). Despite the linear development along Broadway, this area appears to the best possible area for animals to move across Hwy 191 through the town of Jackson.

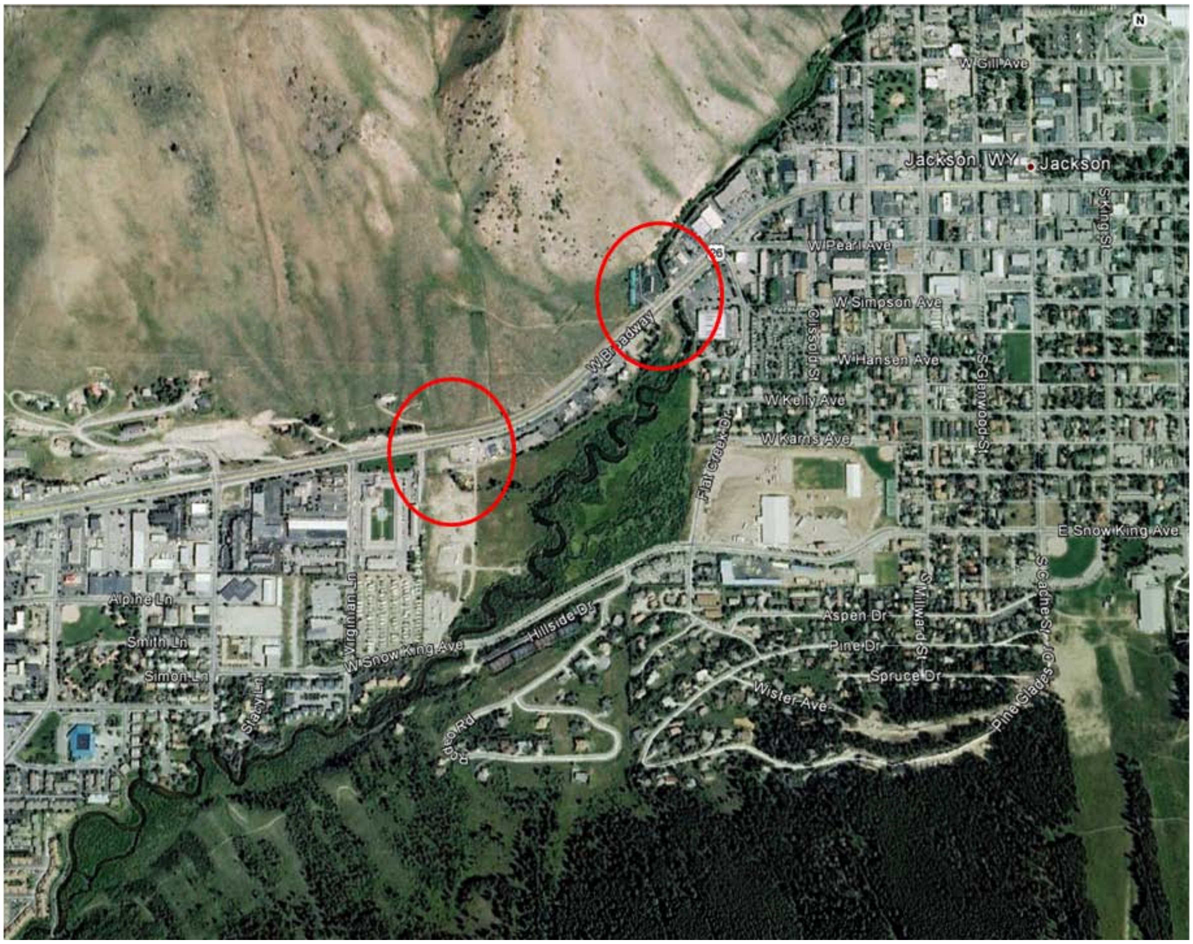

Figure 51. The section of Hwy 191 (Broadway) through Jackson that has the highest concentration of reported large mammal carcasses among the road sections analyzed. The red oval on the right indicates where the creek crosses Broadway and the red oval on the left indicates a gap in the linear development along Broadway.

The linear development along Broadway as well as the topography poses challenges for the implementation of safe crossing opportunities. One may decide to block all large mammal movements across Broadway by fencing the road section on both sides of the road. Wildlife fencing can be expected to substantially reduce the number of wildlife-vehicle collisions along this road section, but it would also block movements of large mammals, which may or may not be acceptable to the community and may or may not be consistent with wildlife conservation goals.

Based on both carcass removal data and observations by the public mule deer, and to a lesser extend moose and elk, cross the road frequently in this area, and the stream may continue to funnel different wildlife species, small and large, towards Broadway. For this reason alone it may be worthwhile to explore the potential for safe crossing opportunities along this road section. Besides the area around the creek crossing there is another area a little further to the southwest where there is a gap in the development along Broadway (Figure 51). Alternatively, one may also decide to remove existing buildings or span across the buildings with a longer overpass. If safe crossing opportunities are provided one may consider three types of measures; at grade crossing opportunities, wildlife underpasses and wildlife overpasses (Table 18).

If safe wildlife crossing opportunities are provided for across Broadway, the land on either side of the road at the crossing opportunities would have to be secured so that wildlife can approach and leave the road and so that the potential for wildlife-human conflicts is reduced. This may involve land purchase, easements or other types of agreements. Furthermore, the potential future land use and other roads further away from Broadway may need to be discussed, especially if a north-south wildlife corridor through Jackson is to be designated. This not only relates to the riparian habitat and the stream immediately south of Broadway, but also to other potential road crossings and development (e.g. the area along W. Snow King Ave).

Depending on the size of the overpass (number of lanes, width of the overpass) and other design features (e.g. including directing the stream across the overpass) the costs may vary substantially. Overpass structures can cost approximately $Can33,650 per m ($Can10,259 per ft) for a 50-m (164-ft)-wide overpass (Terry McGuire, Parks Canada, unpublished data). Actual overpasses constructed in the mid 1990s were estimated at Can$1,750,000 (Anthony P. Clevenger, Western Transportation Institute, Montana State University, personal communication). An overpass across a two lane road in Montana cost about$ 1,800,000. The costs for different wildlife overpasses in the Netherlands ranged between Euro 1,400,000 and 14,750,000 (Table 19).

Table 18. Pros and cons of different types of mitigation measures at the Broadway road section through Jackson (see also Table 12).

Mitigation measure	Mitigation package	Pros	Cons or potential complications
At grade crossing opportunities	No mitigation measures	No costs. Nothing needs to be build or relocated .	The high number of wildlife-vehicle collisions with large mammals (mostly mule deer) can be expected to continue.
	Wildlife fencing with a gap, electric mats across the road, and either permanent warning signs or an animal detection system at the gap.	Theoretically large animals are “protected” when crossing Broadway.	Reducing the number of wildlife-vehicle collisions with large mammals depends on driver response to either permanent warning signs (potentially 40% reduction) or signs that are

			activated by an animal detection system in the gap(s) in the wildlife fence (potentially on average 87% reduction) (Huijser et al., 2009). There is no continuous habitat across the road. Thus animals that may shy away from roads and traffic, the unnatural habitat, and the disturbance associated with the road do not experience enhanced connectivity across the road. The animal detection system component should still be considered experimental (see Table 12). Small and medium sized animals are not detected by an animal detection system and are thus not "protected", at least not by an animal detection system. If wildlife movements are restricted to selected locations it is good practice to secure the land on either side of the road to allow for wildlife movements and reduce the potential for human-wildlife conflicts.
Wildlife underpasses	Wildlife fencing combined with wildlife underpasses	Potential for continuous habitat underneath the road for a wide variety of species including large ungulates. Note: Natural substrate (e.g. soil and litter) and cover (e.g. vegetation, rows of tree stumps or rocks etc.) is essential for species groups such as small mammals, reptiles, amphibians and invertebrates). Note: it is considered good practice to not have steep slopes at the approaches of an underpass; an animal that approaches should be able to see through the structure rather than descent into a "cave" without being able to see the vegetation and or sky on the other side.	The existing roadbed and stream crossing do not allow for an underpass (bridge) that is high enough for large mammals including mule deer. Underpasses for mule deer should be at least 2.4 m (8 ft) high and 6.1 m (20 ft) wide (Gordon & Anderson 2003). Thus a higher road bed and/or excavation of the surrounding areas (including dealing with challenging hydrological challenges because of the stream and the ground water level) may be required. Note: Much larger underpasses are required for larger ungulates such as elk or moose (preferably overspan bridges 4-5 m (13-16 ft) high, perhaps 20-30 m (66-98 ft) wide). If wildlife movements are restricted to selected locations it is good practice to secure the land on either side of the road to allow for wildlife movements and reduce the potential

			for human-wildlife conflicts.
Wildlife overpasses	Wildlife fencing combined with wildlife overpasses	Potential for continuous habitat underneath the road for a wide variety of species including large ungulates. Note: Natural substrate (e.g. soil and litter) and cover (e.g. vegetation, rows of tree stumps or rocks etc.) is essential for species groups such as small mammals, reptiles, amphibians and invertebrates). Note: it is considered good practice to not have steep slopes at the approaches of an overpass; an animal that approaches should be able to see across the structure rather than ascent into the sky without being able to see the vegetation on the other side. A wildlife overpass is very visible to people who travel on the road. Combined with outreach, including information provided to travelers as they approach the overpass, this measure has the potential to be a landmark and a symbol for the values that they community in and around Jackson has with regard to the conservation of wildlife and human safety.	The topography may be challenging for two reasons: 1. High water levels and potentially unstable soils posing potential difficulties for the foundations of an overpass 2. Minimizing the steepness of the slope, especially on the southeast side (stream side). While the stream is likely to funnel the movements for aquatic and semi-aquatic species, and perhaps also for some terrestrial species it may not be possible to combine the stream with the overpass; the stream may still cross under the road. Note: while challenging, it is conceivable that the stream can go across the road, integrated with the overpass. Note: wildlife overpasses for sensitive species (sensitive to human disturbance and sensitive to small structures) are generally 50-70 m (164-230 ft) wide (Clevenger & Huijser 2011). While an overpass designed for mule deer only may be less wide, the researchers recommend an ecosystem approach which also benefits more sensitive species such as elk and moose. If wildlife movements are restricted to selected locations it is good practice to secure the land on either side of the road to allow for wildlife movements and reduce the potential for human-wildlife conflicts.

Table 19. Characteristics of wildlife overpasses in The Netherlands. * = cost in year of completion (Partially based on Kruidering et al. 2005 and Personal Communication, Hans Bekker, Ministerie van Verkeer en Waterstaat, The Netherlands).

Name wildlife overpass	(Rail)road and nearby towns	Dimensions	Costs (in 2004 Euros)	Year completed	Comments
Terlet	A50, between Arnhem and Apeldoorn	50 m wide, 95 m long	€3,600,000	1988	Across a 4-lane motorway and a frontage road. Pond on the east side of the overpass.
Woeste Hoeve	A50 between Arnhem and Apeldoorn	45 m wide, 140 m long	€3,600,000	1988	Across a 4-lane motorway and a frontage road.
Boerskotten	A1, near Oldenzaal	Hourglass shape, 15 m wide in middle of span, 80 m long	€1,400,000	1992	Across a 4-lane motorway.
Harm van de Veen	A1, near Kootwijk, between Amersfoort and Apeldoorn	Hourglass shape, 80 meters wide at each end, 30 meters wide in middle of span	€3,600,000	1998	Across a 4-lane motorway. Pond on the north side of the overpass.
De Borkeld	A1, near Rijssen	Hourglass shape, 30 meters wide at each end, 16 meters wide in middle of span, 51.6 meter long	€3.800.000	2003	Across a 4-lane motorway. Pond on the south side of the overpass.
Slabroek	A50, between Uden and Nistelrode	15 m wide	€5,600,000	2003	Combined with pedestrian/ bicycle path. Across a 4-lane motorway and a frontage road
Leusderheide	A28 between Amersfoort and Zeist	48 m wide, 46 m long	€3,500,000	2005	Across a 4-lane motorway
Groene Woud	A2 between Boxtel and Best	52 m wide	€9,100,000*	2005	With wet zone, including a water pump and ponds on both sides of the overpass. Across a 4-lane motorway and a

					frontage road
No name	N297, between Nieuwstadt and Sittard	3 m wide, 42 m long	€290,000*	2005	A combination of an overpass and a badger tunnel (40 cm diameter), buried inside the overpass as the 4 lane road was constructed in a trench
Crailoo	Naarderweg (N524) and railroad between Hilversum and Bussum	50 m wide, 800 m long, 2 bridges and several sections of fill	€14,750,000*	2006	Combined with pedestrian/bicycle path. Ponds on both sides of the overpass. Across a 2-lane road, a railroad, a railroad yard, and sport fields.
Waterloo	A73, near Beesel	40 m wide, 100 m long	€2,400,000	2007	Combined with pedestrian path. Across a 4-lane motorway. Construction costs were part of larger project

8.5. Combined Use of Structures by Wildlife and Humans

One may consider combining wildlife use of a crossing structure with non-motorized human use for different reasons:

- If the wildlife and human use can be combined it can save money by building fewer structures.
- If the wildlife and human use can be combined one may be able to build more structures that can be used by wildlife as there is a need for crossing structures in many places.

However, human use of crossing structures is negatively associated with wildlife use of those same crossing structures (Clevenger & Waltho, 2000; Grilo et al., 2008). While this effect is stronger for carnivores than for ungulates (Clevenger & Waltho, 2000) it indicates that wildlife use of crossing structures is likely to be higher when humans use separate structures to cross the road. However in landscapes that have a relatively high presence of humans already no or little effect of human co-use on wildlife use at wildlife crossing structures has been observed (Haas & Turschak, 2002; van der Grift et al., 2010). Under certain circumstances the effects of human co-use appear limited and appear to mostly lead to a shift in the time of day the medium and large mammals use the crossing structures rather than a decline (van der Grift et al., 2010). It is important though that such structures have appropriate dimensions (relatively wide overpasses and wide and tall underpasses) and that they are designed correctly (soil, vegetation, cover, features that encourage humans to stay on one side of the structure only and that provide somewhat of a visual barrier to minimize disturbance for the wildlife).

While co-use opportunities (by people and wildlife) are inherently attractive, several items require careful evaluation before moving ahead with them (see also Huijser et al., 2008c; van der Grift et al., 2010):

1. Landscape and sensitivity of species to human disturbance.
- When the crossing structure is in an important or sensitive ecological area or if the target species for the crossing structure are sensitive to human disturbance, wildlife and human use should probably not be combined in the same structure. Two separate structures should be considered in this case.
- When the crossing structure is located in a multifunctional landscape with considerable human disturbance, and if the target species for the crossing structure are not very sensitive to human disturbance, and perhaps even thrive with a certain level of human disturbance (for example, raccoons thrive in an agricultural landscape), wildlife and non-motorized human use can probably be combined in the same structure.

2. Type and dimensions of crossing structure.
   If human and wildlife use are combined on one structure the type of structure and its dimensions should of course be suitable for the target species to begin with. The space needed for human use, e.g. the width of a pedestrian or bicycle path, should be added to the width needed for the target species. In other words a combined use structure should typically be larger than a structure intended for wildlife alone.

3. Proximity of other suitable crossing structures.
   If there are other structures within the immediate vicinity (relative to the home range size of the target species) that are only intended for wildlife (no human use), and if these structures are of the appropriate type and dimensions for the target species one may be more inclined to allow for human use in the first structure, even if the type and dimensions of the structure are marginal for the target species. If there are no appropriate alternative structures present in the immediate vicinity, one may consider separating wildlife and human use rather than combining them at one structure.

4. Potential for human – wildlife conflicts.
   If the species expected to use the structure are known to be involved with human – wildlife conflicts (e.g. bears, mountain lions, moose, and to some degree elk) human use of the structures should probably be avoided and a separate structures should be provided of a type and dimension that is not preferred by that species. If human and wildlife use are combined in the same structure after all then perhaps avoid or discourage human use when it is dark to reduce the likelihood of encounters at short range. Seasonal closures for humans may also be considered during certain times of the year (e.g. elk and mule deer migration).

5. Design features.
- Paths or riding trails intended for human use should be confined to one side of a crossing structure rather than in the middle, leaving greater space for wildlife use. Vegetation or

other cover such as tree stumps, rocks or screens can be used to reduce the likelihood that humans will explore the wildlife portion of a structure and such features can reduce the disturbance to wildlife by limiting the visibility of humans. Ideally the animals still experience the path or trail intended for human use as part of the structure (thus perceiving the full width of the underpass or overpass). If there is more than one path or trail these should be bundled on one side of the structure occupying as little space as possible.

- Cover (vegetation, rows of tree stumps or rocks) at the approaches and on top or inside a structure, and natural substrate (soil) are important to encourage wildlife use, especially if the potential for human associated disturbance is high.
- A physical barrier (e.g. a berm), or a light and sound screen may be placed on the outer side of an overpass to reduce noise and light from passing road traffic. Underpasses may have similar barriers placed above the entrances to an underpass.
- Artificial lighting is negatively associated with wildlife use. Therefore no lighting is preferred at or near the structure. If lighting is installed after all, then consider using alternative colors (e.g. green lights may be less disturbing to wildlife) and aiming the lights away from the wildlife portion of the structure. These measures should be considered experimental as little is known about their effectiveness.
- If the space and topography allows, have the path or trail approach the structure perpendicular to the road, start paralleling the road as far away from the road as possible to minimize potential disturbance in the immediate vicinity of the approaches to the structure.

9. FREQUENTLY ASKED QUESTIONS

1. Q: Wildlife fencing is an integral part of the proposed mitigation measures. Aren't those fences bad for wildlife rather than good?

   A: Indeed fences can be a barrier for wildlife and some types of fence can even wound or kill wildlife. Fencing and other barriers in the landscape contribute to habitat fragmentation and block daily, seasonal or dispersal movements by individuals of different wildlife species. However, the fencing as proposed in this report uses the barrier effect of fencing for two specific purposes that benefit wildlife rather than hurt wildlife:
   - Wildlife fencing along roads discourages large mammals from entering the roadway and thus reduces direct wildlife mortality on the road as a result of collisions with vehicles.
   - Wildlife fencing directs wildlife that approaches the road to safe crossing opportunities such as wildlife overpasses and underpasses, thus encouraging animals to use safe crossing opportunities when they move across the landscape and encounter roads.

2. Q: Wildlife underpasses and overpasses are an integral part of the proposed mitigation measures. Do wildlife even use these structures to get to the other side of the road?

   A: If the crossing structures are located at the correct locations, and if they are of the right type with the right dimensions, and correct design features given the target species wildlife use of crossing structures can be very substantial. For example, in 2010 there were at least 12,000 confirmed wildlife crossings through about 30 crossing structures along US Hwy 93 North on the Flathead Indian Reservation in Montana (Huijser et al., 2011). Similarly over 185,000 wildlife crossings have been documented over 12 years at the wildlife crossing structures along the Trans Canada Highway in Banff National Park, Alberta, Canada (Clevenger et al., 2009). While wildlife use of wildlife crossing structures can be very high it is much more challenging to investigate whether these numbers are "high enough" to satisfy certain conservation or human safety goals. There should be enough "movement" or "connectivity" between populations on both sides of the road so that the target species have viable populations over long time periods. Population viability analyses can provide insight in how many structures may be required to maintain viable populations in a region. However, such population viability analyses require detailed data and funding to conduct the research. Note: photos of different wildlife species using different types of wildlife underpasses and one overpass along US Hwy 93 North can be viewed and downloaded from the internet: http://www.mdt.mt.gov/other/research/external/project_photos/us93info/

3. Q: Aren't wildlife crossing structures a good place for predators to wait until prey passes by and aren't these crossing structures then essentially prey traps and perhaps even population sinks for some species?

A: A review of the literature found that "evidence for the existence of prey-traps is scant, largely anecdotal and tends to indicate infrequent opportunism rather than the establishment of patterns of recurring predation" (Little et al., 2002). More recent research into this issue found no evidence that kill sites (where carnivores had killed ungulates) were closer to roads after wildlife fencing and crossing structures were installed (Ford & Clevenger 2010). In addition, data from wildlife cameras at crossing structures were analyzed to investigate whether presence of prey was followed by presence of predators more often and closer in time as crossing structures were longer in place (Ford & Clevenger 2010). Again, no evidence was found that crossing structures act as prey traps.

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11. APPENDIX A: MORTALITY CLUSTERS AND MITIGATION ZONES

Mortality Cluster

Buffer Zone

Hwy	MP	Deer (*Odocoileus* spp.)	Elk (*Cervus canadensis*)	Moose (*Alces alces*)	Pronghorn (*Antilocapra americana*)	Total	Wildlife Road Mortality Value	Category	Average value for cluster	Ranking cluster
191	141.4	4				4	2.50	very high	2.08	13
191	141.5	1				1	1.67	high		
191	141.6					0	0.33	very low		
191	141.7					0	0.00	absent		
191	141.8					0	0.00	absent		
191	141.9					0	2.33	very high	2.25	12
191	142.0	6	1			7	2.67	very high		
191	142.1	1				1	3.00	very high		
191	142.2		1			1	1.33	high		
191	142.3	2				2	1.67	high		
191	142.4	2				2	3.00	very high		
191	142.5	4	1			5	2.33	very high		
191	142.6					0	1.67	high		
191	142.7					0	0.00	absent		
191	142.8					0	0.00	absent		
191	142.9					0	1.67	high	2.42	8
191	143.0	5				5	2.67	very high		
191	143.1	3				3	3.33	very high		
191	143.2	2				2	2.00	high		
191	143.3	1				1	1.00	medium		
191	143.4					0	0.33	very low		
191	143.5					0	0.00	absent		

191	143.6					0	0.00	absent		
191	143.7					0	0.00	absent		
191	143.8					0	0.33	very low		
191	143.9	1				1	1.00	medium		
191	144.0	1	1			2	1.00	medium		
191	144.1					0	0.67	medium		
191	144.2					0	0.00	absent		
191	144.3					0	0.33	very low		
191	144.4	1				1	0.67	medium		
191	144.5		1			1	0.67	medium		
191	144.6					0	0.67	medium		
191	144.7	1				1	0.67	medium		
191	144.8		1			1	0.67	medium		
191	144.9					0	1.00	medium		
191	145.0	1	1			2	0.67	medium		
191	145.1					0	0.67	medium		
191	145.2					0	0.00	absent		
191	145.3					0	0.00	absent		
191	145.4					0	0.00	absent		
191	145.5					0	0.00	absent		
191	145.6					0	0.00	absent		
191	145.7					0	0.33	very low		
191	145.8	1				1	0.33	very low		
191	145.9					0	1.33	high		
191	146.0	3				3	1.00	medium		
191	146.1					0	1.67	high	2.38	9
191	146.2	2				2	1.33	high		
191	146.3	2				2	2.33	very high		
191	146.4	2	1			3	3.00	very high		
191	146.5	1	3			4	3.67	very high		
191	146.6	4				4	2.67	very high		
191	146.7					0	2.00	high		
191	146.8		2			2	1.00	medium		
191	146.9		1			1	2.00	high	2.00	14
191	147.0		3			3	2.00	high		
191	147.1		2			2	2.67	very high		
191	147.2	1	2			3	2.00	high		
191	147.3		1			1	1.33	high		
191	147.4					0	0.67	medium		
191	147.5	1				1	0.33	very low		
191	147.6					0	1.00	medium		

191	147.7		2			2	0.67	medium		
191	147.8					0	1.33	high	2.33	10
191	147.9	1	1			2	2.67	very high		
191	148.0	3	3			6	2.67	very high		
191	148.1					0	2.67	very high		
191	148.2	2				2	0.67	medium		
191	148.3					0	0.67	medium		
191	148.4					0	0.00	absent		
191	148.5					0	0.00	absent		
191	148.6					0	0.00	absent		
191	148.7					0	0.00	absent		
191	148.8					0	0.00	absent		
191	148.9					0	2.33	very high	2.56	6
191	149.0	6	1			7	2.67	very high		
191	149.1	1				1	2.67	very high		
191	149.2					0	0.67	medium		
191	149.3	1				1	0.33	very low		
191	149.4					0	0.33	very low		
191	149.5					0	0.00	absent		
191	149.6					0	0.00	absent		
191	149.7					0	0.33	very low		
191	149.8	1				1	1.00	medium		
191	149.9	1		1		2	3.33	very high	3.33	3
191	150.0	7				7	3.33	very high		
191	150.1	1				1	3.33	very high		
191	150.2	2				2	1.00	medium		
191	150.3					0	0.67	medium		
191	150.4					0	1.00	medium		
191	150.5	3				3	1.67	high		
191	150.6	2				2	1.67	high		
191	150.7					0	0.67	medium		
191	150.8					0	0.67	medium		
191	150.9	2				2	1.33	high		
191	151.0	1	1			2	1.33	high		
191	151.1					0	0.67	medium		
191	151.2					0	0.67	medium		
191	151.3	1	1			2	1.33	high	2.57	5
191	151.4	1	1			2	3.33	very high		
191	151.5	4	1	1		6	2.67	very high		
191	151.6					0	3.00	very high		
191	151.7	2		1		3	2.33	very high		

191	151.8	3	1			4	3.00	very high		
191	151.9	2				2	2.33	very high		
191	152.0	1				1	1.00	medium		
191	152.1					0	0.33	medium		
191	152.2					0	0.33	very low		
191	152.3	1				1	1.33	high		
191	152.4	3				3	1.33	high		
191	152.5					0	1.00	medium		
191	152.6					0	0.33	very low		
191	152.7	1				1	0.67	medium		
191	152.8			1		1	1.33	high		
191	152.9	1		1		2	1.33	high		
191	153.0	1				1	1.00	medium		
191	153.1					0	1.00	medium		
191	153.2	2				2	1.00	medium		
191	153.3	1				1	3.00	very high	5.33	1
191	153.4	6				6	6.00	very high		
191	153.5	11				11	8.00	very high		
191	153.6	7				7	7.00	very high		
191	153.7	3				3	4.67	very high		
191	153.8	4				4	4.00	very high		
191	153.9	5				5	6.33	very high		
191	154.0	10				10	5.33	very high		
191	154.1	1				1	3.67	very high		
191	154.2					0	0.67	medium		
191	154.3	1				1	0.33	very low		
191	154.4					0	0.33	very low		
191	154.5					0	0.33	very low		
191	154.6	1				1	0.33	very low		
191	154.7					0	0.33	very low		
191	154.8					0	0.33	medium		
191	154.9	1				1	0.67	medium		
191	155.0			1		1	0.67	medium		
191	155.1					0	0.33	very low		
191	155.2					0	0.00	absent		
191	155.3					0	0.00	absent		
191	155.4					0	0.67	medium		
191	155.5	2				2	1.00	medium		
191	155.6	1				1	1.00	medium		
191	155.7					0	0.33	very low		
191	155.8					0	0.00	absent		

191	155.9					0	0.33	very low		
191	156.0	1				1	0.33	very low		
191	156.1					0	0.67	medium		
191	156.2	1				1	0.33	very low		
191	156.3					0	0.33	very low		
191	156.4					0	1.33	high		
191	156.5	2	2			4	1.33	high		
191	156.6					0	1.33	high		
191	156.7					0	0.00	absent		
191	156.8					0	0.00	absent		
191	156.9					0	1.33	high		
191	157.0	3	1			4	2.00	high		
191	157.1	1	1			2	2.00	high		
191	157.2					0	1.00	medium		
191	157.3		1			1	0.33	very low		
191	157.4					0	2.33	very high	3.00	4
191	157.5	4	2			6	2.33	very high		
191	157.6		1			1	2.33	very high		
191	157.7					0	3.67	very high		
191	157.8	8	2			10	3.67	very high		
191	157.9		1			1	5.67	very high		
191	158.0	1	5			6	3.00	very high		
191	158.1	2				2	3.67	very high		
191	158.2	1	2			3	2.00	high		
191	158.3	1				1	1.33	high		
191	158.4					0	0.67	medium		
191	158.5	1				1	0.67	medium		
191	158.6		1			1	0.67	medium		
191	158.7					0	1.00	medium		
191	158.8		2			2	0.67	medium		
191	158.9					0	0.67	medium		
191	159.0					0	0.00	absent		
191	159.1					0	0.00	absent		
191	159.2					0	0.00	absent		
191	159.3					0	0.00	absent		
191	159.4					0	0.00	absent		
191	159.5					0	0.00	absent		
191	159.6					0	0.00	absent		
191	159.7					0	0.33	very low		
191	159.8	1				1	0.67	medium		
191	159.9	1				1	1.67	high		

191	160.0	2	1			3	1.33	high		
191	160.1					0	1.00	medium		
191	160.2					0	0.67	medium		
191	160.3	2				2	0.67	medium		
191	160.4					0	0.67	medium		
191	160.5					0	0.00	absent		
191	160.6					0	2.00	high	2.33	11
191	160.7	3		3		6	2.00	high		
191	160.8					0	3.00	very high		
22	0.0					0	0.50	low		
22	0.1	1				1	1.33	high	1.33	16
22	0.2	3				3	1.33	high		
22	0.3					0	1.00	medium		
22	0.4					0	2.33	very high	2.44	7
22	0.5	7				7	2.33	very high		
22	0.6					0	2.67	very high		
22	0.7		1			1	0.67	medium		
22	0.8		1			1	1.00	medium		
22	0.9	1				1	2.00	high	3.71	2
22	1.0	3	1			4	4.00	very high		
22	1.1	1	6			7	3.67	very high		
22	1.2					0	3.67	very high		
22	1.3	1	3			4	2.33	very high		
22	1.4		2	1		3	5.67	very high		
22	1.5	4	6			10	5.00	very high		
22	1.6		2			2	5.00	very high		
22	1.7	1	1	1		3	3.00	very high		
22	1.8	1	3			4	3.67	very high		
22	1.9	2	1	1		4	5.00	very high		
22	2.0	2	5			7	4.33	very high		
22	2.1	1		1		2	3.00	very high		
22	2.2					0	1.67	high		
22	2.3	1	2			3	1.00	medium		
22	2.4					0	1.33	high		
22	2.5		1			1	0.33	very low		
22	2.6					0	0.33	very low		
22	2.7					0	0.00	absent		
22	2.8					0	0.00	absent		
22	2.9					0	0.33	very low		
22	3.0	1				1	0.33	very low		

22	3.1					0	0.33	very low		
22	3.2					0	0.33	very low		
22	3.3	1				1	0.67	medium		
22	3.4	1				1	0.67	medium		
22	3.5					0	1.33	high		
22	3.6			3		3	1.33	high		
22	3.7	1				1	1.33	high		
22	3.8					0	0.33	very low		
22	3.9					0	0.00	absent		
22	4.0					0	0.67	medium		
22	4.1	2				2	1.00	medium		
22	4.2			1		1	1.33	high		
22	4.3			1		1	1.00	medium		
22	4.4			1		1	1.00	medium		
22	4.5	1				1	1.00	medium		
22	4.6		1			1	1.00	medium		
22	4.7	1				1	0.67	medium		
22	4.8					0	0.33	very low		
22	4.9					0	0.67	medium		
22	5.0	2				2	0.67	medium		
22	5.1					0	0.67	medium		
22	5.2					0	0.00	absent		
22	5.3					0	0.00	absent		
22	5.4					0	0.00	absent		
22	5.5					0	0.00	absent		
390	0.0	1				1	1.00	medium		
390	0.1	1				1	1.00	medium		
390	0.2	1				1	1.00	medium		
390	0.3			1		1	1.33	high		
390	0.4			2		2	1.67	high		
390	0.5		1	1		2	1.33	high		
390	0.6					0	1.00	medium		
390	0.7	1				1	0.67	medium		
390	0.8			1		1	1.00	medium		
390	0.9			1		1	1.00	medium		
390	1.0	1				1	1.33	high		
390	1.1	1		1		2	1.00	medium		
390	1.2					0	0.67	medium		
390	1.3					0	0.00	absent		
390	1.4					0	0.33	very low		

390	1.5			1		1	0.33	very low		
390	1.6					0	0.33	very low		
390	1.7					0	0.00	absent		
390	1.8					0	0.33	very low		
390	1.9			1		1	0.67	medium		
390	2.0			1		1	0.67	medium		
390	2.1					0	0.33	very low		
390	2.2					0	0.33	very low		
390	2.3			1		1	0.33	very low		
390	2.4					0	0.67	medium		
390	2.5	1				1	0.33	very low		
390	2.6					0	0.33	very low		
390	2.7					0	0.00	absent		
390	2.8					0	0.33	very low		
390	2.9	1				1	1.00	medium		
390	3.0	2				2	1.00	medium		
390	3.1					0	0.67	medium		
390	3.2					0	0.00	absent		
390	3.3					0	1.00	medium		
390	3.4	1	1	1		3	2.00	high	1.89	15
390	3.5	2		1		3	2.33	very high		
390	3.6	1				1	1.33	high		
390	3.7					0	0.33	very low		
390	3.8					0	0.67	medium		
390	3.9		2			2	0.67	medium		
390	4.0					0	1.33	high		
390	4.1	1	1			2	0.67	medium		
390	4.2					0	0.67	medium		
390	4.3					0	0.00	absent		
390	4.4					0	0.00	absent		
390	4.5					0	0.00	absent		
390	4.6					0	0.00	absent		
390	4.7					0	0.33	very low		
390	4.8	1				1	0.33	very low		
390	4.9					0	0.67	medium		
390	5.0	1				1	0.33	very low		
390	5.1					0	0.67	medium		
390	5.2		1			1	0.33	very low		
390	5.3					0	0.33	very low		
390	5.4					0	0.33	very low		
390	5.5		1			1	0.33	very low		

390	5.6					0	0.33	very low		
390	5.7					0	0.00	absent		
390	5.8					0	0.00	absent		
390	5.9					0	0.67	medium		
390	6.0		2			2	0.67	medium		
390	6.1					0	0.67	medium		
390	6.2					0	0.00	absent		
390	6.3					0	0.00	absent		
390	6.4					0	0.00	absent		
390	6.5					0	0.00	absent		
390	6.6					0	0.00	absent		

12.APPENDIX B: OBSERVATION CLUSTERS WY GAME & FISH DEPARTMENT

Observation cluster

Hwy	Mi	Mule deer (*Odocoileus hemionus*)	Elk (*Cervus canadensis*)	Moose (*Alces alces*)	White-tailed deer (*Odocoileus virginianus*)	Pronghorn (*Antilocapra americana*)	Coyote (*Canis latrans*)	Red fox (*Vulpes vulpes*)	Mountain lion (*Felis concolor*)	Bighorn sheep (*Ovis canadensis*)	Black bear (*Ursus americanus*)	Total	Observation value	Category	Average value for cluster	Ranking cluster
191	141.2											0	1.00	medium		
191	141.3	2										2	1.33	high	1.44	8
191	141.4	2										2	1.67	very high		
191	141.5		1									1	1.33	high		
191	141.6			1								1	0.67	medium		
191	141.7											0	0.33	low		
191	141.8											0	0.00	absent		
191	141.9											0	0.33	low		
191	142.0	1										1	0.33	low		
191	142.1											0	0.33	low		
191	142.2											0	0.00	absent		
191	142.3											0	0.33	low		
191	142.4	1										1	0.33	low		
191	142.5											0	1.67	very high	1.83	5
191	142.6	1	2	1								4	1.67	very high		
191	142.7	1										1	2.33	very high		
191	142.8	1	1									2	1.67	very high		
191	142.9	2										2	2.00	very high		
191	143.0		2									2	1.67	very high		

191	143.1	1										1	1.00	medium		
191	143.2											0	1.67	very high	2.42	3
191	143.3	1			3							4	1.33	high		
191	143.4											0	2.67	very high		
191	143.5	2	2									4	1.67	very high		
191	143.6	1										1	1.67	very high		
191	143.7											0	3.00	very high		
191	143.8	4	3						1			8	3.67	very high		
191	143.9	1		2								3	3.67	very high		
191	144.0											0	1.00	medium		
191	144.1											0	0.33	low		
191	144.2	1										1	0.33	low		
191	144.3											0	0.67	medium		
191	144.4	1										1	0.33	low		
191	144.5											0	0.67	medium		
191	144.6	1										1	0.33	low		
191	144.7											0	0.33	low		
191	144.8											0	0.00	absent		
191	144.9											0	0.00	absent		
191	145.0											0	0.00	absent		
191	145.1											0	1.33	high		
191	145.2	1	2	1								4	1.33	high		
191	145.3											0	1.33	high		
191	145.4											0	0.00	absent		
191	145.5											0	0.00	absent		
191	145.6											0	0.33	low		
191	145.7			1								1	0.67	medium		
191	145.8									1		1	0.67	medium		
191	145.9											0	2.33	very high	3.25	1
191	146.0	1	4		1							6	4.00	very high		
191	146.1	4			1	1						6	4.33	very high		
191	146.2			1								1	2.33	very high		
191	146.3											0	1.00	medium		
191	146.4	1	1									2	1.33	high		
191	146.5		1	1								2	1.33	high		
191	146.6											0	1.00	medium		

191	146.7					1						1	1.67	very high	1.56	7
191	146.8		2		2							4	1.67	very high		
191	146.9											0	1.33	high		
191	147.0											0	0.00	absent		
191	147.1											0	0.33	low		
191	147.2	1										1	0.33	low		
191	147.3											0	1.00	medium		
191	147.4	1									1	2	2.33	very high	2.67	2
191	147.5		2								3	5	3.00	very high		
191	147.6	1									1	2	2.67	very high		
191	147.7	1										1	1.00	medium		
191	147.8											0	0.33	low		
191	147.9											0	0.00	absent		
191	148.0											0	0.00	absent		
191	148.1											0	0.00	absent		
191	148.2											0	0.67	medium		
191	148.3		1			1						2	0.67	medium		
191	148.4											0	1.00	medium		
191	148.5		1									1	0.33	low		
191	148.6											0	0.33	low		
191	148.7											0	0.33	low		
191	148.8	1										1	0.33	low		
191	148.9											0	0.33	low		
191	149.0											0	0.00	absent		
191	149.1											0	0.00	absent		
191	149.2											0	0.00	absent		
191	149.3											0	0.00	absent		
191	149.4											0	0.00	absent		
191	149.5											0	0.67	medium		
191	149.6	2										2	0.67	medium		
191	149.7											0	0.67	medium		
191	149.8											0	0.00	absent		
191	149.9											0	0.67	medium		
191	150.0	2										2	2.33	very high	2.33	4
191	150.1	2		2					1			5	2.67	very high		
191	150.2			1								1	2.00	very high		
191	150.3											0	0.33	low		

191	150.4											0	0.33	low		
191	150.5			1								1	1.00	medium		
191	150.6		1			1						2	1.00	medium		
191	150.7											0	0.67	medium		
191	150.8											0	0.33	low		
191	150.9	1										1	0.67	medium		
191	151.0			1								1	1.33	high	1.67	5
191	151.1	1	1									2	1.67	very high		
191	151.2	1	1									2	2.00	very high		
191	151.3	1	1									2	1.67	very high		
191	151.4	1										1	1.00	medium		
191	151.5											0	0.33	low		
191	151.6											0	0.67	medium		
191	151.7	2										2	1.00	medium		
191	151.8	1										1	1.00	medium		
191	151.9											0	0.33	low		
191	152.0											0	0.00	absent		
191	152.1											0	0.00	absent		
191	152.2											0	0.00	absent		
191	152.3											0	0.00	absent		
191	152.4											0	0.00	absent		
191	152.5											0	0.00	absent		
191	152.6											0	0.00	absent		
191	152.7											0	0.00	absent		
191	152.8											0	0.00	absent		

13.APPENDIX C: OBSERVATION CLUSTERS NATURE MAPPING JACKSON HOLE

Observation cluster

Hwy	Mi	Mule deer (Odocoileus hemionus)	Elk (*Cervus canadensis*)	Moose (*Alces alces*)	White-tailed deer (*Odocoileus virginianus*)	Pronghorn (*Antilocapra americana*)	American badger (*Taxidea taxus*)	Coyote (*Canis latrans*)	Red fox (*Vulpes vulpes*)	Total	Observation value	Category	Avergae value for cluster	Ranking cluster
191	141.2									0	0.50	low		
191	141.3	1								1	0.67	medium		
191	141.4	1								1	0.67	medium		
191	141.5									0	0.33	low		
191	141.6									0	0.00	absent		
191	141.7									0	0.00	absent		
191	141.8									0	0.00	absent		
191	141.9									0	0.33	low		
191	142.0	1								1	0.33	low		
191	142.1									0	0.33	low		
191	142.2									0	0.00	absent		
191	142.3									0	0.00	absent		
191	142.4									0	0.00	absent		
191	142.5									0	0.00	absent		
191	142.6									0	0.00	absent		
191	142.7									0	0.00	absent		
191	142.8									0	0.00	absent		
191	142.9									0	0.00	absent		
191	143.0									0	0.00	absent		
191	143.1									0	0.00	absent		
191	143.2									0	1.33	high	1.67	11.00
191	143.3	1			3					4	1.33	high		
191	143.4									0	2.33	very high		
191	143.5	2	1							3	1.00	medium		

191	143.6									0	1.00	medium		
191	143.7									0	0.00	absent		
191	143.8									0	0.00	absent		
191	143.9									0	0.00	absent		
191	144.0									0	0.00	absent		
191	144.1									0	0.00	absent		
191	144.2									0	0.00	absent		
191	144.3									0	0.00	absent		
191	144.4									0	0.00	absent		
191	144.5									0	0.33	low		
191	144.6	1								1	0.33	low		
191	144.7									0	0.33	low		
191	144.8									0	0.00	absent		
191	144.9									0	0.00	absent		
191	145.0									0	0.00	absent		
191	145.1									0	0.00	absent		
191	145.2									0	0.00	absent		
191	145.3									0	0.00	absent		
191	145.4									0	0.00	absent		
191	145.5									0	0.00	absent		
191	145.6									0	0.00	absent		
191	145.7									0	0.00	absent		
191	145.8									0	0.00	absent		
191	145.9									0	0.00	absent		
191	146.0									0	0.33	low		
191	146.1				1					1	0.33	low		
191	146.2									0	0.33	low		
191	146.3									0	0.00	absent		
191	146.4									0	0.00	absent		
191	146.5									0	0.67	medium		
191	146.6	1	1							2	1.00	medium		
191	146.7		1							1	1.00	medium		
191	146.8									0	2.00	high		
191	146.9	5								5	1.67	high		
191	147.0									0	1.67	high		
191	147.1									0	0.33	low		
191	147.2	1								1	0.33	low		
191	147.3									0	0.67	medium		
191	147.4	1								1	0.33	low		
191	147.5									0	0.33	low		
191	147.6									0	0.00	absent		

191	147.7									0	0.00	absent		
191	147.8									0	0.00	absent		
191	147.9									0	0.00	absent		
191	148.0									0	0.00	absent		
191	148.1									0	0.00	absent		
191	148.2									0	0.00	absent		
191	148.3									0	0.33	low		
191	148.4	1								1	0.33	low		
191	148.5									0	0.33	low		
191	148.6									0	0.00	absent		
191	148.7									0	0.00	absent		
191	148.8									0	0.00	absent		
191	148.9									0	0.00	absent		
191	149.0									0	0.00	absent		
191	149.1									0	0.00	absent		
191	149.2									0	0.00	absent		
191	149.3									0	0.00	absent		
191	149.4									0	0.00	absent		
191	149.5									0	0.00	absent		
191	149.6									0	0.00	absent		
191	149.7									0	0.00	absent		
191	149.8									0	0.00	absent		
191	149.9									0	0.00	absent		
191	150.0									0	0.67	medium		
191	150.1			2						2	0.67	medium		
191	150.2									0	0.67	medium		
191	150.3									0	0.33	low		
191	150.4	1								1	0.33	low		
191	150.5									0	0.67	medium		
191	150.6	1								1	1.00	medium		
191	150.7	2								2	1.00	medium		
191	150.8									0	0.67	medium		
191	150.9									0	0.33	low		
191	151.0			1						1	0.67	medium		
191	151.1	1								1	1.00	medium		
191	151.2	1								1	1.00	medium		
191	151.3		1							1	1.33	high		
191	151.4	2								2	1.33	high		
191	151.5	1								1	1.00	medium		
191	151.6									0	0.33	low		
191	151.7									0	0.67	medium		

191	151.8	2								2	0.67	medium		
191	151.9									0	0.67	medium		
191	152.0									0	0.00	absent		
191	152.1									0	0.00	absent		
191	152.2									0	0.33	low		
191	152.3			1						1	1.00	medium		
191	152.4	2								2	1.67	high	1.73	10.00
191	152.5	1					1			2	1.67	high		
191	152.6	1								1	2.33	very high		
191	152.7	4								4	1.67	high		
191	152.8									0	1.33	high		
191	152.9									0	0.33	low		
191	153.0	1								1	1.33	high	2.14	9.00
191	153.1	3								3	1.33	high		
191	153.2									0	1.67	high		
191	153.3	2								2	1.33	high		
191	153.4	2								2	2.33	very high		
191	153.5	3								3	2.33	very high		
191	153.6	2								2	2.67	very high		
191	153.7	1		2						3	2.67	very high		
191	153.8	2	1							3	2.33	very high		
191	153.9	1								1	2.67	very high		
191	154.0	4								4	2.67	very high		
191	154.1	3								3	2.33	very high		
191	154.2									0	1.00	medium		
191	154.3									0	0.00	absent		
191	154.4									0	0.00	absent		
191	154.5									0	0.00	absent		
191	154.6									0	0.00	absent		
191	154.7									0	1.67	high	3.00	6.00
191	154.8	2		3						5	3.67	very high		
191	154.9	4		2						6	4.00	very high		
191	155.0			1						1	2.67	very high		
191	155.1							1		1	0.67	medium		
191	155.2									0	0.33	low		
191	155.3									0	0.00	absent		
191	155.4									0	0.00	absent		
191	155.5									0	0.00	absent		
191	155.6									0	0.00	absent		
191	155.7									0	0.33	low		
191	155.8				1					1	0.33	low		

191	155.9									0	0.33	low		
191	156.0									0	0.33	low		
191	156.1					1				1	0.67	medium		
191	156.2	1								1	0.67	medium		
191	156.3									0	0.33	low		
191	156.4									0	0.00	absent		
191	156.5									0	1.33	high		
191	156.6	1	3							4	1.33	high		
191	156.7									0	1.33	high		
191	156.8									0	0.00	absent		
191	156.9									0	0.00	absent		
191	157.0									0	0.33	low		
191	157.1		1							1	0.67	medium		
191	157.2	1								1	1.33	high		
191	157.3	1						1		2	1.00	medium		
191	157.4									0	0.67	medium		
191	157.5									0	0.00	absent		
191	157.6									0	0.00	absent		
191	157.7									0	0.00	absent		
191	157.8									0	0.00	absent		
191	157.9									0	0.00	absent		
191	158.0									0	0.00	absent		
191	158.1									0	0.33	low		
191	158.2	1								1	0.33	low		
191	158.3									0	0.33	low		
191	158.4									0	0.00	absent		
191	158.5									0	0.00	absent		
191	158.6									0	2.33	very high	2.33	7.00
191	158.7	4		3						7	2.33	very high		
191	158.8									0	2.33	very high		
191	158.9									0	0.00	absent		
191	159.0									0	0.00	absent		
191	159.1									0	0.00	absent		
191	159.2									0	0.00	absent		
191	159.3									0	0.00	absent		
191	159.4									0	0.00	absent		
191	159.5									0	0.00	absent		
191	159.6									0	0.00	absent		
191	159.7									0	0.33	low		
191	159.8		1							1	0.33	low		
191	159.9									0	0.33	low		

191	160.0									0	0.00	absent		
191	160.1									0	0.00	absent		
191	160.2									0	0.00	absent		
191	160.3									0	0.33	low		
191	160.4					1				1	0.33	low		
191	160.5									0	0.67	medium		
191	160.6					1				1	0.33	low		
191	160.7									0	0.33	low		
22	0.0									0	1.33	high		
22	0.1	4								4	1.33	high		
22	0.2									0	1.33	high		
22	0.3									0	0.00	absent		
22	0.4									0	2.00	high	2.22	8.00
22	0.5	6								6	2.00	high		
22	0.6									0	2.67	very high		
22	0.7							2		2	0.67	medium		
22	0.8									0	1.33	high		
22	0.9	1	1							2	0.67	medium		
22	1.0									0	0.67	medium		
22	1.1									0	0.00	absent		
22	1.2									0	0.00	absent		
22	1.3									0	0.00	absent		
22	1.4									0	0.00	absent		
22	1.5									0	2.00	high		
22	1.6	3	1	2						6	2.00	high		
22	1.7									0	2.00	high		
22	1.8									0	0.00	absent		
22	1.9									0	0.67	medium		
22	2.0		1						1	2	1.00	medium		
22	2.1			1						1	5.67	very high	5.33	3.00
22	2.2		2	9					3	14	5.33	very high		
22	2.3							1		1	5.00	very high		
22	2.4									0	0.33	low		
22	2.5									0	0.00	absent		
22	2.6									0	0.67	medium		
22	2.7							2		2	2.00	high		
22	2.8			2				2		4	2.00	high		
22	2.9									0	1.33	high		
22	3.0									0	0.00	absent		
22	3.1									0	0.00	absent		

22	3.2									0	0.00	absent		
22	3.3									0	0.00	absent		
22	3.4									0	0.00	absent		
22	3.5									0	2.33	very high	6.57	2.00
22	3.6			7						7	3.33	very high		
22	3.7			3						3	4.00	very high		
22	3.8			1				1		2	3.00	very high		
22	3.9			4						4	5.67	very high		
22	4.0		1	10						11	7.67	very high		
22	4.1		1	7						8	10.00	very high		
22	4.2			11						11	12.67	very high		
22	4.3		3	16						19	10.33	very high		
22	4.4			1						1	6.67	very high		
22	4.5									0	1.00	medium		
22	4.6		1					1		2	1.33	high	4.23	5.00
22	4.7			1					1	2	1.67	high		
22	4.8								1	1	2.00	high		
22	4.9		1					1	1	3	2.00	high		
22	5.0							1	1	2	2.67	very high		
22	5.1							3		3	2.67	very high		
22	5.2			1					2	3	3.00	very high		
22	5.3			2				1		3	8.67	very high		
22	5.4			18	1				1	20	9.67	very high		
22	5.5			6						6	8.67	very high		
390	0.0									0	9.00	very high	9.22	1.00
390	0.1		2	25						27	9.00	very high		
390	0.2									0	9.67	very high		
390	0.3			2						2	1.00	medium		
390	0.4			1						1	1.33	high		
390	0.5			1						1	0.67	medium		
390	0.6									0	0.33	low		
390	0.7									0	0.00	absent		
390	0.8									0	0.67	medium		
390	0.9			2						2	1.67	high		
390	1.0			3						3	2.00	high		
390	1.1			1						1	1.67	high		
390	1.2			1						1	0.67	medium		
390	1.3									0	1.00	medium		
390	1.4			2						2	0.67	medium		
390	1.5									0	1.67	high		

390	1.6			3						3	1.00	medium		
390	1.7									0	1.33	high		
390	1.8			1						1	0.67	medium		
390	1.9			1						1	1.33	high		
390	2.0			1					1	2	1.33	high		
390	2.1			1						1	1.00	medium		
390	2.2									0	0.33	low		
390	2.3									0	0.33	low		
390	2.4			1						1	1.33	high		
390	2.5			3						3	1.33	high		
390	2.6									0	1.00	medium		
390	2.7									0	0.00	absent		
390	2.8									0	0.00	absent		
390	2.9									0	0.00	absent		
390	3.0									0	0.00	absent		
390	3.1									0	0.00	absent		
390	3.2									0	0.33	low		
390	3.3		1							1	0.33	low		
390	3.4									0	0.33	low		
390	3.5									0	0.67	medium		
390	3.6		1	1						2	1.00	medium		
390	3.7	1								1	5.00	very high	4.78	4.00
390	3.8	8		3					1	12	4.67	very high		
390	3.9			1						1	4.67	very high		
390	4.0		1							1	0.67	medium		
390	4.1									0	1.00	medium		
390	4.2		2							2	0.67	medium		
390	4.3									0	0.67	medium		
390	4.4									0	0.33	low		
390	4.5			1						1	1.00	medium		
390	4.6			2						2	1.33	high		
390	4.7			1						1	1.00	medium		
390	4.8									0	0.33	low		
390	4.9									0	1.00	medium		
390	5.0	3								3	1.00	medium		
390	5.1									0	1.00	medium		
390	5.2									0	0.33	low		
390	5.3							1		1	0.67	medium		
390	5.4								1	1	0.67	medium		
390	5.5									0	0.33	low		
390	5.6									0	0.67	medium		

390	5.7		2							2	0.67	medium		
390	5.8									0	0.67	medium		
390	5.9									0	0.00	absent		
390	6.0									0	0.00	absent		
390	6.1									0	0.00	absent		
390	6.2									0	0.00	absent		
390	6.3									0	0.33	low		
390	6.4							1		1	0.33	low		
390	6.5									0	0.33	low		
390	6.6									0	0.00	absent		

14. APPENDIX D: TECHNICAL ADVISORS FOR FIELD REVIEW OF SITES

Louise Lasley; Jackson Hole Conservation Alliance

Megan Smith; Jackson Hole Wildlife Foundation

Bob Hammond and Bob Bonds; Wyoming Department of Transportation

Gary Fralick and Doug Brimeyer; Wyoming Game and Fish Department (WGFD)

Chris Colligan; Greater Yellowstone Coalition

Embere Hall; Teton Science School

Gary Hanvey; Darin Martens, Sandy Jacobsen, Kerry Murphy; US Forest Service