Crossings and Collisions:
A Framework for Identifying Wildlife Crossing Locations in Teton Valley

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Approval

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Abstract

Around the world, landscape architects establish linkages between social needs and natural systems through innovative designs that save lives and protect native landscapes. Population growth has exerted increased pressures on habitat and wildlife populations globally. In the United States, since 1990, increased roadway densities have caused a rise in vehicle-wildlife collisions by 50%, contributing to nearly two-million collisions annually (Huijser et al., 2018). Within the Teton watershed in southeast Idaho, there have been 291 recorded wildlife-vehicle related crashes between 2010 and 2019. Collisions with wildlife are grossly under reported due to inconsistencies in reporting methods and data repositories (Huisjer et al., 2008b). This project explored how standardized conservation best management practices could improve habitat connectivity for wildlife species and reduce vehicle-wildlife collisions. Decisions were informed by alternative future scenarios driven by stakeholders involved in the National Science Foundation (NSF) Established Program to Stimulate Competitive Research (EPSCoR) Genes by Environment: Modeling, Mechanisms and Mapping (GEM3) project in Idaho. Spatial analysis through Geographical Information Systems (GIS) and detailed case studies were evaluated to find high priority road sections for consideration of mitigation measures. Evaluative metrics included historic vehicle-wildlife collisions, carcass removal records, and GAP wildlife habitat. This project considered the long-term implications of wildlife crossings under a single scenario from the GEM3 project to provide solutions for a future trajectory of change.

Through a mixed-methods approach this project a) analyzed and b) identified locations to address habitat issues within Teton Valley. A multivariate regression model in ArcGIS Pro was used to evaluate a set of roadway characteristics (Huijser et al., 2008b) that have been shown to influence wildlife-vehicle collisions. Kernel Density analysis was used on wildlife-vehicle collisions and carcass removal data to find hot spots for conflict areas along major highways. Finally, by evaluating a set of biological conservation factors against the results from the kernel density analysis, priority locations were defined. Results showed a need for mitigation measures at 10 distinct locations and provided support for the greater improvement of standards of reporting for wildlife-vehicle collisions. This work builds a framework for landscape architects to use for habitat corridor connectivity, future transportation planning projects, and to evaluate the need for mitigation retrofits on existing infrastructure.

Acknowledgements

Many thanks to my husband who, even while processing his own master’s thesis, was my sounding board for ideas and editor throughout this entire process. I could not have done it without you!

I would also like to thank my major professor Dan Cronan for his guidance and encouragement during the entirety of this project. Through all of the “first bad drafts” I am proud of the outcome and could not have done it without your help. Thank you!

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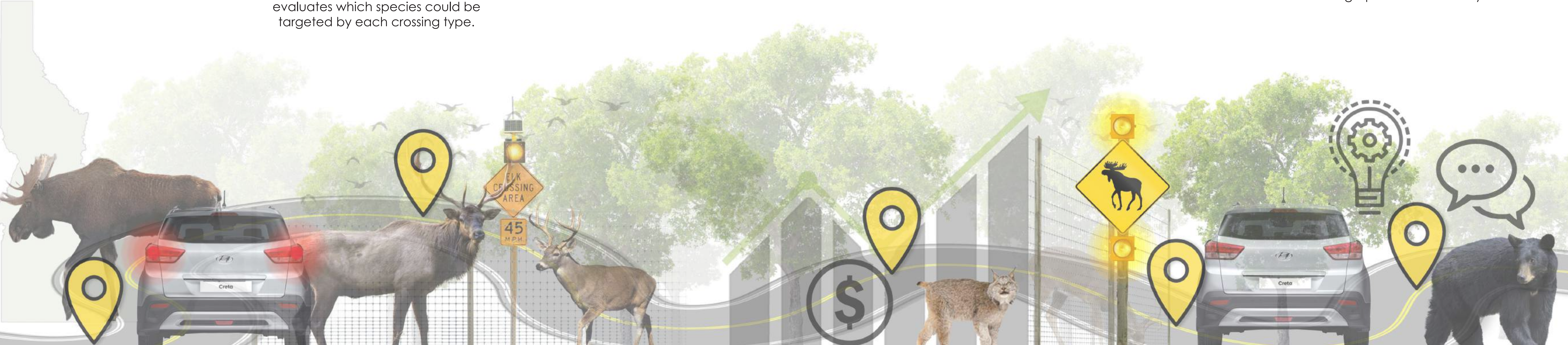
Acronyms

Wildlife-Vehicle Collisions - WVCs
Idaho Fish and Game - IDFG
Idaho Transportation Department - ITD
United States Forest Service - USFS
United States Fish and Wildlife Service - USFWS
Genes by Environment: Modeling, Mapping, and Mechanisms - GEM3
Geographic Information Systems - GIS



Chapter 1: Introduction

This chapter presents the motivation behind this project and gives a brief overview of road ecology and crossing structures. It also outlines the process taken to complete this project and the specific goals and objectives .

1.1 Motivation

Ever growing human populations put a strain on the natural environment through the development of land for community living and agriculture. The United States is projected to grow by nearly 2.3 million people every year until 2030 and reach a total population of four-hundred million by 2058 (Vespa et al., 2020). As populations increase and cities continue to grow to accommodate those people, roadway infrastructure soon follows suit and expands to ease movement between cities and states. While the US is growing at a rate of roughly 6.3%, Idaho has seen alarming amounts of growth since 2010 at a rate of 14% (U.S. Census Bureau, 2020). This growth has put a strain on the current transportation infrastructure and more vehicles are being driven daily on all roadways across the state.

In July of 2016, there was an average of 3.5 million vehicles on Idaho roads per day, compare that to July of 2020, and you see a jump to 3.9 million vehicles per day (Idaho Transportation Department, 2021, Figure 1). As roads become busier and are potentially expanded upon to keep up with the vehicular demand of growing populations, more habitats and wildlife species become disjunct from one another through various ecological effects related to roadway infrastructure. Roads are an obstacle for many species to navigate and pose a risk to species in terms of isolation and endangerment (Clevenger and Huijser, 2009). Most notably, roads act as barriers to species movements, limiting the ability of wildlife to move between critical habitats for survival. If an individual or group of animals decides to risk crossing a roadway, they are tasked with navigating through traffic that is not necessarily expecting wildlife to be on the road. This causes the potential for vehicle-wildlife collisions that pose a major safety issue to both the motorist and the animal.

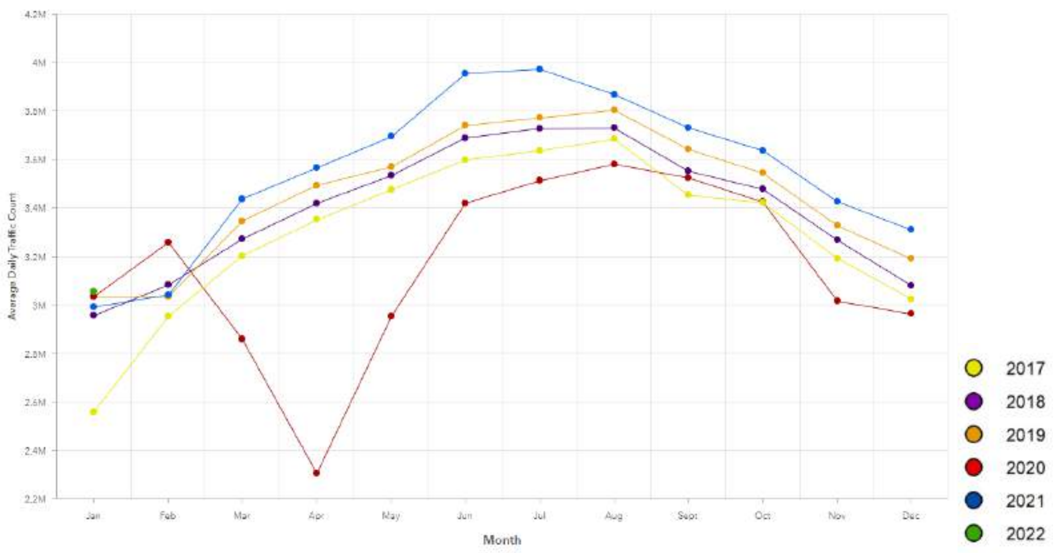


Figure 1. Average daily traffic counts in Idaho, 2017 – 2021 (ITD, 2022).

In the United States, vehicle-wildlife collisions account for nearly 5% of all reported vehicle collisions (Clevenger and Huijser, 2009). Studies from the federal best practices document reported to congress in 2008 showed that wildlife-vehicle collisions are severely under reported due to inconsistencies in the recording process (Huijser et al., 2008a). Annually, it is estimated that there are 211 human fatalities, 29,000 injuries and over $1 billion in property damages from between 1 and 2 million collisions with wildlife (Clevenger and Huijser, 2009). When looking at crash databases alone, in 2008 there were roughly 300,000 wildlife-vehicle collisions reported, however, when looking at insurance claims for the same period there was a reported 1-2 million collisions with wildlife (Huijser et al., 2008a). While there are many factors that contribute to collisions, such as traffic volumes and visibility, it is clear that vehicle collisions are a leading source of mortality for species caught in the headlights. In 2020, there were 4,214 animals reportedly killed by vehicles across Idaho (IDFG, 2022, Figure 2).

Therefore, the main goal of this project is to reduce vehicle-wildlife collisions and wildlife mortality by utilizing various crossing structures and detection systems to conserve critical habitats, wildlife populations, and to reduce human fatalities related to collisions.

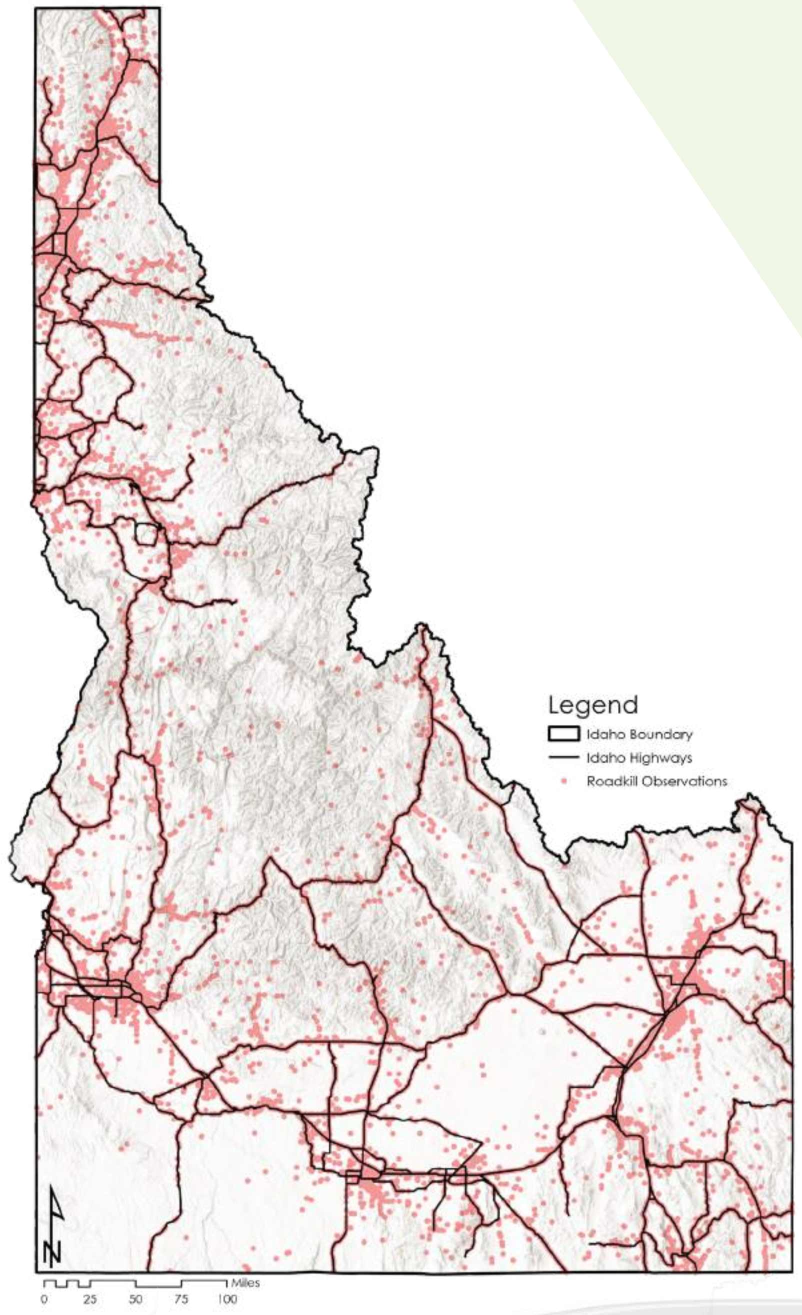


Figure 2. Map of observed road kill in Idaho 2002 – 2021 (IDFG, 2022).

1.2 Contributions from literature

1.2.1 Road Ecology

The impacts of roads on natural environments have been widely studied and have been evolving over time to not only include the direct impacts of roads, but the effects that occur away from roadways to habitats and wildlife species that have lasting consequences (Figure 3). The “road-effect zone” is a conceptual framework used to quantify the negative impacts on the areas adjacent to roads and traffic (Ree et al., 2015). This can include, but is not limited to, direct impacts to wildlife getting hit crossing roadways and habitat degradation due to pollution from runoff. In addition, roads have been described as having five different ecological functions that specifically affect wildlife populations including acting has habitats, sources, sinks, barriers, and conduits (Clevenger and Huijser, 2009). Some species have been found to avoid roads altogether due to noise and lights while others have been found to be attracted to roads and are thus more likely to be hit by vehicles. The configuration and density of roadways also impacts wildlife in different ways. Road density is defined as the measurement of length of road per unit of area and threshold densities have been identified for some species (Ree et al., 2015). Density and configuration of roads also play a key role in separating wildlife in smaller populations, called sub-populations. For groups of animals that are separated by a barrier for long periods of time, the risk of endangerment and possible extinction to that sub-population increases as individuals are no longer connected to the greater population (Ree et al., 2015). Because of these threats to wildlife species and natural habitats, existing roadways should be retrofitted to allow for greater movement between isolated populations.

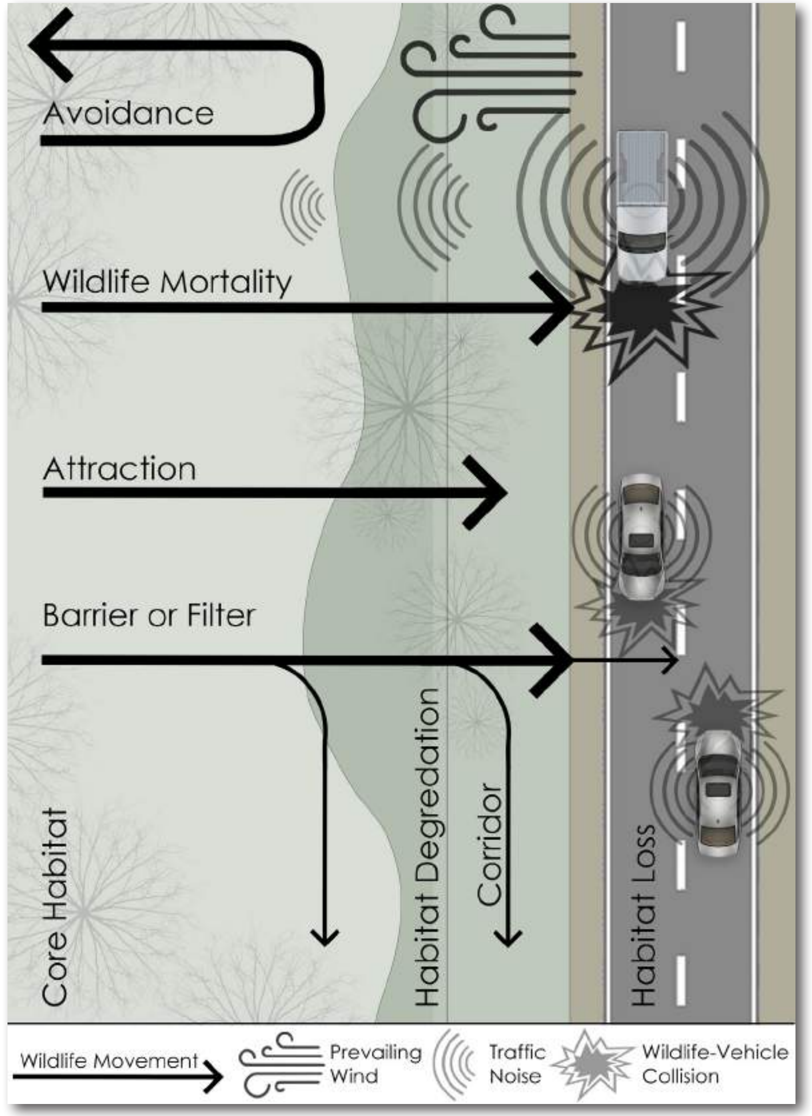


Figure 3. Ecological effects of roadways.

1.2.2 Wildlife Crossing Structures

The barriers created by roads can be mitigated through a variety of methods including overpasses, underpasses, fencing, and detection systems to provide opportunities for safe crossings. Crossing structures and detection systems can decrease the number of wildlife-vehicle collisions. This, in turn, improves safety for motorists and prevents unintended wildlife fatalities. The “Handbook for Design and Evaluation of Wildlife Crossing Structures in North America” by Clevenger and Huijser (2009) is widely used by state transportation agencies as the standard for wildlife crossing design. In it, the technical specifications, costs, and benefits of each crossing type are explored in depth. Many studies done in Canada within Banff National Park look at the efficacy of various crossing structures for specific target species. In a study published in 2012, Sawaya et al. evaluated populations of grizzly (*Ursus arctos*) and black bear (*Ursus americanus*) to figure out how many individuals were utilizing crossing structures to move between habitats within the Bow Valley. They found that grizzly bears would use overpasses more often than culvert crossings and that for both grizzly and black bears, there was a peak period in which crossings were more frequent, which aligned with heightened foraging activities in the summer (Sawaya et al., 2012). This study concluded that wildlife crossing structures provide adequate connectivity for bear populations within Banff NP.

Another study conducted by Clevenger et al. published in 2001, looked at the use of drainage culverts for creating linkages between habitats also in Banff NP. This study focused on small- and medium-sized mammals that would be using culverts under roadways to move through the park. Distinct types and sizes of culverts were evaluated for use by various species by comparing tracks inside and around 36 culverts (Clevenger et al., 2001). This study found that traffic volume, road noise levels, and roadway width as well as vegetation cover near culverts played a role in species’ use (Clevenger et al., 2001). Results from this study show the importance of looking beyond the structure itself and into the surrounding area to evaluate how roadways inadvertently affect species movement away from the road corridor. For example, understanding species behavior can help identify the types of mitigation measures that would be most beneficial. When looking at mountain goats (*Oreamnos americanus*) in Glacier National Park, Singer (1978) found that visitor presence and increased traffic were key players in the success of the goats crossing the highways to get to salt licks. It was found that when traffic volumes were higher, the mountain goats exhibited more alerted behaviors such as raising their tails and hesitating before entering roadways or walking with stiff legs (Singer, 1978). Through the observations of behaviors and movements it was determined that an underpass along one of the most used crossing zones would prove most beneficial in reducing collisions as well as stress to the animals using the crossing. This shows that the direct and indirect effects of roads on wildlife movements should be considered.

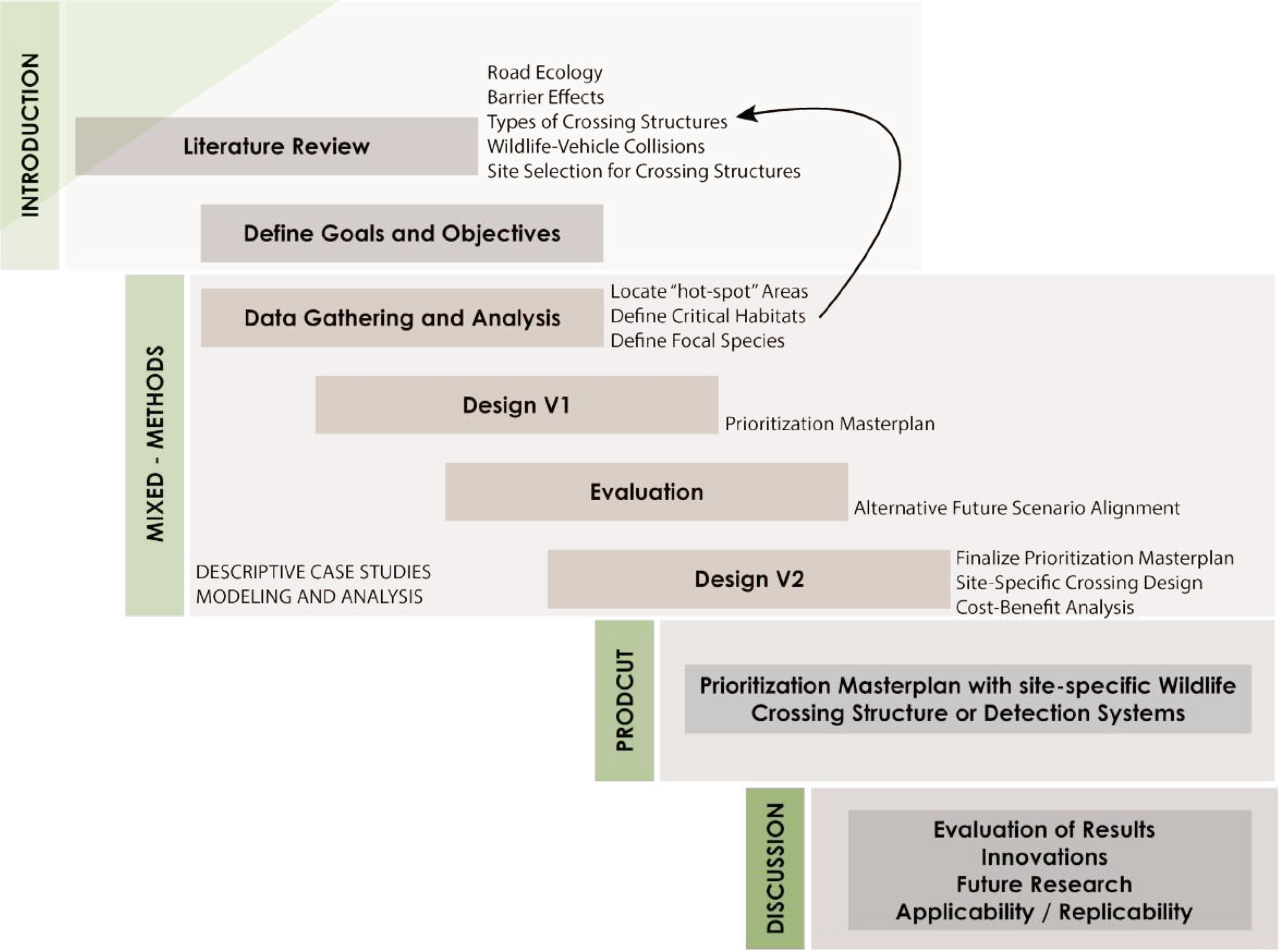


Figure 4. Process diagram for this project.

1.3 Framework for design

This project utilizes a mixed-methods approach through the evaluation of case studies about wildlife crossing designs and the use of geographic information systems (GIS) to identify areas within the Teton region of Idaho where wildlife crossing structures could reduce the prevalence of wildlife-vehicle collisions (Figure 4, 5). Additionally, the inclusion of a stakeholder defined scenario from the greater GEM3 project in Idaho will guide the solutions that would be possible under the "Recreational Sprawl" scenario to provide a long-term glance into the future of wildlife crossings in Teton. For the selection of specific locations for possible crossing structures, the base framework used by Huijser et al. (2018) in the Teton County Wildlife Crossings Master Plan for Wyoming (explained in detail in chapter 3, section 1) will be used with a discussion about the inclusion of land ownership and new innovations in design for promoting safe crossings and reducing collisions. This project will provide a prioritization master plan for wildlife crossing structures with site-specific designs and evaluate possible innovations for future design and research as well as, show the applicability of this process to other locations within Idaho.

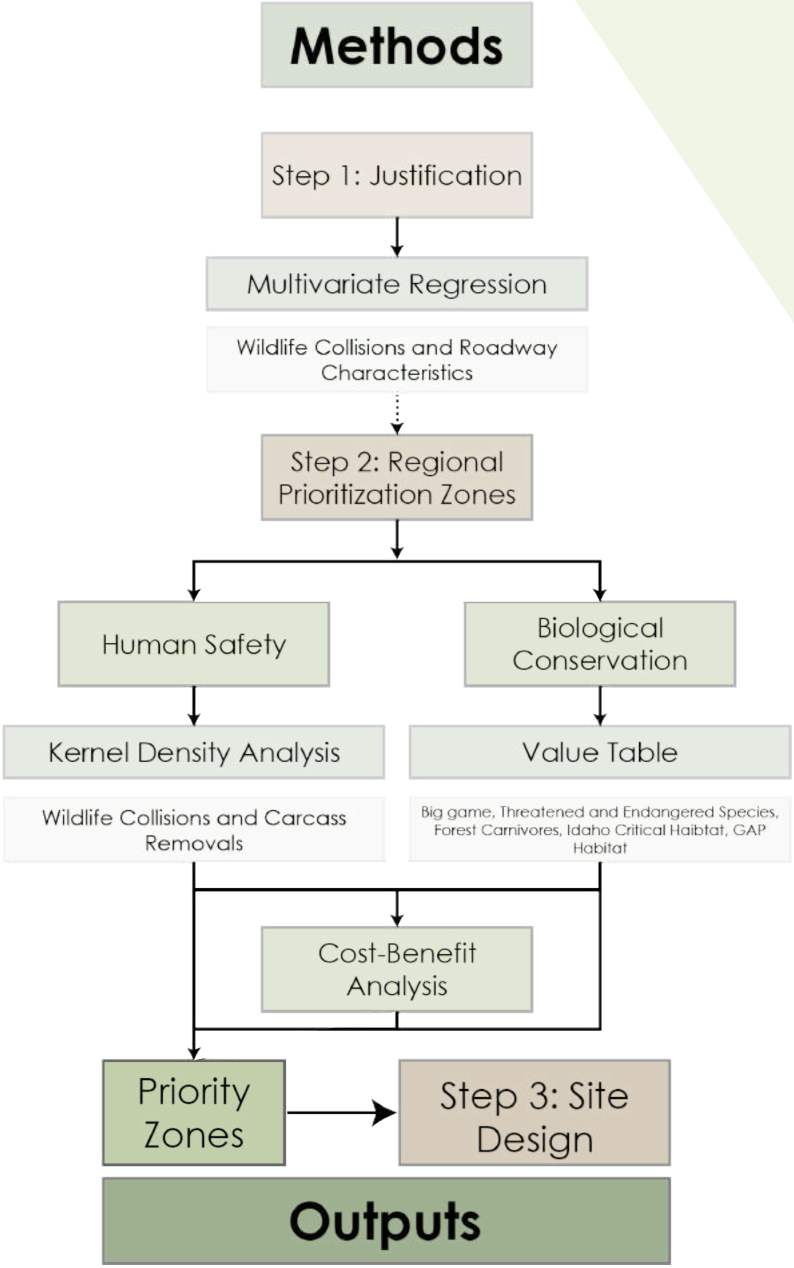


Figure 5. Process diagram for the methods section of this project.

1.4 Teton region overview

The Teton region is in southeast Idaho on the Wyoming border including Teton National Park. For the purpose of this study, the focus area will be within the 8-digit Hydrologic Unit (HUC8) delineated sub basin named Teton which includes parts of Madison, Fremont, and Teton counties in Idaho as well as Teton county Wyoming (Figure 6). The eastern most edge of the watershed lies at the peak of the Teton Mountains and extends to Henry's Fork River at its western most boundary. Encompassed within the watershed is the Jedediah Smith Wilderness along the Teton Mountains and Targhee National Forest to the west of Teton Basin. Within the basin lies the towns of Victor, Driggs and Tetonia. At the west edge of the watershed is Rexburg Idaho. East of Tetonia, lies the Grand Targhee Ski Area, which is slated for expansions in the future.

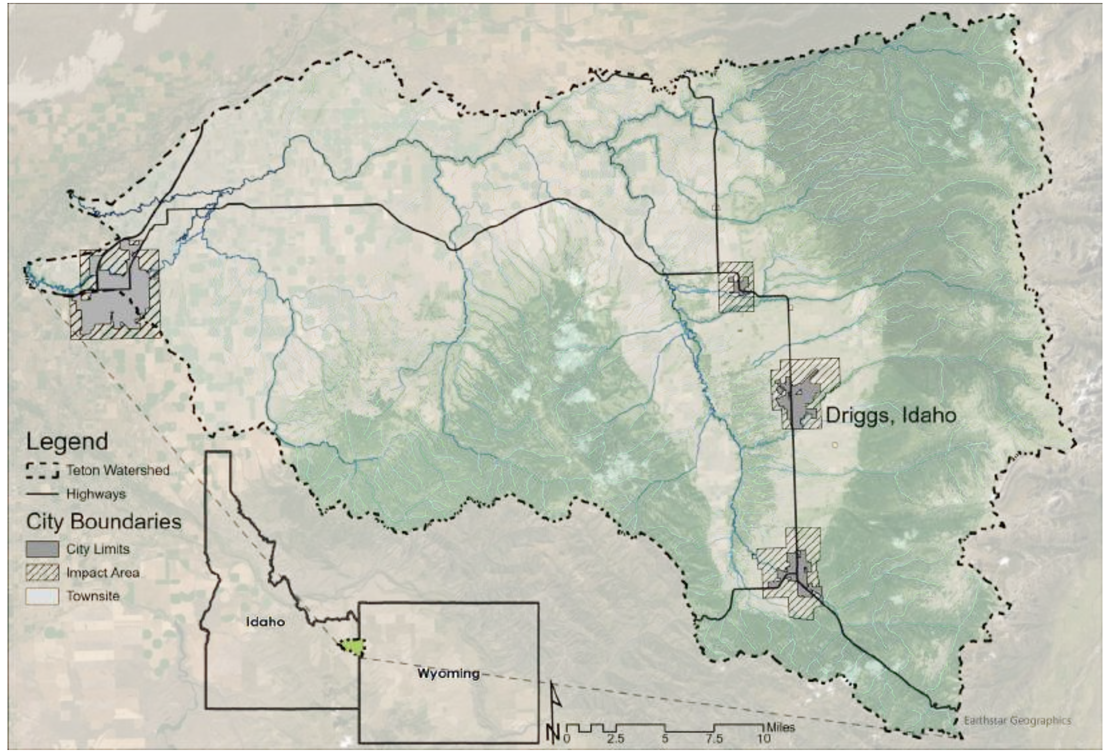


Figure 6. Context map of the HUC8 Teton Watershed.

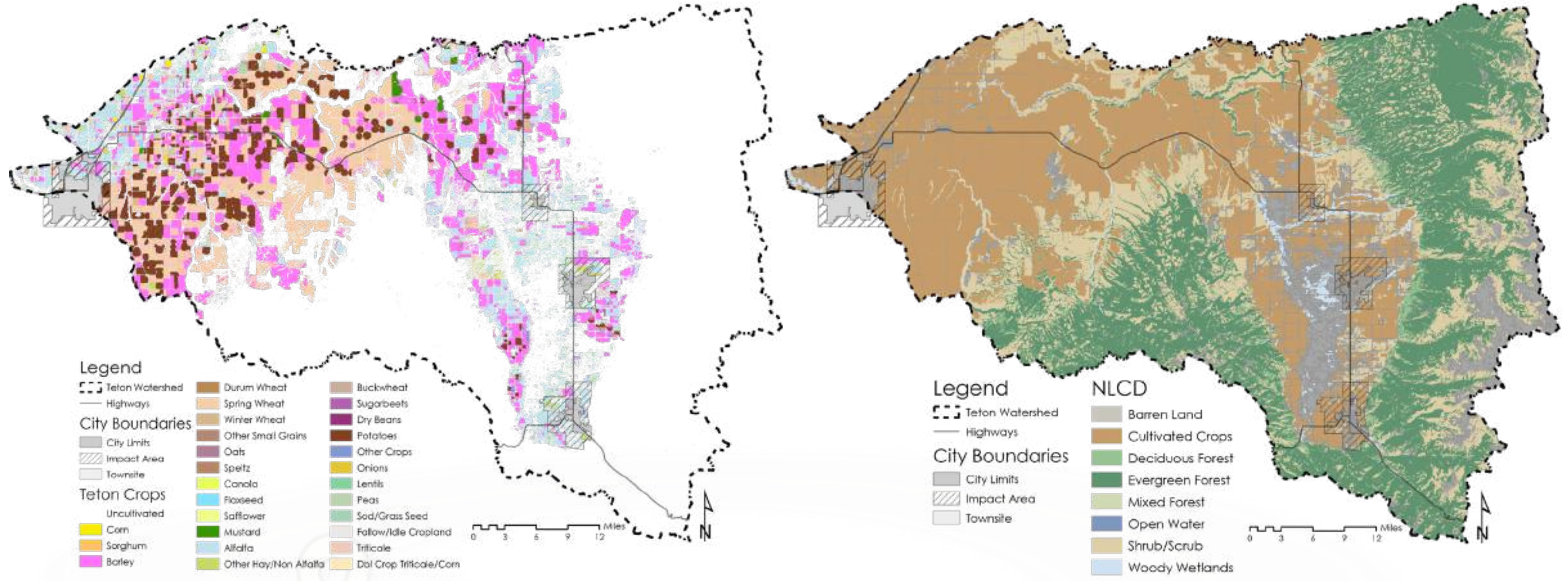


Figure 7. Cropland Data Layer and National Land Cover Dataset for Teton Watershed.

Population growth in this area is staggering when compared to national averages (Figure 8). Teton county has seen a 19.4% population increase since 2010 with a total population of 12,142 (U.S. Census Bureau, 2020). In Rexburg, which is in Madison County and has a population of 29,400, growth rates have also been increasing at 15.3% since 2010 compared to the national average of 6.3% (U.S. Census Bureau, 2020). Major highways through the Teton Watershed include Idaho State Highways 31,32, and 33 as well as United States (US) Highway 20. The average commute time to work for people living in Teton County is 29 minutes, suggesting that many people are traveling around the basin and possibly to Rexburg or Jackson, Wyoming for work opportunities (U.S. Census Bureau, 2020). This rapid population growth is cause for examination of transportation corridors and the effects it has on habitat fragmentation.

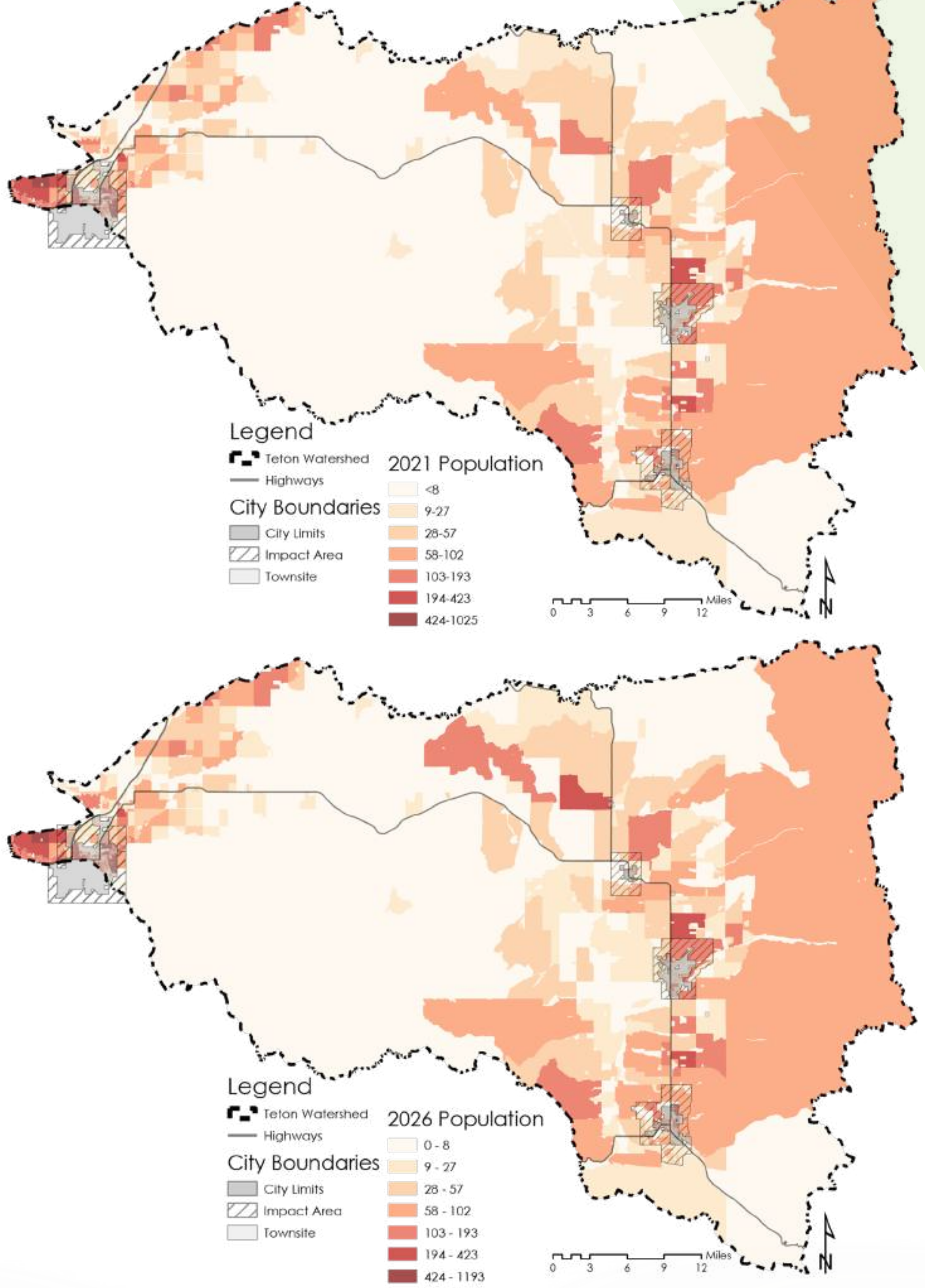


Figure 8. Population counts for 2021 and 2026 within the Teton Watershed.

To better describe the ecosystems of the watershed, ecoregion delineations were used. Ecoregions are areas of similar ecosystems including geology, soil, vegetation, climate, wildlife, hydrology, and land use (Omernik, 1987, Figure 9). Federal agencies, like the Environmental Protection Agency (EPA), developed ecoregions for the implementation of ecological management strategies. Ecoregions are broken down into four levels depending on the degree of detail desired. In the Teton Watershed, the level 3 ecoregions include the Middle Rockies and Snake River Plain. When zoomed into the level 4 ecoregions there are areas of Alpine, Subalpine, Mid-elevation Mountains, Dissected Plateaus and Teton Basin, Partly Forested Mountains, Yellowstone Plateau, and the Upper Snake River Plain all within the watershed. These ecoregions characterize and define the habitats and wildlife present throughout the watershed.

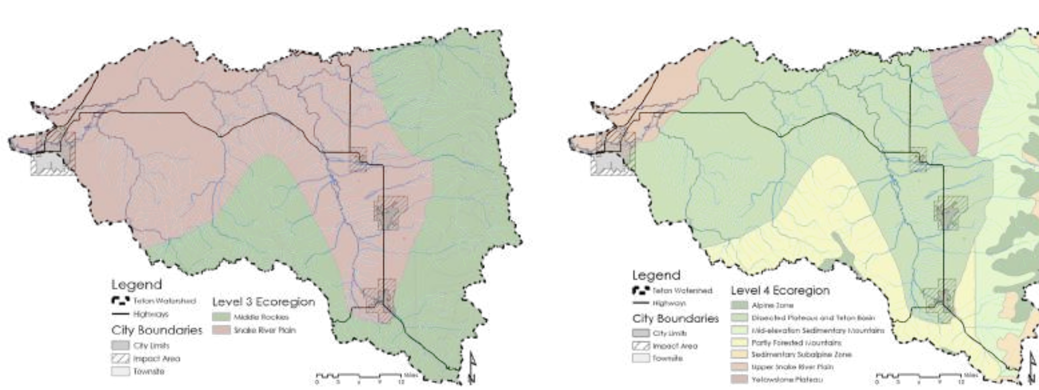


Figure 9. Level 3 and Level 4 Ecoregions within the Teton Watershed.

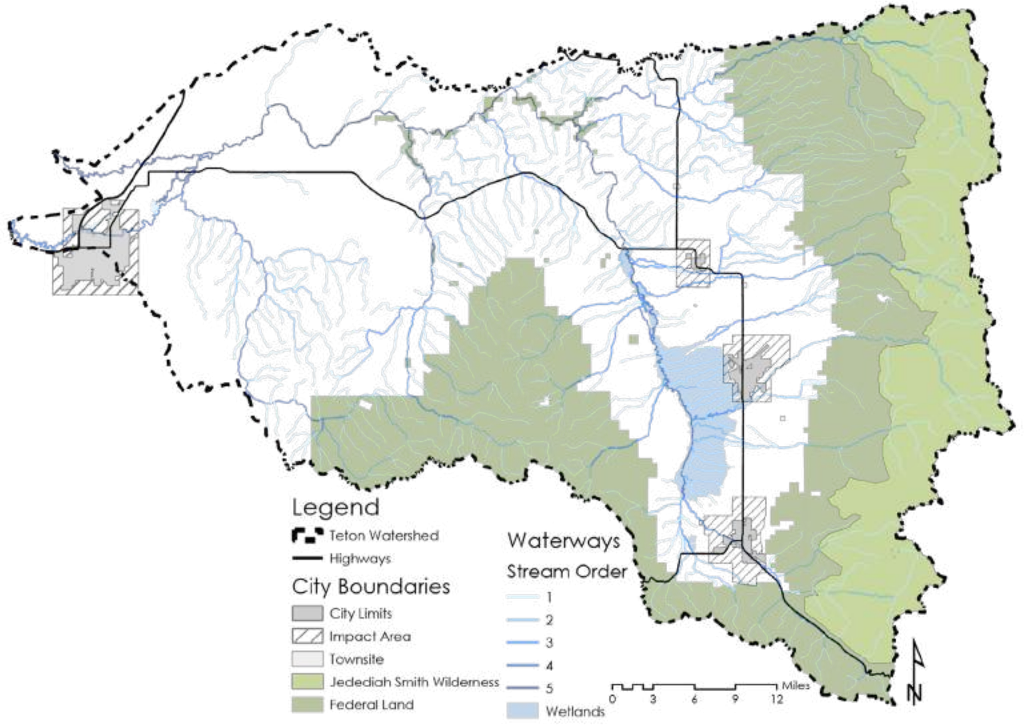


Figure 10. Natural features and federal land.

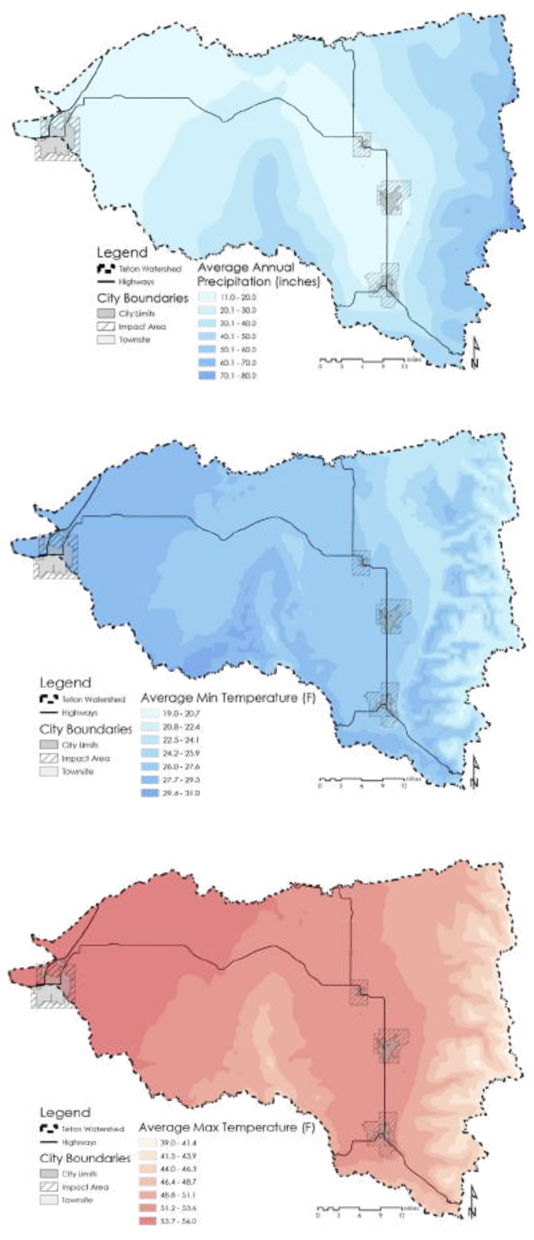


Figure 11. Average annual precipitation, average annual high temperatures, and average annual low temperatures.

There are many fish and wildlife species within the Teton Watershed across the various habitat zones (Image 1). This includes many big game animals that are recognized as significant to local culture and economy because of their value to local and regional hunters (IDFG, 2012). Idaho Fish and Game (2012) has specifically mentioned that mule deer (*Odocoileus hemionus*) is a keystone species for the area as they act as key indicators about habitat health within the region. Other important mammals in this area include the federally threatened carnivores Canada lynx (*Lynx canadensis*) and Grizzly bear (*Ursus arctos*). Additionally, the National Audubon Society (2006) has appointed the Teton Basin as an Important Bird Area (IBA) within the state for the protection and conservation of various species including Columbian sharp-tailed grouse (*Tympanuchus pasianellus*) and Greater sandhill cranes (*Grus canadensis*). Sport fishing is also prevalent in the Teton basin with Bitch Creek in the northern part of Teton county having some of the best conditions for fishing for Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*) (IDFG, 2012). Also notable, are the 26,760 acres of wetlands within the basin, as chosen by the National Wetlands Inventory that includes marches, sloughs, wet meadows, and willow thickets that hold many rare plants and animal species (National Wetlands Inventory, U.S. Fish and Wildlife Service, 1993). The diverse range of fish and wildlife in the Teton basin are unique and important to protect from becoming threatened or endangered.

Image 1. Wildlife species commonly found within the Teton Watershed.

The Teton watershed is an area experiencing rapid growth due to its unique landscapes and recreational opportunities. As cities expand and roadways become busier, it is imperative to analyze and address the impacts of growth on the landscape and adapt to prevent the endangerment of the natural habitats within the Teton area.

1.5 Genes By Environment: Modeling, Mechanisms and Mapping (GEM3)

The National Science Foundation (NSF) Established Program to Stimulate Competitive Research (EPSCoR) Genes by Environment: Modeling, Mechanisms and Mapping (GEM3) project (funding award OIA-1757324) in Idaho seeks to explore how organisms adapt to changing environments in order to inform future management practices (Idaho GEM3). This research combines both researchers with strengths in bioinformatics, complex modeling, ecology, fisheries science, genomics, geospatial science, remote sensing, and social-ecological science (SES) as well as an abundance of local knowledge garnered from stakeholder advisory groups (SAGs). The GEM3 project will evaluate scenarios using Geodesign based on the robust methodology developed by Carl Steinitz (Steinitz, 2012) to model alternative futures for Owyhee and Teton County in southern Idaho. These models intend to simulate various alternative futures depending on separate, but related, variables encompassing historical, economic, cultural, social, ecological, and constructed systems through time and space throughout the region.

Within the Teton Valley, researchers have met with the SAG to identify core themes and parameters for scenario development through workshops and interviews to gain a deeper understanding of the area. The first round of draft scenarios have been created and will be reviewed by stakeholders along side geospatial scenarios for future development. The three scenarios developed for the Teton area are: 1) Keep Teton Valley Wild, 2) Recreation Sprawl, and 3) Sustainable Mountain Community. General themes across these scenarios are growth, recreation, and wildlife habitat. The alignment between the GEM3 project and this research will center around growth impacts over time, under the SAG defined scenarios, on habitat change and how to mitigate the negative effects of urban expansion on wildlife movements, specifically wildlife-vehicle collisions.

1.6 Goals and objectives

Through a mixed-methods approach, driven by the framework provided in the Teton Wyoming Wildlife Crossings Master Plan (2012), this project intends to a) analyze, b) plan and design, c) evaluate, and d) revise a set of solutions to address habitat issues within Teton Valley in Idaho by answering the question:

How can conservation best management practices improve habitat connectivity for wildlife species and reduce wildlife-vehicle collisions across roadway infrastructure in the Teton watershed?

The goals and objectives of this project are to:

1. Locate high priority road sections for the implementation of mitigation measures within the Teton region.

    a. Locate high densities of vehicle-wildlife collisions – "hot spots" through the use of spatial analysis tools

    b. Locate critical habitats for species survival that are bisected by roadway infrastructure by evaluating species range maps

    c. Identify the most at-risk species for road mortality by exploring species abundance and range maps in relation to collision "hot spots"

2. Identify mitigation measures that can be used to promote multi-species movement and decrease wildlife-vehicle collisions.

    a. Consider the cost-benefit of each mitigation measure at a given location

Chapter 2: Road Ecology and Crossing Structures

This chapter explores the literature focusing on road ecology, barrier effects and specifics about roadway crossing structures and devices were explored for their purpose and general applicability to this project. This chapter also looks at how locations are selected for interventions through a case study analysis. Subsequently, this chapter evaluates which species could be targeted by each crossing type.

2.1 Road Ecology

The public road system in the United States covers approximately 4-million miles and accounts for nearly 1% of all land area (Clevenger and Huijser, 2009). When considering the broader environmental impacts of roadways, it has been estimated (Forman, 2000) that roads affect nearly 20% of the land area within the U.S. (Figure 12). Increase in road densities have naturally led to an increase in motorist-wildlife conflicts by nearly 50% between 1990 and 2004 (Huijser et al., 2018). Roads affect species by destroying key habitats and fragmenting the landscape and ultimately, through the barrier effect, prevent species from travelling between habitats necessary for survival (Clevenger and Huijser, 2009). Not only do roadways impact wildlife through habitat manipulation, but wildlife-vehicle collisions contribute to the majority of wildlife mortality and pose as a safety concern for motorists (Clevenger and Huijser, 2009). Annually, there are nearly one to two million large mammal-vehicle collisions causing an estimated 211 human fatalities, 29,000 human injuries and costing nearly one billion dollars in property damage (Huijser et al., 2018). This high number of collision and fatalities is the driver behind the need for more effective wildlife crossing structures.

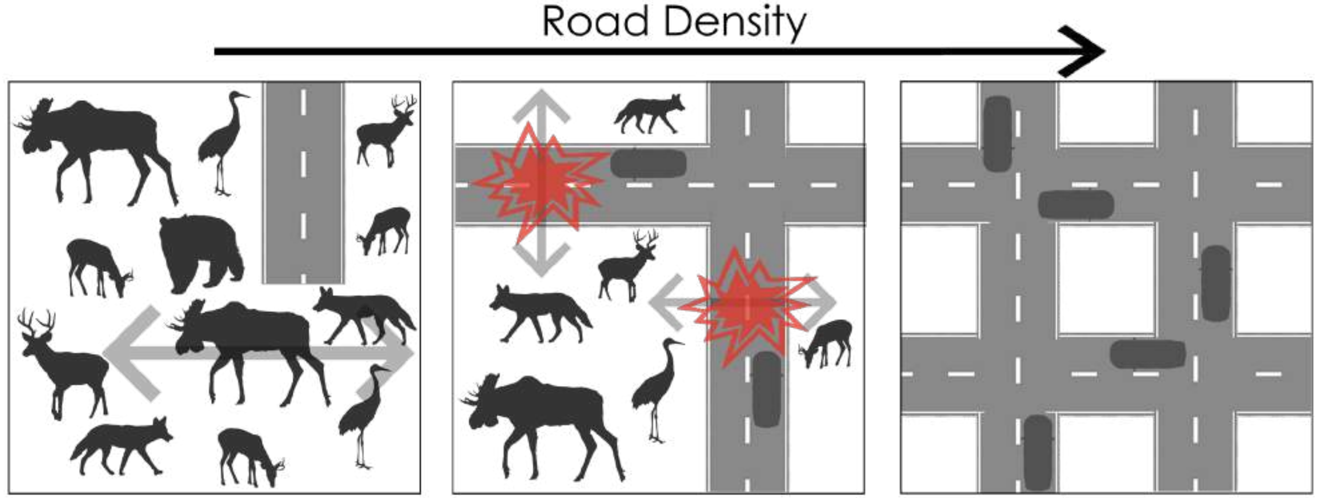


Figure 12. As road densities increase, wildlife populations become more fragmented.

2.1.1 Avoidance, Compensation, Mitigation

When a new road is being implemented, or an existing road is being expanded, it is important to consider the design approach to determine whether a crossing structure is warranted. Three approaches to address are: avoidance, mitigation, or compensation (Huijser et al., 2018, Figure 13). When possible, avoidance of critical habitat and migration areas should be the first choice (Huijser et al., 2018). To do this, the extent of proposed roadway should be evaluated, and any areas of concern should be avoided all together by rerouting the proposed roadway to prevent any conflicts (Clevenger and Huijser, 2009). Many existing roads were developed long before the ecological impacts were known and thus, many current road networks have been implemented in areas that have proven to be detrimental to some species (Forman and Alexander, 1998). Areas that are not evaluated for potential ecological effects are subject to have higher barrier effects and the potential to create genetic isolation between smaller populations of species resulting in a higher possibility of extinction of those metapopulations (Forman and Alexander, 1998). With the information available today, it is widespread practice to consider all the environmental impacts of roadways and when avoidance isn't possible, compensation and mitigation efforts are the next best option.

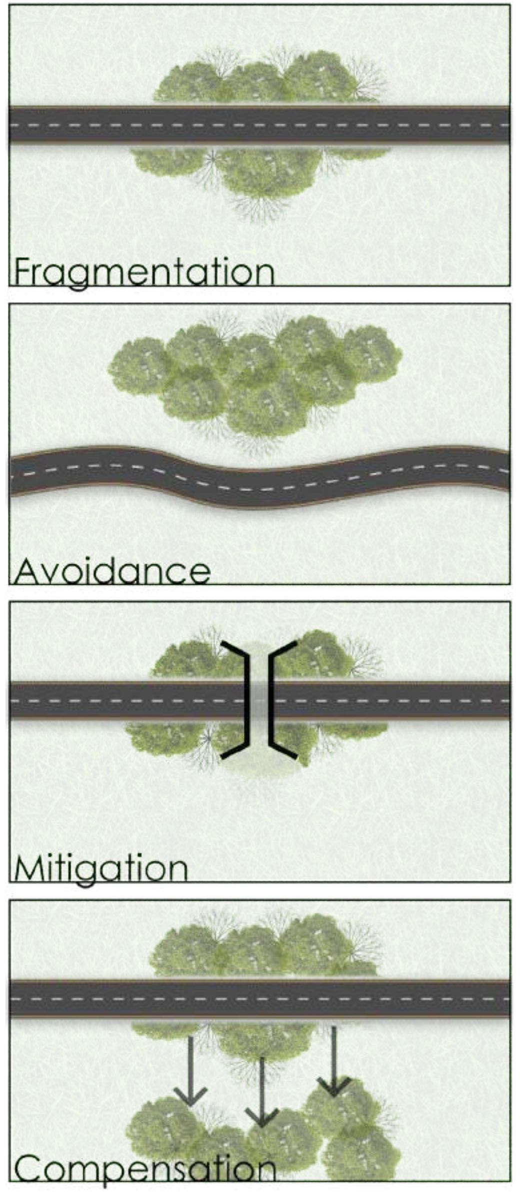


Figure 13. Three design considerations for roadway development; avoidance, mitigation, and compensation.

Mitigation attempts to lessen ecological impacts of roadways through the implementation of wildlife crossing features such as warning signs, active detection signs, crossing structures and/or reduced speed zones (Clevenger and Huijser, 2009; Forman and Alexander, 1998). This approach aims to reduce wildlife-vehicle collisions and lessen the barrier effect (Huijser et al., 2018). Mitigation measures aim to aid in the movement of animals between habitat patches to reduce genetic isolation and improve migration between crucial habitats. Most crossing structures, whether they are overpasses or underpasses, including tunnels, are combined with fencing and proper vegetation in order to be most successful for the target species (Forman and Alexander, 1998). In Banff National Park, grizzly and black bears were studied for a three-year period to determine any patterns of use of wildlife crossing structures. Researchers found that many observations of the bears uncovered a seasonal relationship between foraging habits in riparian areas between the highway and Bow River and concluded that the wildlife crossings were important for access to seasonal food resources for those species (Sawaya et al., 2013). This suggests that mitigation efforts can be effective at providing access to crucial habitats for various species.

The compensation approach looks to lessen the impacts at a particular section of roadway that cannot be overcome by mitigation efforts. This may include practices such as increasing existing habitat patches, creating new habitat patches, or improving the connectivity between species away from the proposed roadway design (Huijser et al., 2018; Forman and Alexander, 1998). Another term used to describe compensation is biodiversity offsets or the minimize technique (Chee, 2015). Generally, this technique should be used at a concerted but final attempt to compensate for residual impacts of roadway development after a thorough investigation into avoidance and mitigation techniques have been explored (Chee, 2015). The main goal of biodiversity offsets is to “achieve no net loss and preferably a net gain of biodiversity on the ground with respect to species composition, habitat structure, ecosystem function and people’s use and cultural values associated with biodiversity” (BBOP, 2009). It should also be noted that some impacts cannot be offset. This includes effects on endangered species, species that only occur in the proposed location, and lack of understanding of the ability for a species to thrive elsewhere (Chee, 2015). Compensation efforts have wide reached effects and are complex in nature to design and implement without proper research and evaluation of impacts on the landscape scale. By considering all design approaches the greater impacts of roadways on habitats and wildlife can be minimized to prevent large biodiversity loss.

Regardless of the type of approach taken, it has been noted that any roadway design project should include a multi-disciplinary group of agencies and individuals well-versed in road ecology, engineering, and wildlife habitat management. This is important because of the need for communication between designers and the builders. While engineers and construction contractors can reliably follow any detailed construction plans given to them, they may not fully understand the reasoning behind why certain vegetative elements are needed to ensure the effectiveness of the design (Weller, 2015). For this reason, it has been suggested that a list of key performance indicators be followed to ensure all acting parties are working together to minimize the impacts of construction and produce the most effective result (Weller, 2015). To achieve greater understanding of the environmental impacts of the project, it is suggested that educational efforts are made between ecological planners and construction teams. This can be done through site visits, “toolbox” meetings and educational materials around the work site (Weller, 2015). Weller (2015) notes that even though mitigation efforts are often seen as a waste of time and money, pointing out the benefits of preventing wildlife-vehicle collisions and the benefits to motorists’ safety can be key to raising support. Multidisciplinary approaches to roadway construction and the attention to the ecological impacts of roads can aid in the identification of areas to avoid or mitigate to prevent collisions and reduce the barrier effects on wildlife species.

2.1.2 Barrier Effects

To better understand road barrier effects, it is helpful to look at the ‘road-effect zone’ first. Historically, roads would follow the natural landscape running parallel to rivers and streams and other natural features, however, most transportation planning has changed to supply the most direct route and efficient travel between population centers (Figure 14). Because of this change many roads run through habitats and isolate populations that were once connected. The ‘road-effect zone’ is defined as the total area in which the ecological effects of roads and traffic extend into the surrounding landscape directly adjacent to the roadway (Ree et al., 2015). There are many different things that can affect the size of this zone including the road itself (the width, surface type, and elevation compared to the landscape), traffic volumes and speed, the characteristics of the surrounding landscape, prevailing winds, and species sensitivity to roads (Ree et al., 2015). It has been shown in studies conducted in the Netherlands that traffic noise impacts sensitive bird species, and the effects can be seen over 10-20% of the land area (Forman and Alexander, 1998). Road density, the abundance of roads within a given area, can also play a role in the extent of the ‘road-effect zone’ (Ree et al., 2015). In general, as road densities increase, populations decrease, especially with species with large home ranges. It has been shown that a road density of around 1mi/mi2 could be the maximum threshold for many large species including cougars (*Puma concolor*), moose (*Alces alces*), and bears (Forman and Alexander, 1998). At the landscape-scale, ‘road-effect zones’ impact every aspect of the landscape away from roads and plays a significant role in the decisions made about mitigation efforts to reduce wildlife-vehicle collisions.

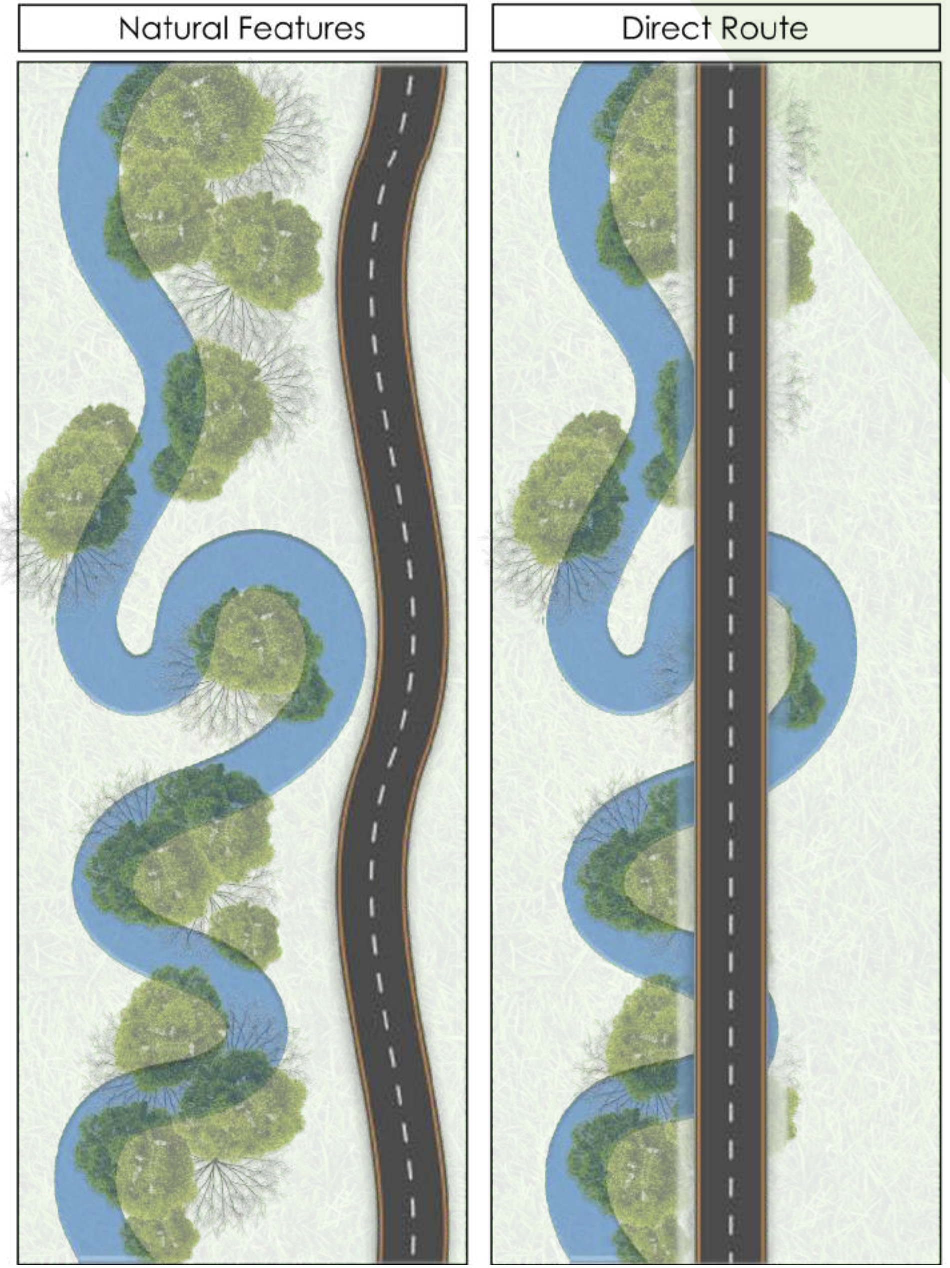


Figure 14. Roadways historically followed natural land formations and direct routes cut through natural features.

Roads have five different ecological functions that affect wildlife in the ‘road-effect zone’: roads can function as habitats (could hold entire populations), sources (some populations thrive in linear habitats), sinks (high mortality rates), barriers (disruption of movement) and conduits (movement parallel to roads) (Clevenger and Huijser, 2009). These functions are important to consider when considering the greater impacts of the roadway on the surrounding landscape (Figure 15). Roads can affect wildlife through a change in habitat via habitat loss (conversion of land to roads, increase of habitat edge), diminished habitat quality (increased noise), and improved habitat quality (construction barriers can improve food quality) (Clevenger and Huijser, 2009). As an example, some snake species are attracted to roadways because of easy prey availability and warmth (Clevenger and Huijser, 2009). Roads can also change the distribution of wildlife through barrier effects (cutting off one habitat from another), corridor functions (right-of-way habitats), and mortality (wildlife-vehicle collisions) (Clevenger and Huijser, 2009). These qualities of roadways and their impacts at the landscape-scale are drivers for selection of road sections for the implementation of wildlife crossing structures. While the “road-effect zone” categorizes the impacts of the great landscape in relation to roadways and traffic, barrier effects consider the direct impacts at the site scale that roads have on wildlife.

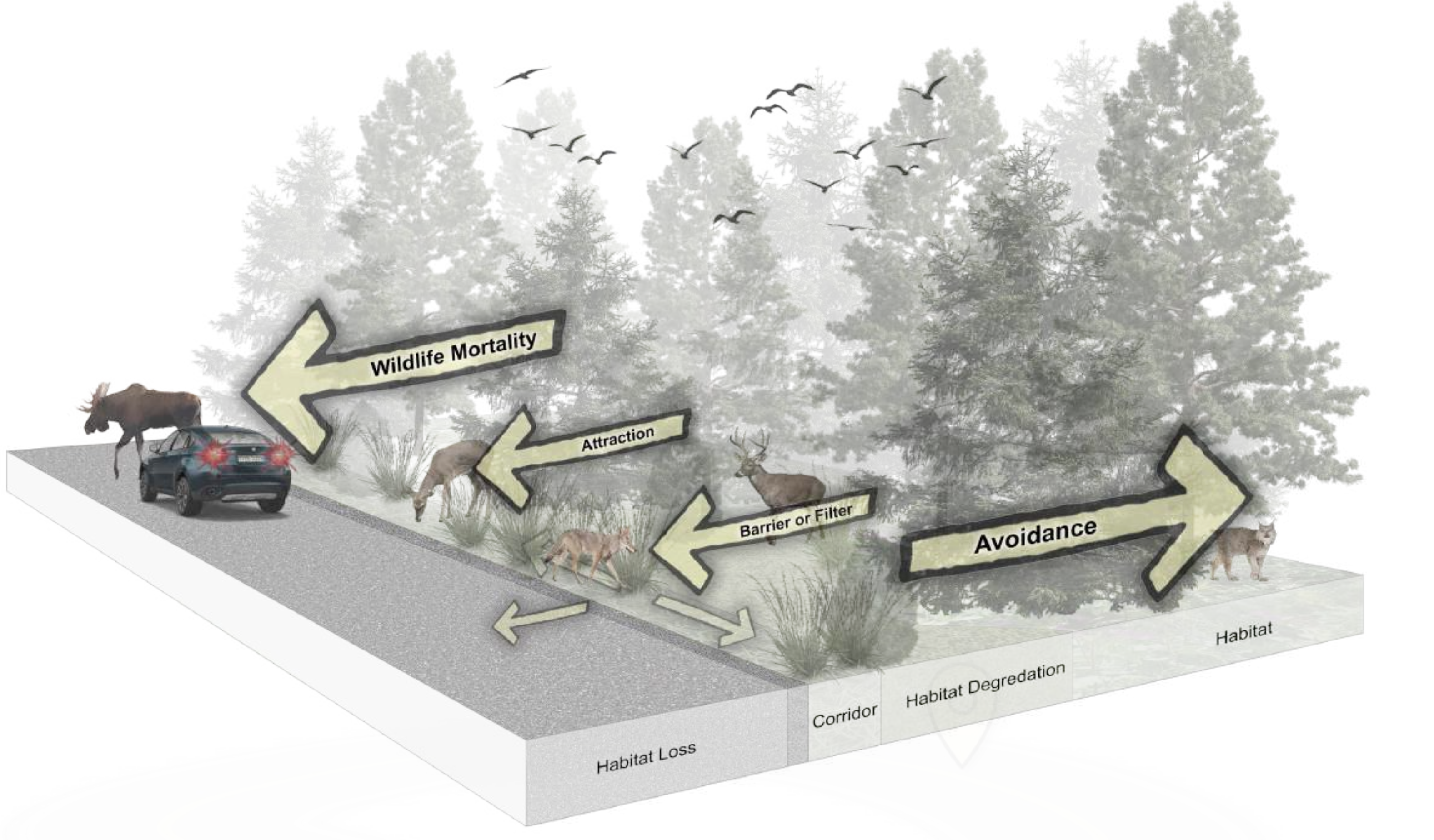


Figure 15. Ecological impacts of roadways to wildlife.

Barrier effects are directly related to the ways in which roads prevent movements between landscapes. Landscape connectivity is described as the degree in which a landscape allows animal movement and other ecological processes to flow naturally (Clevenger and Huijser, 2009). Barriers impede connectivity and reduce the ability of free movement. Almost all roadways serve as barriers to movement in one way or another. Roadway width and traffic density are the two major factors in determining barrier effects (Forman and Alexander, 1998). The greatest roadway barriers tend to be those that have high volumes of vehicles and high-speed limits (Clevenger and Huijser, 2009). Roads that bisect and fragment the landscape isolate populations into smaller groups called metapopulations (Figure 16). The separation of larger population groups alters the genetic composition of those populations due to isolation that can persist over many generations (Forman and Alexander, 1998). This isolation increases the chance of extinction of that metapopulation and prevents recolonization due to the difficulty of other animals to reach that area (Forman and Alexander, 1998). Maintaining landscape level connectivity is important for species that require a variety of habitats for seasonal biological needs, like foraging and mating, as well as reducing the risk of genetic alterations through inbreeding as a result of becoming a small isolated metapopulation (Clevenger and Huijser, 2009). The greater effects of roadways and the way they function as barriers to movement is essential for understanding how the construction of roads can impact the landscape and wildlife species directly. By evaluating roadway effects, methods and decisions about reducing wildlife-vehicle collisions can be evaluated to aid in the reduction of negative impacts to wildlife species and landscape functions.

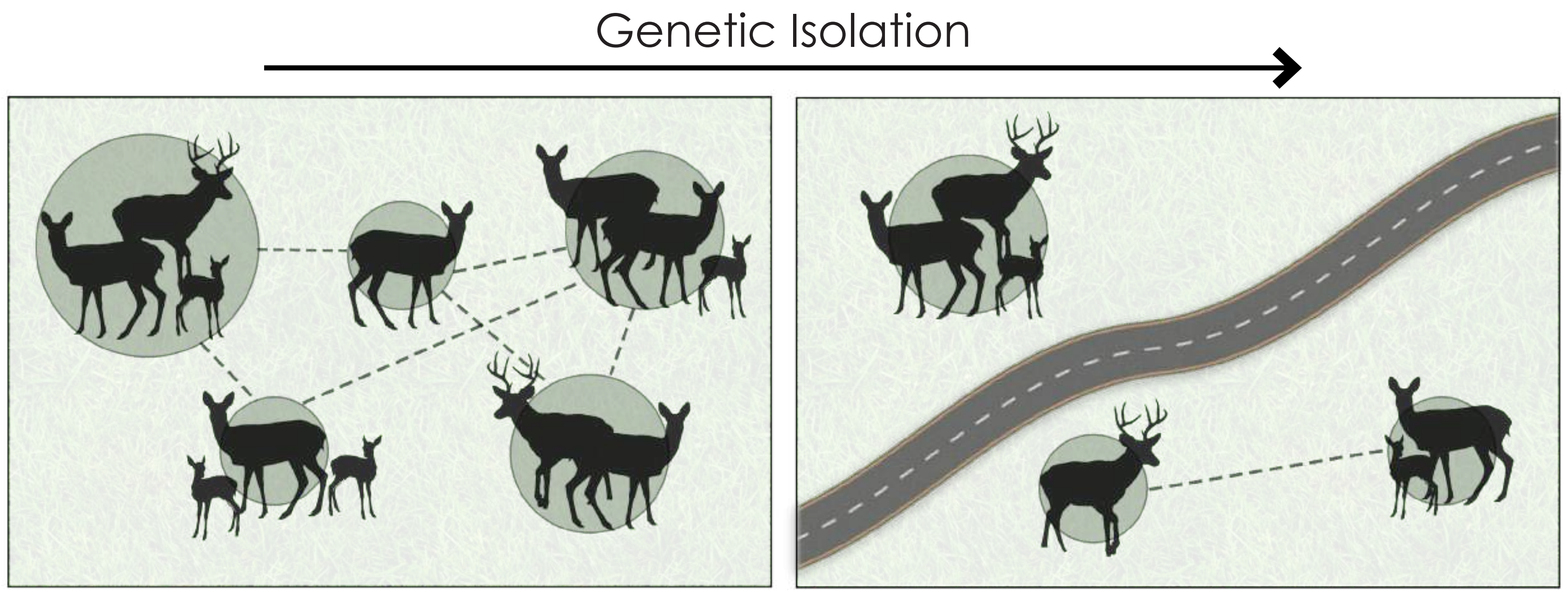


Figure 16. Roadway development can separate populations and cause genetic isolation.

2.1.3 *Wildlife-Vehicle Collisions*

Collisions with wildlife have been becoming more prevalent and the immediate and indirect impacts of those collisions are wide ranging (Figure 17). While most people associate WVCs with rural areas, in the 2008 Report to Congress (Huijser et al.) it was found that two-lane highways that serve as critical corridors between cities are also areas where a high percentage of collisions occur. Between 2001 and 2005, 89% of all WVCs occurred on two-lane roads (Huijser et al., 2008b). While it is difficult to account for all collisions involving wildlife, estimates take into consideration crash statistics from police and highway patrol agencies, carcass counts, insurance claims, and public interviews (Huijser et al., 2008b). Even with all these sources, collisions can still be under reported due to non-significant damages, or the animal does not die directly because of the accident. For example, many crash databases will not record accidents that do not exceed $1,000 in damages and some agencies do not have the tools to accurately collect information about WVCs (Huijser et al., 2008b). Additionally, some collisions, including single-vehicle accidents with determined causes such as "collisions with roadside objects" (such as trees) that result in death may have been caused by the driver swerving to miss wildlife in the road (Ree et al., 2015). Regardless, the information available on the impacts to human safety and economics and to wildlife population health is key to understanding why the prevention of collisions is necessary.

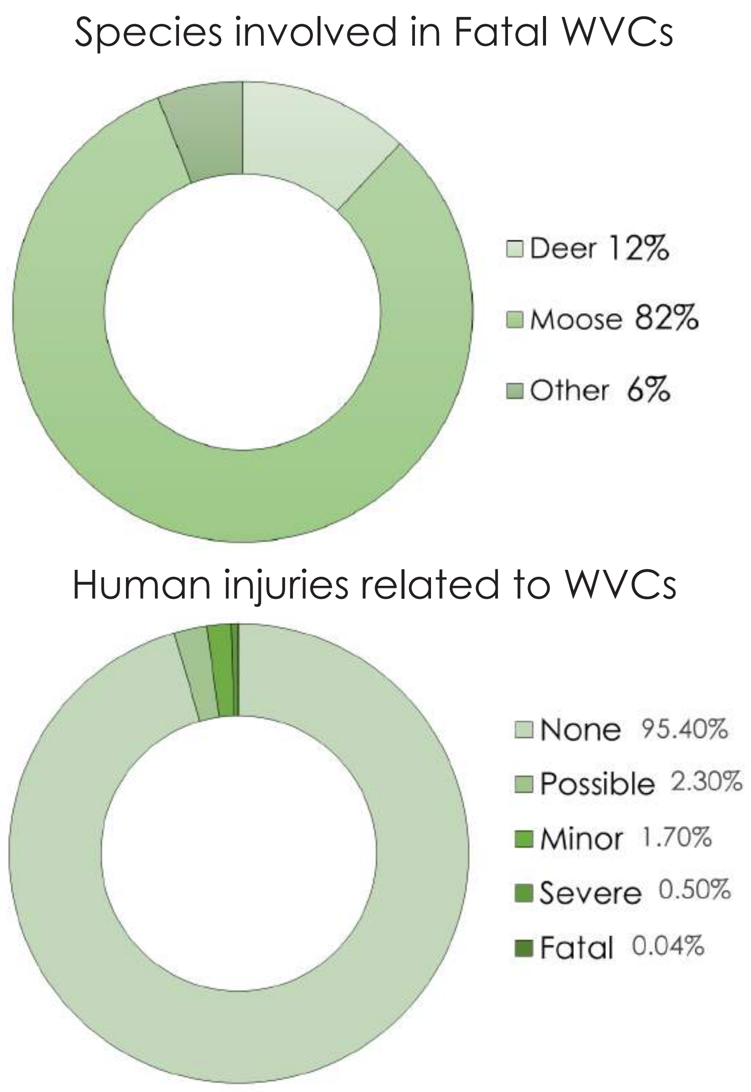


Figure 17. Species involved in fatal wildlife-vehicle collisions and human injuries related to WVCs (adapted from Huijser et al., 2008b)

As discussed, roads create barriers to movement for many species and in turn, where wildlife decides to cross roadways there is a potential for a conflict with motorists. It is estimated that of the up to 2 million WVCs annually, the majority (95.4%) do not result in human injury (Huijser et al., 2008b). In the United States the majority of wildlife collisions (up to 90%) involve deer and are most likely to occur in the early mornings (5-9am) and evenings (4pm – 12am) when wildlife is most active and traffic volumes are high due to work commutes between cities (Huijser et al., 2008b). Additionally, seasonal variations can act as indicators for when collisions are more likely to occur. In spring and fall, when many species are migrating for foraging and mating opportunities there is often a spike in WVCs (Clevenger and Huijser, 2009; Huijser et al., 2008b). Locations of these collisions vary, but most often they occur in areas of regular wildlife activity where roadways have impeded movements between habitat patches and in drainages where wildlife often move in parallel to streams or rivers (Forman and Alexander, 1998). Increases in collisions over time has also been correlated with increased vehicle miles travelled (VMT) and large increases in deer populations (Huijser et al., 2008b). There are many factors that play a role in collision likelihood and the impacts of these collisions effect humans and wildlife differently.

Traffic volume and designed speed play a key role in mortality rates (Figure 18). Low traffic volumes (less than 2500 annual average daily traffic [AADT]) show low mortality rates and animals are generally repelled by roadways, while high traffic volumes (more than 10,000 AADT) show that only a small portion of attempted road crossings are successful and that there is a higher likelihood of an animal being repelled due to traffic (Clevenger and Huijser, 2009). A study conducted by Huijser et al. (2018) evaluated the effectiveness of wildlife crossing signs along highways and determined that speed played a huge role in the ability of motorists to stop before hitting wildlife, even when warning signs were in place. In Florida, a large carnivore, the Florida panther (*Felis concolor coryi*) was experiencing a roadway mortality rate of 10% of its entire population and only when mitigation efforts were introduced did that rate fall to 2% (Forman and Alexander, 1998).

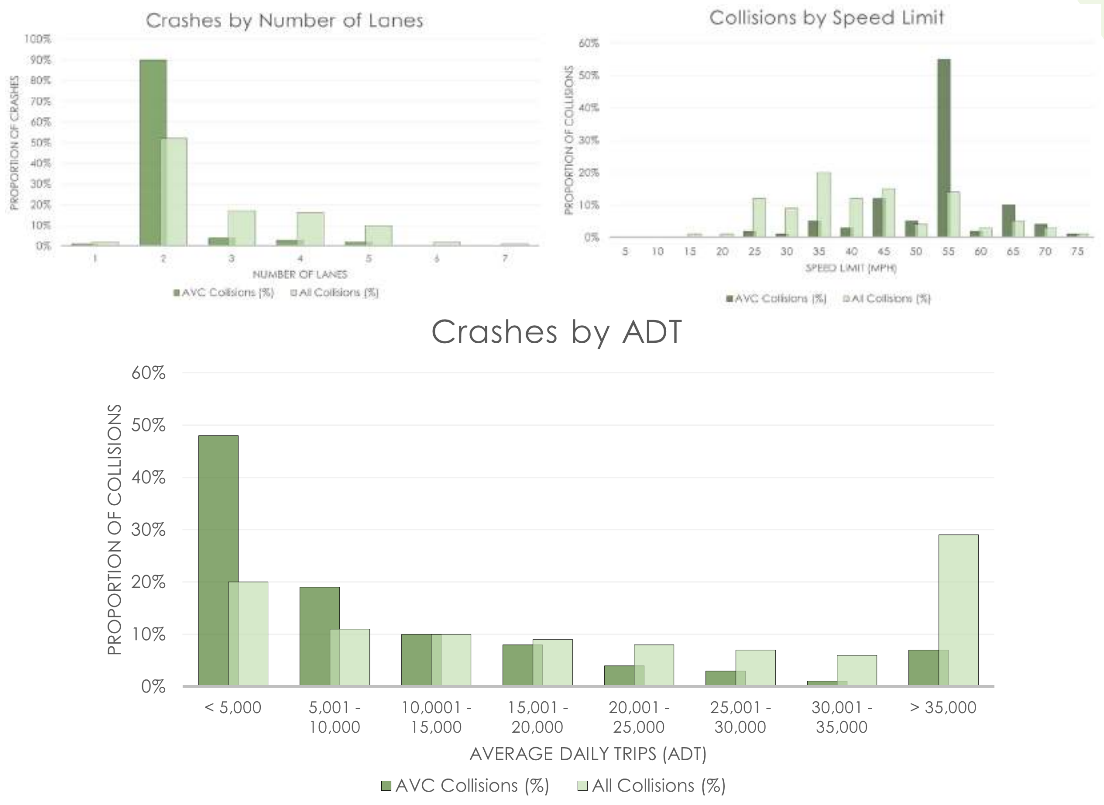


Figure 18. Crashes by number of lanes, speed limit and average daily trips (adapted from Huijser et al., 2008b)

The direct impacts to humans that are involved in WVCs includes safety risk and monetary loss. While it is more common for collisions involving wildlife to not cause injury, in some cases, including those involving large mammals like moose and elk, there is a higher chance of severe injury or death. It has been reported that between 4-10% of reported WVCs that involve large mammals result in serious injuries totaling roughly 26,000 injuries annually (Huijser et al., 2008a). Fatality collisions with wildlife only account for 0.5% of all WVCs, however, this is still nearly 200 people annually and in a span between 2001 to 2005, the Report to Congress (Huijser et al., 2008b) found that 38,493 fatal crashes had occurred. Unfortunately, because collisions with wildlife are widely under reported, these numbers are likely much higher.

As mentioned earlier, the total estimated cost of collisions involving wildlife in the United States costs approximately $1 billion in property damages annually. The monetary impacts of collisions with wildlife were explored in depth by the researchers and contributors of the 2008 Report to Congress and include damages to vehicles, agency fees, towing, medical care and lost wages due to accidents (Table 1). It was found that 90% of collisions with deer and nearly 100% of collisions with large mammals result in damage (moderate to substantial) to the vehicle. It was estimated that the costs to repair a vehicle after a collision with a deer was around $1,840 and with an elk or moose was $3,000 and $4,000 respectively. Additionally, drivers may encounter other costs related to the accident including an estimated $125 in towing fees, and average of $2,702 in medical fees, and an undetermined amount of money in lost wages due to inability to return to work following an accident. Local public agencies are also impacted by WVCs. Law enforcement agencies experience fees related to the cost to investigate the accident and the time to manage traffic and clear the scene after an accident. Transportation agencies are usually responsible for disposal of the carcass and to make any necessary repairs to the roadway to keep the area safe for drivers. Finally, other public entities such as fish and game, national and state parks and conservation groups may lose the value of the animal itself in terms of hunting license fees, recreational attraction to the area and wildlife viewing, depending on the species. Overall, it is estimated that WVCs cost an average of $8.3 billion annually and accounts for the single largest category damages for humans and vehicles (Huijser et al., 2008b).

Description	Deer (2007 USD)	Elk (2007 USD)	Moose (2007 USD)
Vehicle repair costs per collision	$2,622.00	$4,550.00	$5,600.00
Human injuries per collision	$2,702.00	$5,403.00	$10,807.00
Human fatalities per collision	$1,002.00	$6,683.00	$13,366.00
Towing, accident attendace, and investigation	$125.00	$375.00	$500.00
Hunting value of animal per collision	$116.00	$397.00	$387.00
Carcass removal and disposal per collision	$50.00	$75.00	$100.00
Total	$6,617.00	$17,483.00	$30,760.00

Table 1. Average cost of collisions with deer, elk, and moose circa 2007 (adapted from Huijser et al., 2008b).

Aside from the monetary impacts to humans involved in collisions with wildlife, there are other indirect factors that are difficult to quantify but are important to consider. In relation to the collision, travel delays that occur because roads need to be closed or rerouted impact other motorists on the road (Huijser et al., 2008b). Additionally, for motorists approaching the scene immediately following the collision, there is a possibility of secondary collisions if the animal is in the right of way or vehicles cannot stop in time to avoid the original vehicle involved (Huijser et al., 2008b). Finally, in addition to the physical trauma of experience a collision, emotional trauma can occur because of the accident and the unintentional killing of a large animal (Huijser et al., 2008b). The direct, monetary, and indirect impacts of WV's on motorists is an important part of the puzzle as to why and how mitigation measures for safe crossings can reduce fatalities and the economic strain of collisions.

The impacts of collisions on wildlife can be even greater than those on humans but are often more difficult to assess. Forman and Alexander (1998) note that at some point mortality related to collisions with vehicles has likely surpassed hunting activities as the number one source of mortality for vertebrates. Reduction of wildlife movements and increases in road related mortality for wildlife have been shown to reduce population viability over the long term (Clevenger and Huijser, 2009). Road mortality in combination with urbanization, fragmentation, and habitat loss due to agricultural activities also affect the long-term survivability of species (Huijser et al., 2008a). Not all species are affected in the same way. Generally speaking, deer populations in most of the United States are at an all time high and thus high mortality rates are not a significant issue. However, for many threatened and endangered species, any added mortality to their dwindling populations can have major effects (Image 2). The 2008 Report to Congress identified 21 federally listed threatened or endangered species that experience the greatest threat of extinction from road related mortality (Huijser et al., 2008b). For these reasons, it is paramount to reduce the frequency of WVCs to prevent the further endangerment of those species most at risk and to not at to that list of species on the brink of extinction.

Image 2. Canada lynx and grizzly bears are the only two mammalian species in the Teton Watershed that are federally and/or state listed threatened species.

There are two broad ways in which wildlife-vehicle collisions could be reduced: influencing wildlife behavior through various tactics including, but no limited to, fencing and over- and underpasses, and modifying motorist behaviors by reducing speeds, education, and warning systems. Influencing wildlife behavior can be achieved through use of mitigation techniques to deter animals from entering the roadway at certain points and funneling them to areas of safe crossing locations. Fencing and crossing applications must be carefully considered to not increase the barriers to movement and to work with the natural flow of the landscape (Huijser et al., 2008a). Aside from providing safe crossing locations, wildlife culling could be an option, usually only with deer. Culling is the substantial reduction of wildlife through hunting or targeted mortality methods to reduce the reproductive potential of the population (Huijser et al., 2008a). This method has not been widely studied on its efficiency, however, in Minnesota, a small-scale test showed that a culling program reduced the deer population density by 46% and deer-vehicle collisions by 30% (Huijser et al., 2008a). Since culling has not been widely studied on its effects on WVCs it is assumed that culling practices would need to be repeated periodically to ensure populations remain small and it is unlikely for this technique to reduce collisions greater than 50% (Huijser et al., 2008a). Finally, culling operations generally have a negative response from the public and therefore, do not act as a highly regarded method for reducing collisions (Huijser et al., 2008a). Combinations of fencing and crossing structures for influencing wildlife behavior are the best options for reducing collisions.

Modifying motorist behavior involves providing information to the driver about reducing chances of collisions with wildlife. Public education can inform people on ways to increase their awareness of wildlife while driving in certain areas, identify areas where wildlife might try to cross, and educate them on the times of year in which wildlife might be more active (Huijser et al., 2008a). In addition to education, the implementation of animal detection and warning systems can actively inform motorists of where and when wildlife might be on the roadway to increase their alertness to their surroundings. Detection systems are still considered experimental, however, preliminary studies in Switzerland have shown that collisions with large ungulates (deer, elk, moose, etc.) were reduced by 82% across 7 study areas (Huijser et al., 2008a). These methods rely fully on the drivers to be aware of their surroundings to avoid hitting animals in the roadway, not preventing wildlife from entering the road entirely.

Combinations of changes to wildlife behavior and educating drivers to increase awareness are key to the overall reduction of WVCs across the U.S. This can be accomplished through an interdisciplinary approach between transportation and wildlife management agencies to identify key locations for safe crossing opportunities.

Behavioral Modifications - Motorist and Wildlife

Figure 19. Examples of techniques that modify motorist or wildlife behaviors to avoid WVCs.

2.1.4 Teton road ecology
Road Context in Teton Watershed

Within the Teton watershed, there are three Idaho state highways (highway 31, 32, 33), one Wyoming state highway (highway 22), and one US Interstate Highway (US highway 20). State Highway 33 is the main highway that connects from Rexburg at US highway 20, through Tetonia, Driggs, and Victor, and connects with Wyoming State Highway 22 on its way to Jackson, Wyoming. Most of the highways in this area run through croplands, over some river and creek crossings and meets with national forest in the southern part of the watershed.

Highway Speed Limits

Speeds in this area average around 60 mph with US highway 20 at 70 mph with the two lanes of traffic in each direction. All other highways have one lane of traffic in each direction. Where the minor highways meet town centers they slow to around 25 mph. Only highway 31, in the south of the watershed, has a max speed limit of 50 mph as it climbs quickly through a mountain pass (Figure 20).

Average Daily Trips

Average Daily Trips are a metric used by transportation departments to monitor the number of vehicles on the roadway for a specific set of miles. Idaho Transportation Department measures traffic counts in two ways: Automatic Traffic Recorders (ATR) and Weigh-in-Motion (WIM) devices. ATR systems are permanent roadside devices that, through various sensors, can measure vehicle volume, length, speed, and classification data (ITD, 2021). WIM devices are also permanent systems that collect axle weights along with vehicle volumes, length, and speed (ITD, 2021). In this area, highway 33 between Driggs and Victor is the most travelled section with an average up to 8,700 vehicles per day. Around Rexburg, there can be as many as 30,000 vehicle per day (Figure 20).

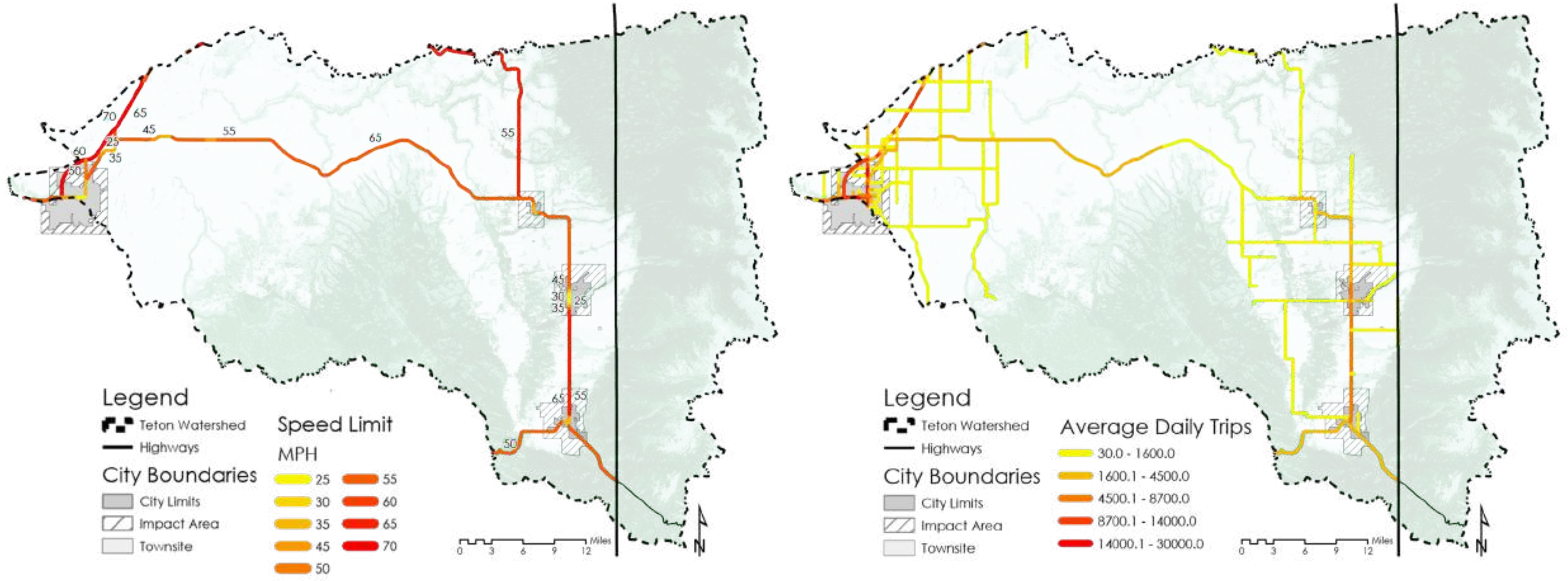


Figure 20. Speed limits and Average Daily Trips (ADT) in the Teton Watershed.

Average Commute to Work (minutes)

By examining the average commute times to work, a greater understanding of how the area highways are used by the local communities can be achieved. There is a large pocket around Victor that have higher travel times than most other places in the watershed. This could indicate that many people in Victor commute to either Driggs or Jackson, Wyoming for work. There is also an area to the northeast of Rexburg with a long commute time, suggesting those people might commute to Driggs, or another town outside of the watershed that is up to 50 minutes away (Figure 21).

Drive Times between Cities

Comparing the average commute times, with states of employment along with the average time it takes to get between each town during a 5 p.m. commute time during the week, it is clear that those people living in Victor with an average 30-40 minute commute time would be travelling the approximately 36 minutes to Jackson, Wyoming. It is also possible that some of the people outside of Rexburg with upwards of a 50 minute commute might be traveling the less than 52 minutes to Driggs. However, it is unlikely that people from Driggs or Victor are travelling to Rexburg for employment as none of the average commute times reach the threshold of 52 minutes to travel to Rexburg from either town. Finally, it is possible for many people to travel the less than 14 minutes between Victor and Driggs for work and many people who work in-state in the area travel between 0 and 20 minutes to their place of employment (Figure 22).

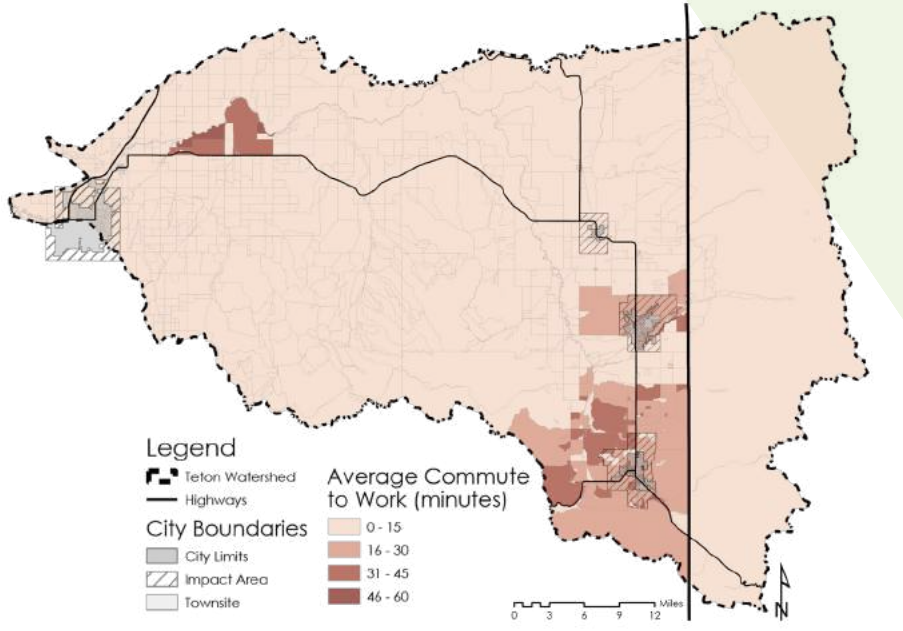


Figure 21. Average Commute time (in minutes) to work.

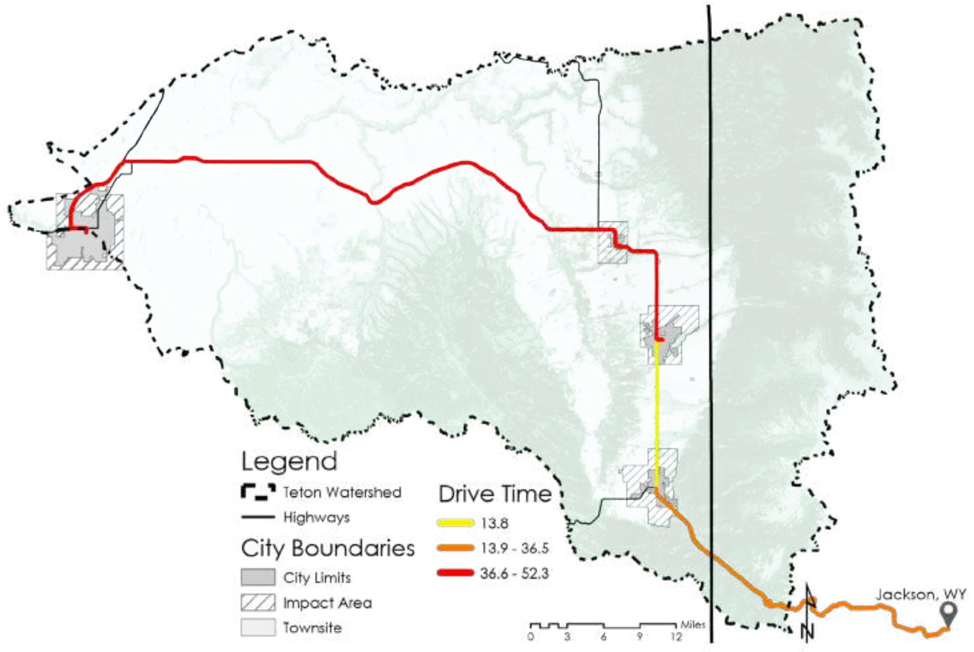
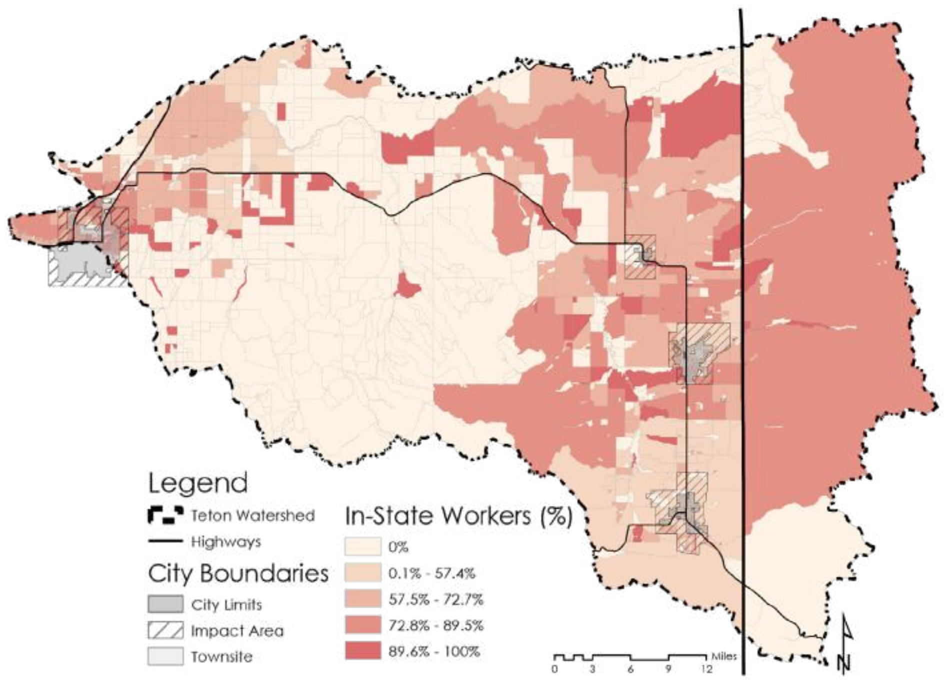


Figure 22. Drive time between major cities in the Teton Watershed.

In- and Out-of-State Workers

Data reporting commute destinations were evaluated as an indicator of how highways are used for travel. There is a relatively even spread of in-state workers throughout the Tetonia, Driggs and Victor regions. However, when looking at out-of-state workers, the area around Victor shows a larger amount of people choosing to work in Wyoming. This, in conjunction with the average commute to work, indicates that many people in Victor travel over Highway 33 towards Wyoming State Highway 22 to work in Jackson, Wyoming (Figure 23).



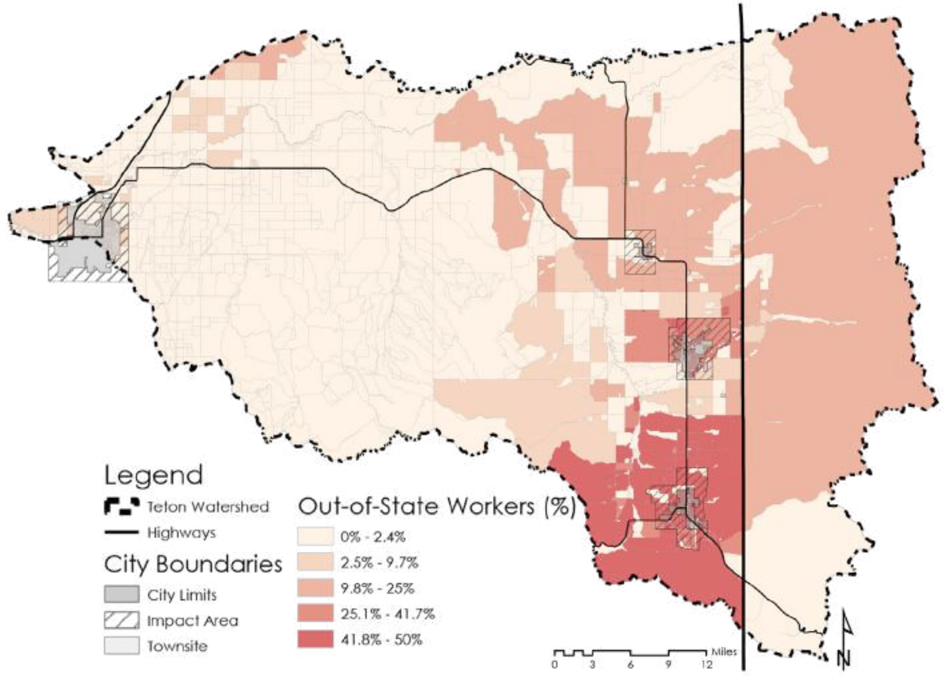


Figure 23. In and Out-of-State Workers (density).

Wildlife Highway Linkage Zones Idaho Fish and Game

In 2007, a project undertaken by the Idaho Transportation Department and Idaho Fish and Game sought to identify areas of important "wildlife linkages" in relation to Idaho highways and roads (IDFG, 2021). The report identified these linkage zones as areas important for habitat requirements and movement during migration. In the Teton Watershed there were linkages delineated for moose, mule deer, white tailed deer, black bears and other forest carnivores. These areas align with portions of highway with high AADT's and where many commuters are driving during times where they are more likely to encounter wildlife on the roads, morning and evening. This shows that careful consideration of wildlife movements across highways that are most travelled is important for motorist safety and wildlife survival (Figure 24).

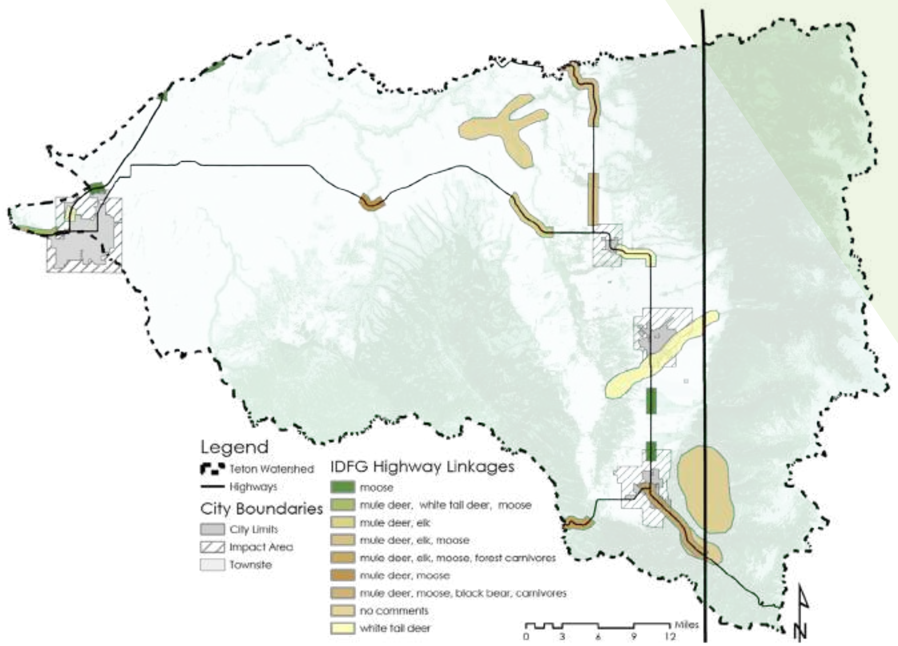


Figure 24. Idaho Fish and Game Highway Linkage Zones (IDFG, 2021).

All Wildlife Carcass Removals 2002–2021 Idaho Fish and Game

Idaho Fish and Game in partnership with Idaho Transportation Department collect data about wildlife carcass removals due to collisions with vehicles across the entire state. In the Teton watershed there is a concentration of collisions between Tetonia, Driggs and Victor as well as the are around Rexburg. This information, combined with what is known about commute times, daily vehicle trips, and key habitat linkage zones show how wildlife are impacted by increased vehicular traffic and the need for a comprehensive look at strategies to reduce wildlife-vehicle collisions (Figure 25).

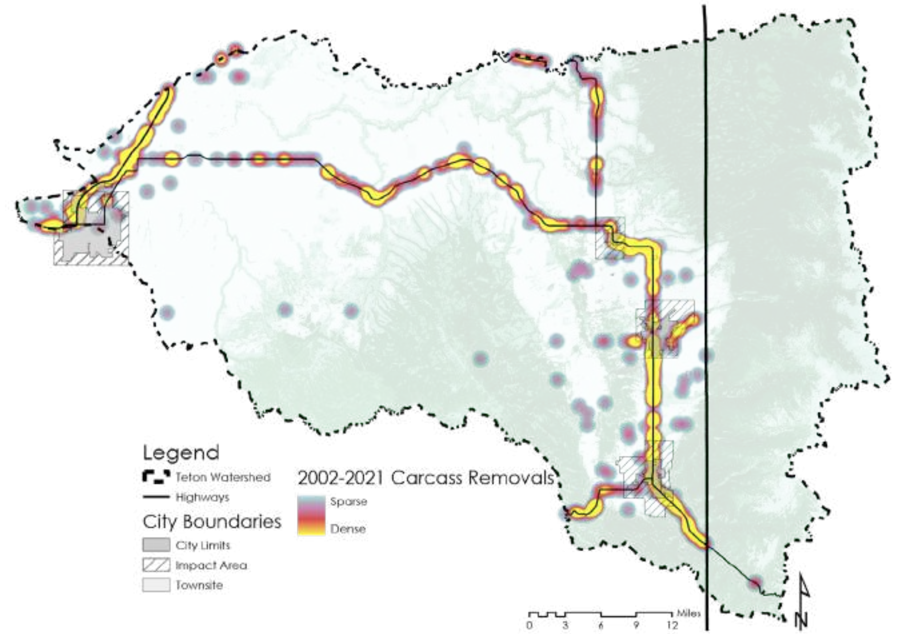


Figure 25. All wildlife carcasses removed between 2002 and 2021 (IDFG, 2021).

2.2 Crossing Structures and Detection Systems

The Handbook for Design and Evaluation of Wildlife Crossing Structures in North America by Clevenger and Huijser (2009) defines the distinct types of overpass and underpass structures for wildlife crossings and their intended purpose. It is widely used by many transportation departments, including Idaho Transportation Department, and is mentioned in the 2008 Best Practices Manual delivered to Congress, which was written in part by Dr. Clevenger and Dr. Huijser. Within the manual there are design specifications for all crossing types including usage, general guidelines, design details, variations, and maintenance considerations as well as species specific guidelines. The Best Practices Manual (2008) includes other tactics to mitigation efforts including non-structural devices such as deer whistles, olfactory repellents, and de-icing alternatives. Overall, the diverse types of methods for reducing WVCs and providing safe crossing locations have different levels of success up to 100%. In general, animal detection systems show a reduction in collisions around 82%, however, a combinations of wildlife crossing structures and fencing allowed for a sustainable 80%-99% reduction in collisions (Huijser et al., 2018; Huijser et al., 2008a). There are two key objectives for all crossing types and devices. Crossings should 1) Facilitate connections between habitats and wildlife populations, and 2) Improve motorist safety and reduce wildlife-vehicle collisions (Clevenger and Huijser, 2009). Design and implementation of functional wildlife crossings is therefore important to increase population viability, improve connection to resources needed for survival, and decrease wildlife-vehicle collisions.

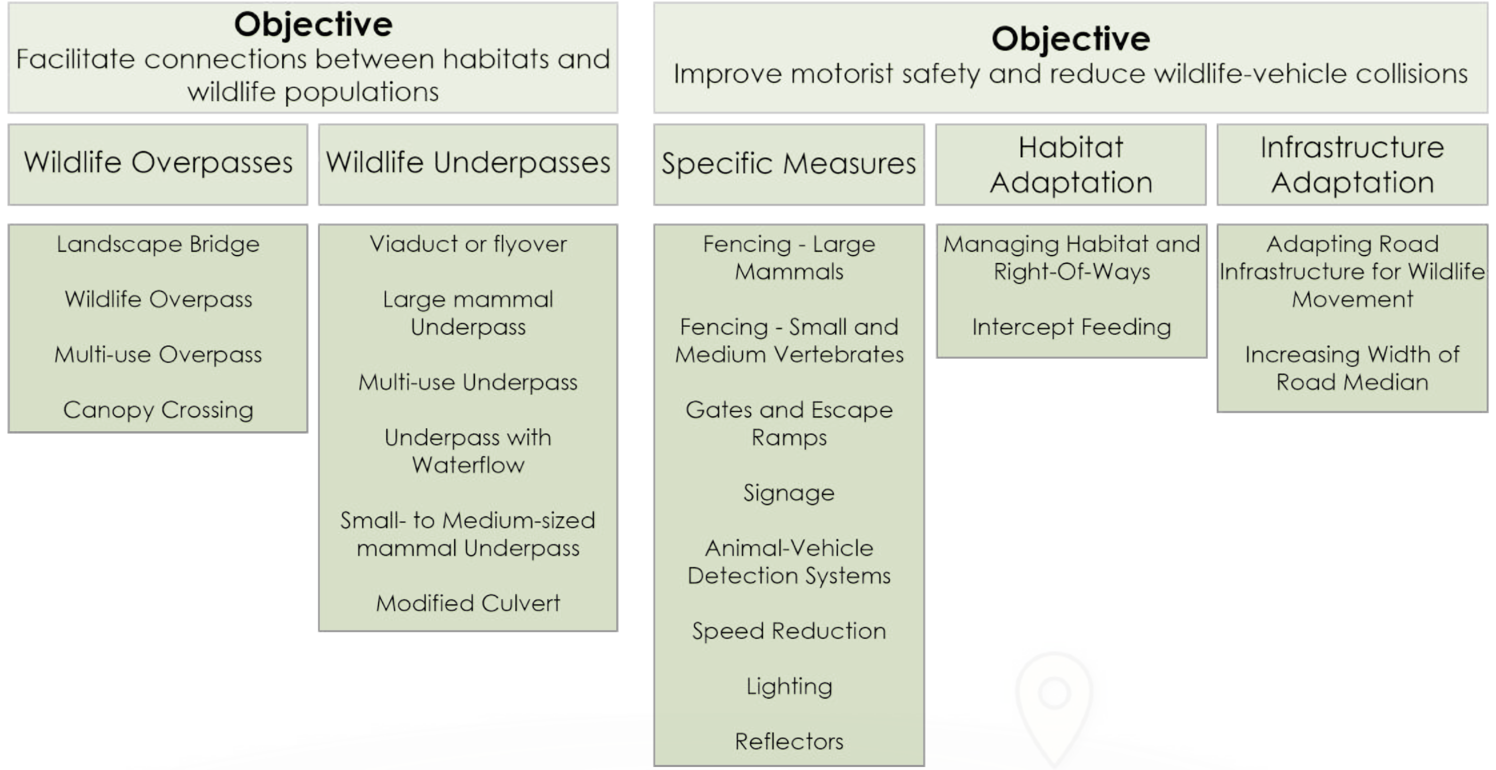


Figure 26. Types of measures used to reduce the impacts of roads on wildlife (adapted from Iuell 2005, Huijser et al., 2008b).

2.2.1 Overpasses

Overpasses are intended to provide a direct connection across a barrier, such as roads, between two areas of critical habitat or along a specific migration route needed by a target species. Acting alone, overpasses are not entirely effective at reducing wildlife from entering the roadway, however, when used in tandem with wildlife fencing, overpasses can reduce the number of WVCs by an average of 86% (Huijser et al., 2008a). In general, overpasses should be located in areas where the terrain on either side of the road is higher to allow for a more gradual approach to the road and reduce the amount of material needed to raise the bridge up high enough for traffic to move underneath (Huijser et al., 2008a). Fencing should be placed on either side of the overpass to prevent wildlife from jumping or falling off the bridge into traffic. Soil and vegetation on the overpass will depend on the target species, but in general, designs should reflect the need for various depths of soil and weight support for all vegetation (Huijser et al., 2008a). To preserve the effectiveness of the crossing over time, adjacent land use should be considered. The surrounding landscape, and in particular, the right-of-way should be secured and protected for the lifespan of the crossing structure (Huijser et al., 2008a). This time can vary depending on the crossing type, but in general, overpasses tend to have a lifetime of 75 years (Huijser et al., 2008a). In short, overpasses for safe crossing locations can be an extremely effective way to reduce WVCs, however, careful planning must be done to ensure the crossing is appropriate for the roadway, goals and objectives of the acting agencies, and the target species.

There are four main types of overpass crossings for wildlife defined by Clevenger and Huijser (2009) that can be used for wildlife exclusively or mixed-use for humans and wildlife. Landscape bridges are large bridges that allow for the greatest variety in species use. Wildlife overpasses are smaller landscape bridges that are meant to target a wide range of animals. Multi-use overpasses are the only crossings designed for both human and wildlife use and are considered the smallest of the crossing bridges. These crossing types are best suited for urban environments and for species that are considered to be generalists and are adapted to life around human disturbances. Finally, canopy crossings are designed specifically for semi-arboreal and arboreal species that use canopy cover for movement between key patches of habitat.

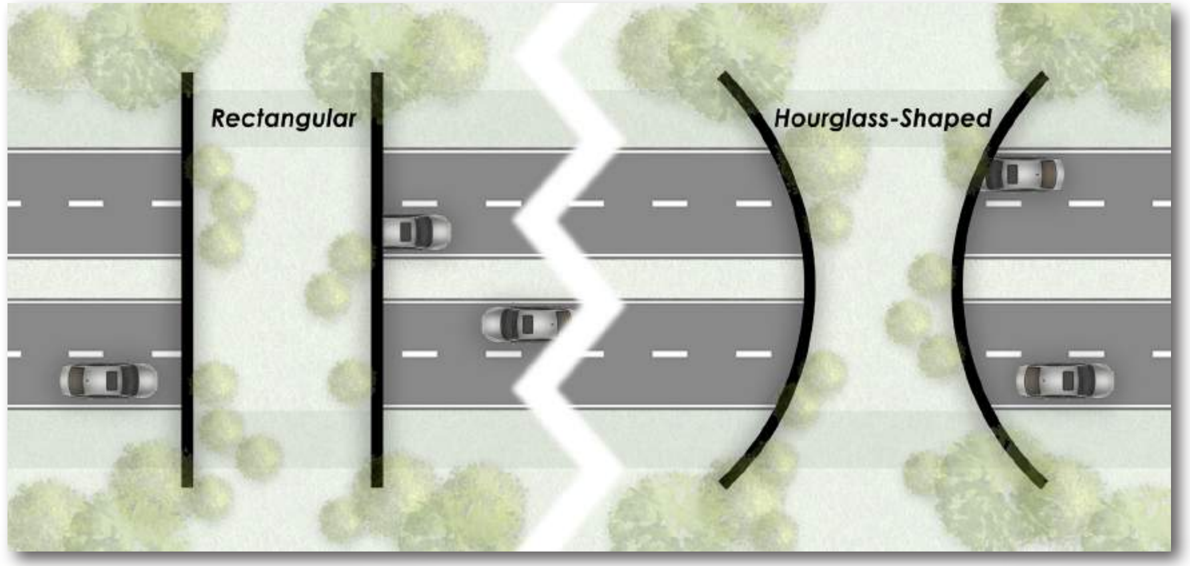


Figure 27. Rectangular and hourglass-shaped wildlife overpasses (adapted from Kruidering et al., 2005, Hujser et al., 2008b).

2.2.2 Underpasses

Much like overpasses, underpasses are best for connecting two habitats across barriers but tend to be smaller in scale and sometimes used in tandem with creeks and rivers that flow below roadways. Forman and Alexander (1998) note that road barriers disrupt steam flow and ground water flow in addition to preventing wildlife movements and therefore, underpasses allow for the controlled movement of water across road corridors. This is important for many species that rely on riparian areas for foraging and habitat requirements for reproduction, like many amphibians and reptiles. Underpasses are best suited for areas where the roadway is relatively high compared to the surrounding terrain (Huijser et al., 2008a). Also, like overpasses, fencing used in combination with underpasses and tunnels increase the effectiveness of the crossing. Fencing and underpasses used together can reduce the number of WVCs by 86% (Huijser et al., 2008a). Vegetation surrounding and inside of the pass should be habitat and species dependent and use of tree stumps, rocks and branches should be used to provide shelter for the smaller species using the tunnel. A frequent problem with underpasses is livestock use for shade during the day. The presence of livestock can deter some wildlife species from using the tunnels and force them to cross the road in unsafe locations in attempt to avoid conflicts (Huijser et al., 2008a). There are many different types of underpasses suitable for the target species and roadway conditions to be considered.

There are seven distinct types of underpasses for all manner of species and mixed-use for humans as well (Image 3). Viaduct or fly-over passes are the largest of the underpasses meant for wildlife passage. These are generally built for reasons other than wildlife use but function for a wide range of species and can be adapted for amphibians and reptiles as well. Large mammal underpasses are the second largest option designed specifically for large mammals but is also often used for medium and small species as well. Multi-use passes are similar to the large mammal passes but are intended to be used by both humans and wildlife. These passes are usually smaller but are well adapted for use in urban environments where generalist species move more freely. Underpasses with water flow are intended for use by species that move parallel to water systems or use riparian habitats for cover. Small to medium-sized mammal underpasses are one of the smaller crossing types and are suitable for many species depending on the size of the crossing. Modified culverts are designed for use by small and medium-sized wildlife that are associated with riparian habitats or irrigation canals. These crossings typically have platforms and walkways inside above the high water mark so that even during high water events wildlife is able to pass through the culvert. Finally, amphibian and reptiles tunnels are intended for a specific species or group of species but have also been shown to facilitate movement for some smaller mammals as well (Clevenger and Huijser, 2009). Underpasses and tunnels can be more cost effective and suitable for smaller species and riparian dependent species.

Long or Open-Span Bridge, Viaduct

Photo credit: Rimba Reuben

Wildlife Underpass

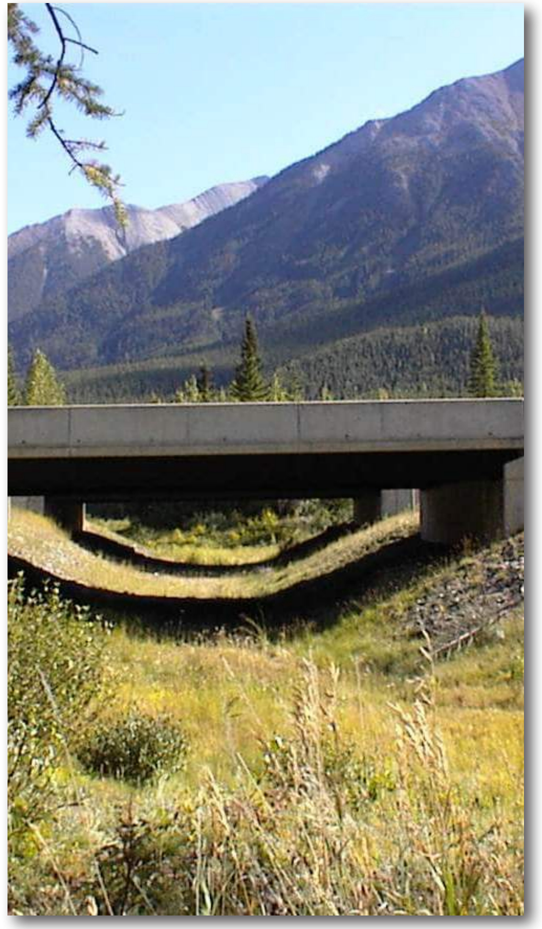


Photo credit: Trisha White

Amphibian Tunnels

Photo credit: Clara Grilo

Image 3. Types of wildlife underpasses, viaducts, wildlife underpass, and amphibian tunnels.

2.2.3 Fencing

Another method for keeping wildlife away from roadways is the use of fencing. Wildlife exclusion fencing is a useful method when used in combination with crossing structures. When used alone, it can cause isolation of populations and create a new barrier to movement, separate from the roadway itself (Clevenger and Huijser, 2009). Small populations become more fragmented from one another, reducing their overall survival (Huijser et al., 2018). In areas where fences are knocked over or deteriorating, wildlife is still able to access roadways in inappropriate locations and cause collisions (Clevenger and Huijser, 2009). When used properly with crossing structures, animals are funneled to the safe structures, allowing greater access across roadways, and reducing the barrier between key habitat patches (Huijser et al., 2018). Fencing is mainly useful for larger mammal species, since small and some medium-sized species can move through the fencing and onto roadways (Clevenger and Huijser, 2009). Overall, fencing should be considered whenever a crossing structure location has been identified to assess the need to usher wildlife to those crossings more effectively to reduce collisions.

As with many of these mitigation practices, the type and use of fencing are site and species dependent. The height of the fencing used is particularly important for the target species because some animals, like deer and elk, are able to jump over shorter fences, but carnivores like bear and wolves (*Canis lupus*) are not. There are three main types of fencing: woven metal wire, chain-link, and electric (Huijser et al., 2008a). Each type can be used for different target species, but woven metal wire tends to be the most widely used because it comes in a variety of sizes to allow smaller species to still move through the fence freely (Huijser et al., 2008a). In cases where there is a desire to prevent both large and small animals from entering a roadway, a combination of smaller and large mesh can be used with the smaller mesh at the bottom of the fence and larger above. Some species, like coyote (*Canis latrans*) might try to dig under a fence. In that case, a dig barrier is placed up to 2 feet underground to prevent the animal from going under the fence and entering the roadway (Huijser et al., 2008a). Fences should be used to funnel wildlife towards safe crossing opportunities, however, sometimes the end of fencing that is away from the crossings presents an area where increased WVCs may occur.

Fence ends are considered the areas away from crossing structures where fences terminate and pose a threat to motorist due to the increased chance of wildlife entering the road at that location. For that reason, fence ends are almost as important to consider in design as the safe crossing structure itself. Clevenger and Huijser (2009) note that WVCs at fence ends tend to be most prevalent directly after construction when wildlife is first encountering the fence and are unsure about where to cross the road. There are many methods to attempt to reduce the chances of wildlife entering the road at fence ends. Most commonly are the placement of fence ends at locations where wildlife are least likely to attempt a crossing such as rugged terrain associated with cliffs and locations with high human activity that would deter animals (Clevenger and Huijser, 2009). Alternatively, the use of large boulders that extend beyond the fence end has been shown to reduce ungulates from entering the roadway (Clevenger and Huijser, 2009; Huijser et al., 2008a). While there has been little research into the efficacy of the use of lighting to deter wildlife, it is suggested that lighting at fence ends might deter wildlife and provide increased visibility for motorists (Huijser et al., 2008a). Finally, the use of animal detection systems at fences ends could increase awareness for motorists and prevent any collisions that might occur if wildlife enter the roadway (Huijser et al., 2008a). While fences can be effective at keeping wildlife from entering road corridors, they can also trap wildlife inside the corridor and increase the time wildlife spends on the road.

Fences are not perfect at preventing animals from entering the roadway. Damage to fences because of vehicle collisions, falling trees and vandalism can allow wildlife to enter the roadway in locations not suitable for safe crossings. When this happens, animals need to be able to exist the road corridor safely. The two main way to allow animals to exit the right of way is through the use of one-way gates and jump-outs. One-way gates function as a freely swinging gate that wildlife can push open from the road to the outside of the corridor but do not open the other direction (Clevenger and Huijser, 2009). Some swing gates do not open freely and are used in areas that are frequently patrolled by law enforcement or rangers that have to manually open and close the gates (Clevenger and Huijser, 2009). However, swing gates can be faulty by design and are subject to jamming open, allowing wildlife to enter the roadway or jamming close, locking animals in the right of way (Ree et al., 2015). Additionally, it has been found that some animals hesitate or refuse to push open the gates especially if the gates are jammed and require extra force to open (Ree et al., 2015). Small wildlife can usually escape under these gates since there are no dig barriers or low fencing involved (Huijser et al., 2008a). Unfortunately, if designed poorly, large wildlife might impale themselves on the gates if they are stuck and the animal attempts to run through it (Ree et al., 2015). Careful consideration must be given to gate design and placement for optimal benefits.

Jump-outs, or earthen ramps, allow wildlife to exit the right of way without having to push open gates or relying on an agency employee to manually open and close the gates. As the name implies, jump-outs allow animals to jump out of the road corridor though an elevated break in the fence (Clevenger and Huijser, 2009; Huijser et al., 2008a, Ree et al., 2015). Locations of the break in the fence should be set-back from the fence line and densely vegetated to allow animals time to calm down and exit the roadway (Clevenger and Huijser, 2009). The use of guide wings and additional fencing can help to funnel wildlife into the jump-outs for easier access to escape routes (Ree et al., 2015). Jump-outs should be designed depending on the target species and need to be high enough to prevent animals from climbing the outer wall, but too high as to deter animals from jumping out of the corridor Clevenger and Huijser, 2009). The outer wall should be smooth to prevent other animals, like bears, from climbing the walls and gaining access to the road corridor (Huijser et al., 2008a). The landing outside of the jump-out should be soft to prevent injury to the animals using it (Clevenger and Huijser, 2009; Huijser et al., 2008a). For smaller species, natural objects like tree stumps and branches or bushes can serve as small scale jump-outs that are also cost effective (Huijser et al., 2008a). Use, spacing, and types of escape opportunities is all target species or species group dependent.

Species	Height (feet)
White-tailed deer	8-9 ft
Mule deer	8-9 ft
Elk	8-9 ft
Moose	8-9 ft
Mountain goat	8-9 ft
Bighorn sheep	10-12 ft
Cougar	11 ft
Wolf	8 ft
Black bear	8-9 ft
Grizzly bear	8-9 ft

Table 2. Recommended height of wildlife fencing by species (adapted from Clevenger and Huijser, 2009).

Figure 28. Example of wildlife fencing.

2.2.4 Detection Systems

In addition to physical crossing structures, wildlife warning signs and animal detection systems can be considered for reducing vehicle-wildlife collisions. Warning signs and detection systems are often applied because they are relatively cheap compared to large overpasses and underpasses (Huijser et al., 2018). However, many studies indicate that standard warning sings do not reduce the rate of wildlife-vehicle collisions (Huijser et al., 2015; Riginos et al., 2016). Standard warning signs are simple with black animal symbols on a yellow background and enhanced signs are larger with flags or permanently flashing amber lights aimed at attracting the attention of drivers in the area (Huijser et al., 2018). However, it has been found that because standard signs are vague in the time and place of potential danger, only 5-10% of motorists stopped only 200 m from these signs are able to recall seeing a sign about wildlife in the area (Huijser et al., 2015; Drory and Shinar, 1982). Standard and enhanced signs only reduce collision rates by 9-50% and 33-97% respectively and are not considered to be effective at significantly reducing collisions (Huijser et al., 2018). These signs do, however, provide legal protection to transportation organizations in the event of a collision, provide information and raise awareness of the problem to the public, and potentially increase the public support of other mitigation techniques like larger crossing structures (Huijser et al., 2018). Crossing signs may serve as a first step in designating and improving safety and high use crossing locations but are not necessarily the most effective for preventing accidents from happening.

Animal detection systems are a type of enhanced signage that can detect when a large animal is near a roadway and alerts drivers to its presence. Since this strategy does not physically prevent an animal from entering the roadway, it relies heavily on drivers to be aware of their surroundings and pay attention to the signs. Huisjer et al. (2008b) note that this requires motorists to respond by either being more alert to their surroundings and any potential hazards on the roads or lowering their speed for a short section or a combination of both. Detection systems provide a sense of time and place for potential wildlife in the roadway because the triggering of the sensors by animals turns on the flashing lights or signage that alerts drivers. This can also be beneficial during seasonal changes such as migrations for many ungulate species and during certain times of year when some animals are more attracted to roadways (Huijser et al., 2015). One benefit of these types of systems is that they don't create a barrier to movement, it simply allows animals to cross freely while alerting drivers of the potential dangers.

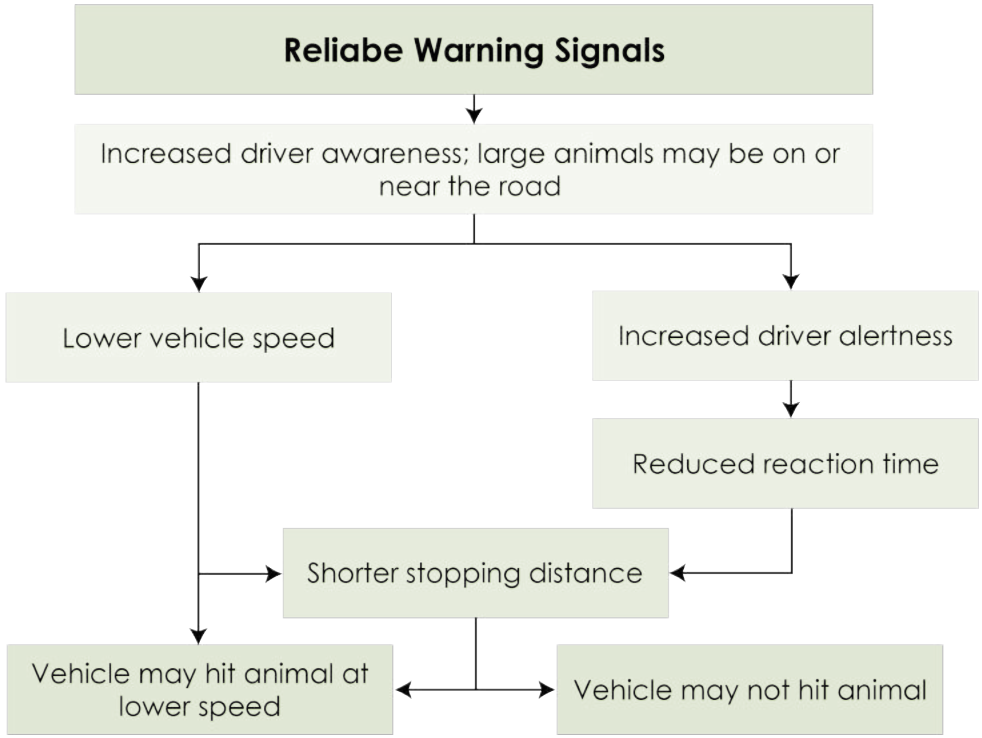


Figure 29. Reliable warning signs to effective results (adapted from Huijser et al., 2008).

While there are many different types of detection systems, most fall into one of the two categories: "area-cover" sensors or "break-the-beam" sensors. "Area-cover" sensors work by detecting larger animals within a given range of a sensor and can be either passive or active (Huijser et al., 2008a). Passive systems work by receiving a signal from either infrared or video detections that then send a signal to the alerting device, usually a sign with lights, to turn on (Huijser et al., 2008a; Huijser et al., 2008b). In order for this type of passive system to work, a specific code must be used within the device to differentiate between hot moving vehicles and large animal bodies (Huijser et al., 2008a). Alternatively, these systems can be active, which means using microwave signals to broadcast over an area and measure the reflection of waves back to the sensor (Huijser et al., 2008a). This type of system covering large areas can have many blind spots and result in false positives that engage the lights alerting drivers when there is no real danger. "Break-the-beam" sensors work by detecting when animals move in front of a concentrated sensor using an intra-red beam, laser, or microwave radio signal (Huijser et al., 2008a). These function much like pedestrian counters and will signal the lights to notify motorists when the beam has been broken. Other types of detection systems may include recording ground vibrations from animal movements, buried sensors in the ground that can detect when an animal walks over it, or use of radio-collared animals with transmitters found along the sides of roads (Huijser et al., 2008a). All the mentioned systems have their limitations and should be carefully considered when deciding when it is right to use these devices.

There are many factors that play into the suitability of a site for an animal detection system. The terrain and vegetation around the roadway should not impede the ability of the system to detect wildlife and the surrounding landscape should not be altered for the lifespan of the systems, which is around 10 years (Huijser et al., 2008a). Additionally, access roads coming off the main roadway can create blind spots for many systems or result in false positive readings and thus access roads should be minimized (Huijser et al., 2008a). Finally, power is essential to the operation of the system, whether that is through a direct power source or with solar panels (Huijser et al., 2008a). While the use of animal detection systems is still considered experimental, initial studies have shown to reduce WVCs by an average of 87% (Huijser et al., 2008a; Huijser et al., 2008b; Clevenger and Huijser, 2009). A study in Switzerland by Kistler (2002) showed a reduction in WVCs at seven separate locations of 81.5% when evaluation pre- and post-installation collisions. As more data is available, the full effectiveness of these systems can be evaluated.

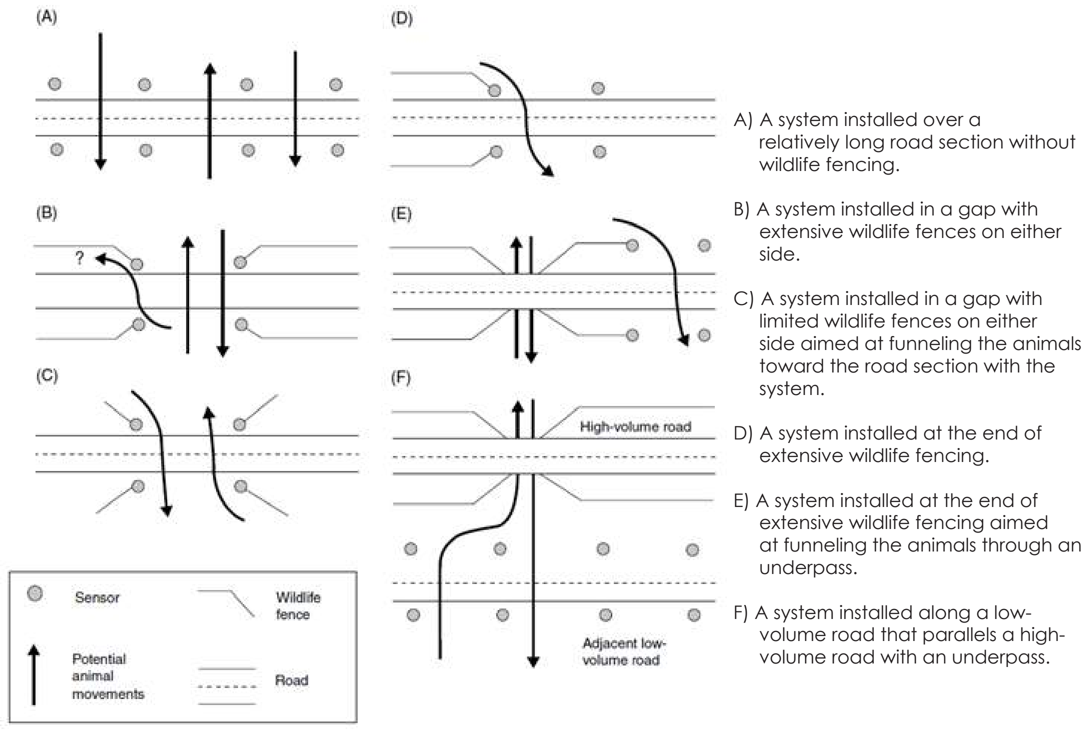


Figure 30. Placement of detection systems under various conditions (Huijser et al., 2008a).

2.2.5 Other methods of mitigation

While all of the mitigation measures so far are the most common and most widely studied ways to lower the rate of WVCs it is worth mentioning other methods that are either currently being study or need to be studied to truly evaluate all means of reducing collisions. These strategies can be broken down into two major categories: those that aim to influence human behavior and those that influence wildlife behavior (Huijser et al., 2008b).

The strategies and methods that try to influence driver behavior are:

- Public information and education.
- Improvement in driver attentiveness using warning signs by:
  - Standard signs
  - Large, nonstandard signs
  - Seasonal signs
  - Animal detection systems
- Improvement of driver attentiveness with in-vehicle warning systems by:
  - In-vehicle warning linked to roadside animal detection systems
  - In-vehicle warning linked to on-board animal detectors
- Increase in visibility to drivers by:
  - Roadway lighting
  - Vegetation removal
  - Wider striping
  - Reflective collars for animals
  - Reduced height of snowbanks
- Reduction in traffic volumes on roadways by:
  - Reduction in traffic volume on road network
  - Temporary road closures
- Reduction of average speeds on roadways by:
  - Reduction of the posted speed limit
  - Traffic calming/reduction of design speed
  - Posting of advisory speed limits
- Wildlife crossing guards

The strategies and methods that try to influence wildlife behavior are:

- Deer reflectors and mirrors
- Audio signals in right of way or attached to vehicles
- Olfactory repellents
- Deer flagging models
- Hazing
- Deicing alternatives
- Intercept feeding
- Influence species composition or minimize nutritional value of vegetation in the right of way
- Remove carcasses along transportation corridors
- Increase median width

2.2.6 Multi-use structures

Multi-use crossing structures can be used by both wildlife and humans, though they are not suitable for all species and groups. In more urban environments, small- and medium-size mammals live alongside humans and are more adapted to using general human designed bridges and crossing structures around established roadways (Asari et al., 2020). To separate pedestrian use and wildlife use, pathways and trails should be confined to one side of the bridge and the other side should be vegetated to provide a safe space for animals (Clevenger and Huijser, 2009). Ree and Grift (2015) classify these areas as ‘recreational’ and ‘wildlife’ zones. It is also important to reduce light and noise from vehicles to not deter wildlife from using the passage. This can be done by using berms, walls, and vegetation along the bridge (Clevenger and Huijser, 2009). As with the other passage types, vegetation on and surrounding the crossing should be native and promote a natural environment for the wildlife of the area (Clevenger and Huijser, 2009). Since these structures are generally placed in urban settings, they are not suitable for many larger carnivores or large ungulates like moose and bighorn sheep (Clevenger and Huijser, 2009).

Wildlife underpasses can also be designed with a multi-use intention in mind. Larger underpasses, like fly-overs, can include a possibility for a pedestrian path as well as safe wildlife passages (Clevenger and Huijser, 2009). Much like multi-use bridges, these passes should try to restrict human use to one side of the passage with a vegetative buffer between areas that will be used primarily by wildlife and the pedestrian pathway (Clevenger and Huijser, 2009). These types of passes may be common in rural areas and may allow for some vehicular traffic. All-terrain vehicle (ATV) use of the passage should be limited because of increased noise disturbance, however, low-level traffic such as agricultural use or rural travel is acceptable (Clevenger and Huijser, 2009). It is important for these passes to flow with the local topography to prevent flooding events from blocking the passage (Clevenger and Huijser, 2009).

In developed urban areas there is a need for safe crossing locations for local wildlife and pedestrian bridges and underpasses could be the solution. There has been a push for more multi-use structures, especially for co-human-wildlife use, because the cost of constructing two separate passages is greater than one multi-use option (Ree and Grift, 2015). In a study done by Asari et al. (2020), three bridges, one designated for wildlife only and two pedestrian bridges, across a major highway were evaluated for species use of those bridges over time. They found that many small and medium-sized mammals including raccoons (*Procyon lotor*), red foxes (*Vulpes vulpes*), and sika deer (*Cervus nippon*), used all three crossings, showing no significant difference between use of human designated bridges and wildlife designated bridges (Asari et al., 2020). This shows the potential applicability of using multi-use bridges for humans and wildlife in urban settings for some mammal species.

Other instances of multi-use passes could include more than just wildlife and pedestrians. This format could be used in places where rivers and creeks flow under roadways or railroads where wildlife also need to cross (Huijser et al., 2008a). Broadly speaking, multi-use structures could mean any crossing whose purpose is to connect two areas for the benefit of more than one entity. There are many species that rely on riparian habitats for survival and therefore are more likely to attempt a crossing where they are able to remain in that habitat (Huijser et al., 2008a). This means that an underpass may need to be modified to allow for more than just water flow. Modified culverts are a prime example of this types of multi-use structure. Culverts that have been modified for use by wildlife often include elevated walkways or ledges for movement alongside the water way and allow for movement in low and high water events (Huijser et al., 2008a). These types of crossings are ideal for small and medium sized mammals such as mink (*Neogale vison*), river otter (*Lontra canadensis*), and fisher (*Pekania pennanti*) (Clevenger and Huijser, 2009).

2.2.7 Teton wildlife crossing structures and devices

While there are no known wildlife crossing structures in the Teton watershed, there are some standard wildlife signs. Through a virtual drive study using Google Earth Pro (2009 - 2018 imaging), locations of wildlife crossing signs were found. There were two locations, at Canyon Creek along Highway 33 between Rexburg and Tetonia and at Bitch Creek along Highway 32 north of Tetonia, where there were tall, long-bridges that could be acting as fly-over underpass crossing, but it is unlikely that they were designed specifically as wildlife crossings as they both span large canyons in the landscape. It is more likely that building bridges in these locations were easier than going down and then up the canyon walls. Additionally, there were no noticeable wildlife fences, or any wildlife warning signs in the area and from the locations of road kill in those areas, there are clear motorist conflicts with wildlife at either side of the bridges, meaning wildlife is likely going around these areas instead of utilizing the underpass. There were only two "Game Crossing" signs that were located in the watershed along Highway 33 between Victor and Jackson, Wyoming on Teton Pass.

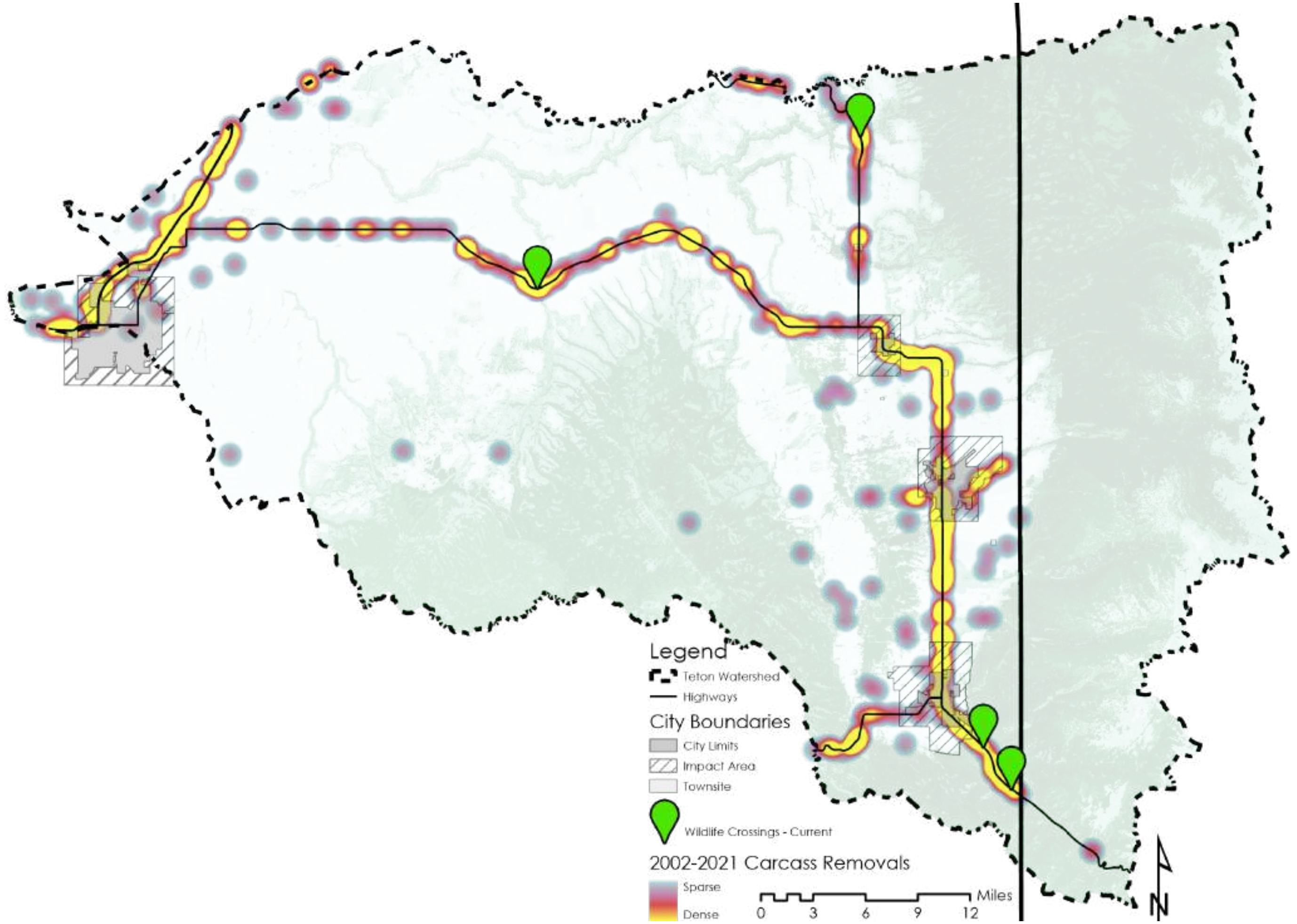


Figure 31. Locations of wildlife crossing devices in the Teton Watershed currently.

Just to the north, outside of the watershed, there was a report conducted to consider the implementation of a wildlife crossing structures along Targhee Pass which crosses the Idaho-Montana border. This project evaluated a section of U.S. Highway 20 at the border near Henrys Lake to determine if a crossing structure was necessary to reduce WVCs. This study concluded that, given the costs associated with each crossing structure proposed, overpasses were not ideal and the Idaho Transportation Department opted for the use of an animal-detection system along a 4-mile segment of road instead. This system will be solar powered and include a series of line-of-sight radar systems for detection. They also plan to widen the shoulder of the roadway, improve sight distance for motorists but cutting into hillsides and clearing trees from the right-of-way, and add turning lanes onto major arterial roads. These improvements should increase motorist awareness of their surroundings and hopefully, through a monitoring effort, reduce the number of WVCs on this sections of highway (ITD, 2022).

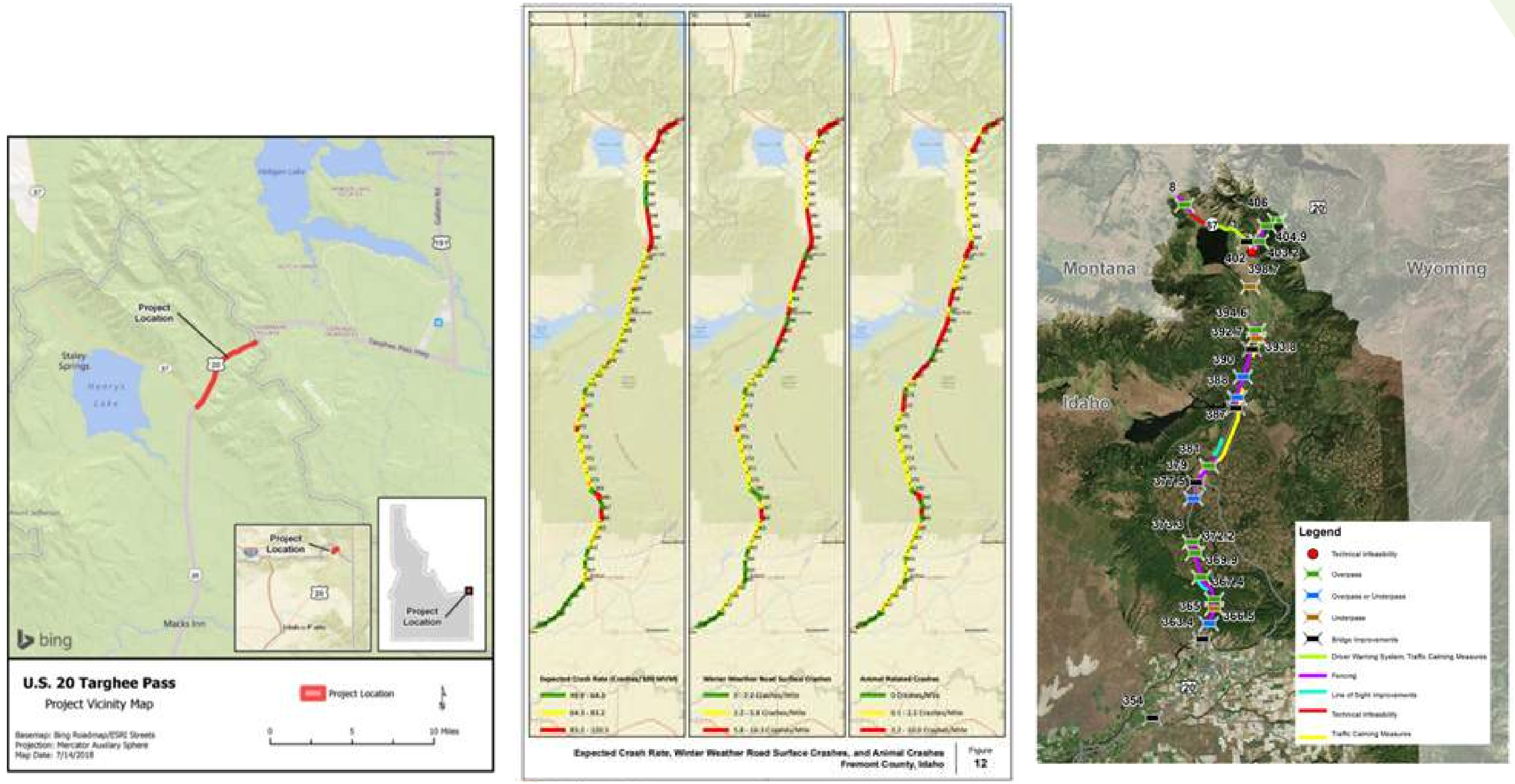


Figure 32. Targhee Pass wildlife crossing studying target zone, analysis, and solution recommendations (ITD, 2022)

2.3 Frameworks for Selection of Crossing Locations

2.3.1 Landscape scale approach to planning

Proper planning for the placement of wildlife mitigation measures is important to ensure the most effective outcome to reduce collisions. This means that every situation will be different and crossing types and roadway considerations will vary widely on a case-by-case basis. However, the questions that need to be answered to complete the selection process remain the same (Clevenger and Huijser, 2009):

1. Where should wildlife crossing structures go?
2. What should they look like?
3. How will they perform?

Since mitigation is generally an afterthought of road design, or a way to retrofit existing roadways, it is important to consider avoidance as a design possibility for new roads. However, it is likely that mitigation is the only option due to existing roadways bisecting now minimal critical habitat corridors due to land conversion and development adjacent to the road. To assess areas for site-specific locations for wildlife crossings, a landscape-level approach for determining key habitat linkages should be evaluated first. By approaching a site-level design with a wide lens, the bigger picture about wildlife movements and critical habitats can be explored to ensure the highest potential for corridor connectivity. Clevenger and Huijser (2009) discuss the various levels of habitat connectivity potential and why it is key to consider these when deciding crossing locations. There are three major categories of connectivity potential: high, moderate, and low. High potential areas are those where high-quality critical habitats for key wildlife species are present and they are an important corridor for movement at a local or region scale (Clevenger and Huijser, 2009). At these locations, suitable crossing types include all over- and underpasses, however, multi-use wildlife-human structures should be avoided (Clevenger and Huijser, 2009). Areas with moderate potential include relatively undisturbed habitats that may not be considered critical wildlife habitats but are still beneficial for wildlife use (Clevenger and Huijser, 2009). In these areas, landscape bridges, fly-overs, and viaducts are not recommended, and multi-use structures can be considered (Clevenger and Huijser, 2009). Finally, low potential sites are those where human activity and disturbance is wide spread and many crossing types are not ideal, but multi-use structures are encouraged to still allow movement for urban wildlife (Clevenger and Huijser, 2009). Habitat potential is important to consider to ensure the most effective crossing structures are designed given the surrounding area.

After identifying critical habitats and movement corridors, observing how transportation systems fragment and create barriers within the landscape further assist in the site-specific location for mitigation measures. When looking at a transportation system, it is important to consider what is occurring at the road itself, but also in areas adjacent to the roadway, in order to gain a clearer picture of how the system affects habitat overall (Clevenger and Huijser, 2009). This can take the form of looking for areas along rood corridors with high carcass counts from wildlife-vehicle collisions or mapping fragmentation of corridors. Land management adjacent to roadways is also important to consider because land conversion can create more barriers or funnel wildlife to certain points along the roadway to attempt a crossing (Clevenger and Huijser, 2009). Clevenger and Huijser (2009) also suggest that this approach allows for the exploration of future roadway developments and provides insight into how crossing structures will play a role in new and expanded roadways. By looking at transportation corridors at the landscape-scale, larger habitat linkages and fragments become more apparent and aid in the determination of habitat connection potential which is key for determining proper wildlife crossing locations.

A landscape-level approach for determining crossing locations also entails a cooperative interaction between large transportation systems and comprehensive wildlife conservation plans. Clevenger and Huijser (2009) suggest that to effectively manage wildlife migration corridors and crucial wildlife habitat, there needs to be a cross-disciplinary discussion between traffic and roadway engineers and local and federal wildlife officials and suggest a list of planning resources to be considered. This approach may not be explicit, however, as shown by Zeller et al. (2020) the use of transportation systems in tandem with global positioning system (GPS) location data from collared black bears in Massachusetts at a regional scale is more effective at location appropriate crossing locations. A study conducted by Huijser et al. (2018) used a combination of existing data on large-mammal-vehicle collisions including wildlife-vehicle crash data, carcass removal data, and known migration routes to identify stretches of highway that had a higher concentration of wildlife-vehicle accidents. This allowed them to identify focal species in that area that were hit more frequently and thus determine which types of crossing structures would be more efficient in those locations.

While vehicle-wildlife collision and carcass data are important to consider when selecting a location for wildlife crossings, there are a few caveats that should be understood when using this data. Generally speaking, both types of data tend to relate to large mammals only, while medium- and small-sized mammals and other groups like amphibians, reptiles and birds are not recorded (Huijser et al., 2018). Additionally, vehicle crash data may only represent a fraction of actual collisions, around 14%-50% and again, mainly related to large mammals only. Carcass data can also pose and issue because sometimes an animal may get hit and run off and die elsewhere and the body is never recovered and will not be recorded (Huijser et al., 2018). With this knowledge, it is important to consider more than just collision information when deciding upon crossing locations.

Maps and Data for Planning Wildlife Crossing Mitigation

Aerial Photos

Land Cover - Vegetation Maps

Topographic Map

Landownership Map

Wildlife Habitat Map

Wildlife Movement Models

Wildlife Ecology Field Data

Road-kill Data

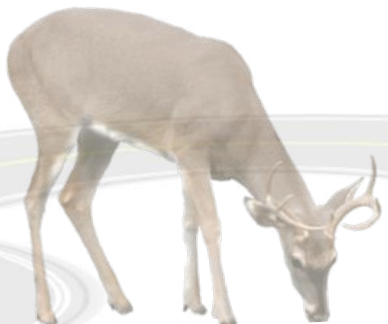
Road Networks

There is a consensus among researchers about the types of data that are most beneficial for determining wildlife crossing locations. These types of data can vary depending on the regional extent of the project and the availability of data, however, to some degree the following data resources are believed important for site evaluation (Clevenger and Huijser, 2009; Huijser et al., 2015, Huijser et al., 2008a).

- Aerial photos
- Land cover-vegetation maps
- Topographic maps
- Landownership maps
- Wildlife habitat maps
- Wildlife movement model maps
- Wildlife ecology field data
- Wildlife road-kill data
- Road network data

In addition to a regional or local view of roadway fragmentation and habitat corridors, it is suggested that understanding the characteristics of WVCs and what may influence them could help in the decision process for implementation of certain crossing types. In the 2008 Report to Congress, an extensive review of literature related to wildlife collisions and the conditions in which they occurred led to the designation of key characteristics of collisions involving wildlife. They included the following:

- Total magnitude of collisions
- Growth rate (population)
- Temporal distribution
    - o Time of day
    - o Time of year
- Severity of human injuries and fatalities
- Roadway facility type
- Traffic density and speed
- Weather conditions
- Animal species
- Landscape adjacent to roads
- Number of vehicles involved
- Deer population density
- Driver characteristics



An initial look at a landscape-level approach to identifying key habitat connectivity areas and their relationships with transportation systems will aid in the use of a modeling program to identify areas of high, medium, and low connectivity potential for various wildlife crossing structures. The identification of key species in those landscape-level habitats and any vehicle-wildlife collision data will also aid in the modeling process to further identify appropriate crossing structure locations. When the key habitats and linkage areas across the transportation system are identified, a site-scale analysis for each crossing location can then be assessed to determine the specific crossing structure to be implemented.

To see how this process would function in a real-world situation and to provide the anchor framework for this project I studied the Teton County Wildlife Crossings Master Plan in Teton Wyoming, conducted by the Western Transportation Institute in 2018. The following framework for the master plan will be used in this project and explain further in section 2.3.2 and 3.1.

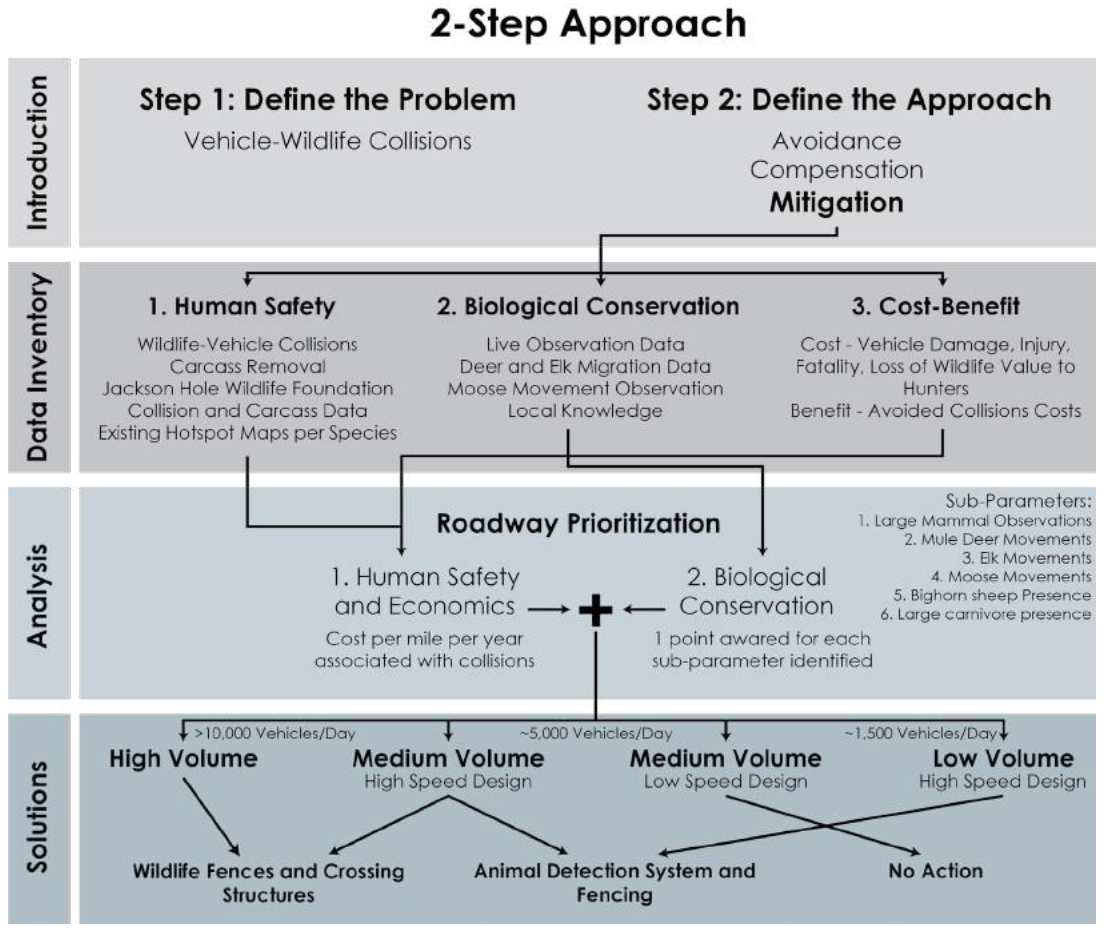


Figure 33. Process diagram for the Teton County Wildlife Crossing Masterplan in Teton County Wyoming conducted by the Western Transportation Institute in 2018.

2.3.2 Teton Wildlife Crossings Master Plan - A Case Study

The Teton County Comprehensive Plan developed in 2012, specifically outlines in policy 1.1.c and 1.4.d that habitat connectivity for wildlife and developing safe wildlife highway crossings are high priorities for the region. However, prior to the research done by Huijser et al. in 2018, no such plan or documentation existed to meet the goals of these policies. The Teton County Wildlife Crossings Master Plan prioritizes human safety, biological conservation, and economic parameters to identify suitable mitigation measures and provides cost estimates for the development of wildlife crossing structures. These crossing structures will help wildlife populations thrive and provide safer roadways for motorists.

Process:

A stepwise approach was used for deciding priority areas and site-specific crossing locations through analysis of existing data, field reviews of sites, and cost-benefit analyses for the proposed mitigation measures with stakeholder engagement and feedback. The two-step approached focused on 1) defining the problem, and 2) deciding on the approach: avoidance, mitigation, or compensation.

To define the problem, safety for humans was the focus based on the issues that arise with vehicle-wildlife collisions. In the U.S. there are an estimated one to two million large mammal-vehicle collisions annually that cause around 211 human fatalities, nearly 30,000 injuries, and cost over one billion U.S. dollars in property and infrastructure damage. Because of this, wildlife-vehicle collision data was the primary driver behind defining the problem and selecting prioritization zones. There are two types of data available to evaluate priority areas: crash data and carcass data. Crash data are collected by law enforcement and are often only recorded if the vehicle damage exceeds $1,000 U.S. and/or there are human injuries or fatalities associated with the collision. Carcass data are collected by road maintenance crews when carcasses are removed from roadways after a collision or by natural resource management agencies, researchers, or the public. The researchers note, however, that by only focusing on wildlife-vehicle collisions, which often only involve large mammals, there are other wildlife groups that are excluded and thus this approach may not fully show all priority areas needing mitigation.

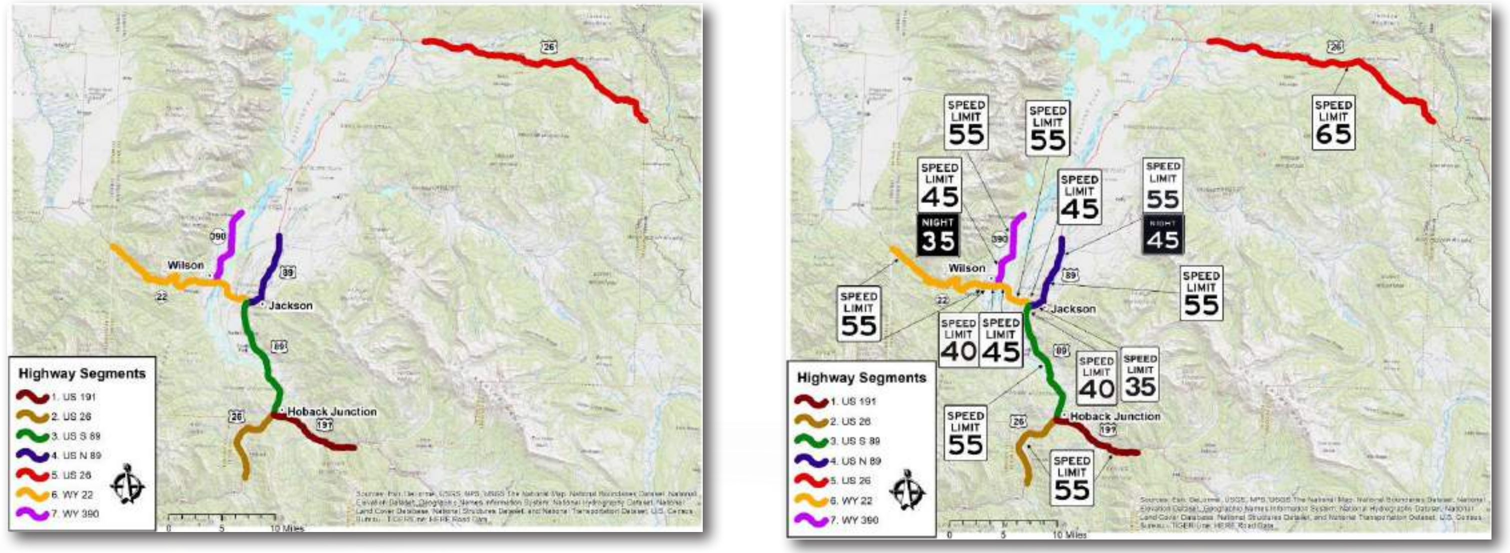


Figure 34. Project location and speed limit overview for highway segments considered in the 2018 masterplan analysis for Teton County Wyoming (Huijser et al., 2018).

Deciding on the approach to take involves considering the trade-offs between avoidance, mitigation, and compensation (Figure 35). While avoidance strategies are the best choice for preventing the degradation of critical habitats and wildlife migration routes, it is often not the most feasible. Mitigation is the most widespread practice typically carried out using various wildlife crossing structures. However, sometimes the implementation of crossing structures is not possible or may not be sufficient for the wildlife in question. When avoidance and mitigation are not options a compensation approach can be considered. Compensation, or off-site mitigation, may include increasing the size of existing habitat patches, creating new patches, or improving connections between patches away from the developed roadway. In some scenarios, a combination of all three approaches is necessary. For this study, the primary approach was mitigation because of the unlikelihood that major highways will be removed or rerouted.

Mitigation measures were evaluated from the literature and selected for their ability to reduce wildlife-vehicle collisions with large mammals. The researchers note that while there are over forty diverse types of crossings, not all of them have been thoroughly evaluated for their effectiveness. Wildlife fencing when used in combination with crossing structures such as overpasses and underpasses have been identified as the most effective for human and wildlife safety. Additionally, wildlife detection systems are also useful for alerting drivers of the potential for wildlife on the roadway. The mitigation efforts focused on for Teton County were wildlife warning signs and animal detection systems, speed management, wildlife fences, wildlife crossings, and multiple use structures.

Stakeholders were engaged in the research and gained input from representatives of local governing agencies including Wyoming Department of Transportation, Wyoming Game and Fish, U.S. Fish and Wildlife National Elk Refuge, U.S. Forest Service, Grand Teton National Park, Teton County, Teton Conservation District, Trout Unlimited, Greater Yellowstone Coalition, Jackson Hole Conservation Alliance, Nature Mapping Jackson Hole, and Wyoming Migration Initiative. Stakeholders were invited to public meetings to discuss potential priority areas, solutions, and provided feedback on designs.

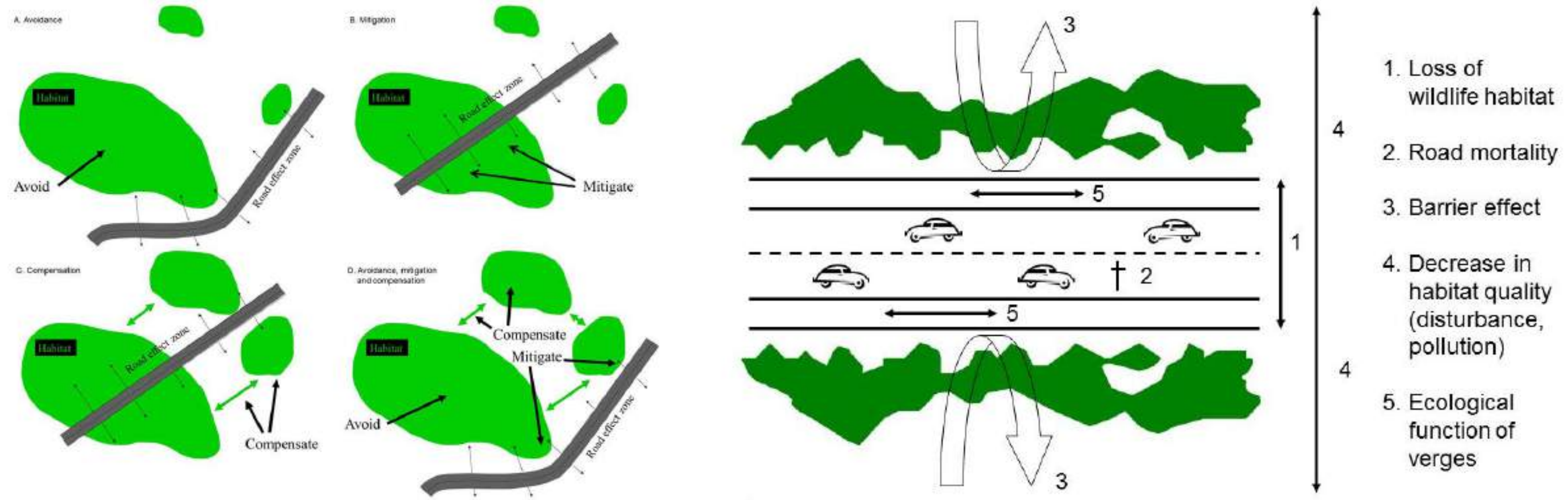


Figure 35. Roadway development techniques and road ecology effects (Huijser et al., 2018).

Data Analysis:

Three parameters were evaluated across the seven road sections to define prioritization areas for wildlife crossing mitigation: human safety, biological conservation, and cost-benefit analysis of the chosen mitigation measures.

Researchers used three data sets and exiting maps to aid in the identification of road sections with higher concentrations of wildlife-vehicle collisions and posed a greater risk to human safety. Wildlife-vehicle collision data, which is reported by law enforcement officers provided information about crashes that were informed to officials when at least $1,000 US of damage was reported and/or an injury occurred (Figure 36). These crashes often involved larger mammals. Carcass removal data, reported by maintenance personal from the Wyoming Department of Transportation included all carcasses that were considered large enough to be a potential danger or distraction to motorists and were visible from the roadway. This data also included mainly large mammals. The Jackson Hole Wildlife Foundations (JHWF) and the Nature Mapping Jackson Hole (NMJH) group provided data related to a combination of collisions, carcasses, and incidental observations from the public. For this data set, researchers only used species larger than coyotes which allowed for some medium sized mammals to be included in the analysis. Finally, existing wildlife-vehicle collision hot spots maps for deer, elk, and moose based on collisions and carcass removal were used to define a set of high, medium, and low densities of collisions along the seven road sections.

These data sets were originally gathered within the same 10-year time frame from January 2006 through December 2015. Wildlife species for consideration were selected by researchers based on the concern for human safety. Species that were greater than one-hundred pounds were considered a risk and domesticated species, such as cattle and horses, were excluded from further consideration for crossing design. Additionally, medium and small sized species were also excluded because they did not result in a high risk for human safety. Through an analysis of these data sets a species list was developed showing the percent of wildlife-vehicle collisions organized by species.

Temporal fluctuations in collisions were also evaluated to find specific times of the year where collisions were more prevalent. Researchers found that carcasses were recorded more often in the winter and early spring (December through April) as well as in the summer months (June and July). This seasonal change is attributed to migrations between summer and winter habitats for larger species like deer, elk and moose, as well as the increased tourism, and thus more vehicle traffic, during the summer and winter months. In addition to seasonal changes in collision patterns, variation in the time of day in which a collision is more likely to occur was also determined to be between 6 pm and 11 pm as well as 5 am through 9 am.

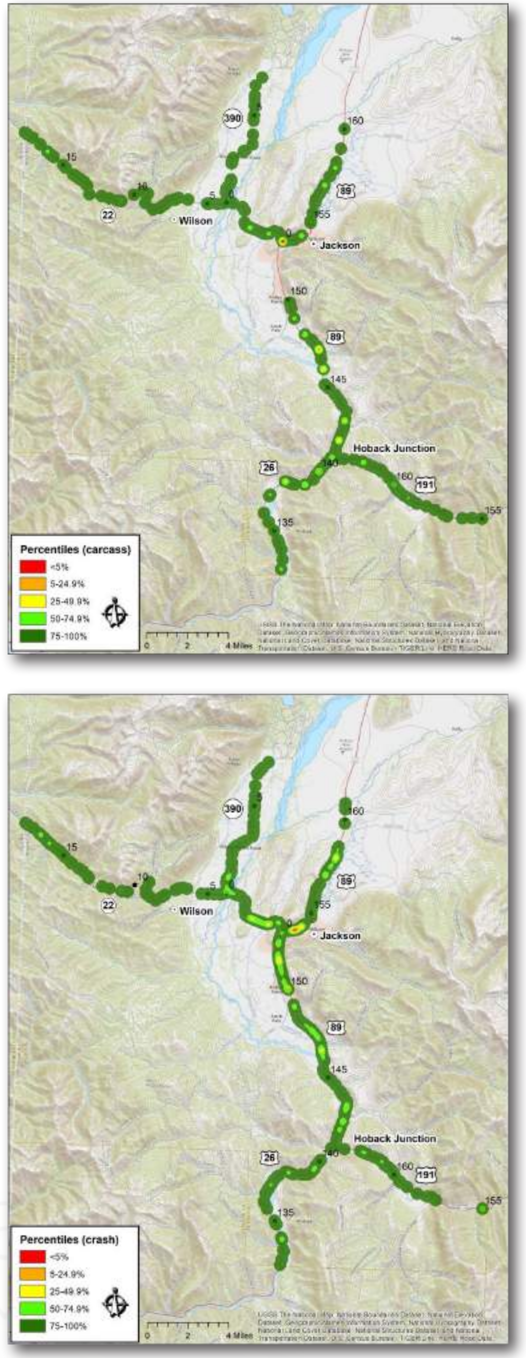


Figure 36. Density analysis for crashes and carcass removals (Huijser et al., 2018).

To figure out generalized wildlife-vehicle collision hot spots, a Kernel density analysis (Silverman, 1986) for point features using ArcGIS 9.3 was used. This analysis used crash data, carcass data and the JHWF carcass/crash/observation data to find areas with a high concentration of collisions. The study area, including all seven road sections were divided into a grid of cells measuring 25 m by 25 m. All collision and carcass data were considered points and the Kernel density analysis uses those points to calculate the density of crashes or carcasses around each cell. Road sections with the two lowest densities were considered "background" and those sections in the top densities were counted as "hot spots".

Species specific collision hot spots were also found using the same process described above for elk, deer, and moose. This allowed for a comparison between generalized areas for all species of concern and a single species. These sets of outcomes were summarized in a single map to show high, medium, and low collision risk for all large mammals and deer, elk, and moose separately (Figure 37).

The second parameter evaluated was biological conservation using migration data, movement observations, and live observation data from the JHWF. Observation data was limited to wildlife species greater than coyotes within 100 m of major highways between January 2006 and December 2015. Migration data was collected for mule deer and elk from the Wyoming Game and Fish Department and the Wyoming Migration Initiative. Moose movement observational data along a specific section of road in the Buffalo Fork River area as well as observations of live and dead moose in the county were gathered from WYDOT and JHWF. Finally, stakeholders were able to supply insight through local knowledge and encounters of wildlife within the area considered to be species of concern. These data were used to categorize sections of road into hot spots and background sections similarly to the collision ranking system based on wildlife movement instead of collisions. These crossing paths were found for all examined species as well as deer, elk, and moose separately.

Landownership along these sections of roads were considered in the decision-making process to find crossing structure locations. Wildlife crossing structures should only be places in areas where the land on either side of the crossing is already secured as wildlife habitat such as state and federal lands or private lands with conservation easements. Otherwise, if the land use changes on either or both sides of the crossing it is unlikely that the crossings would be used and thus result in poor use of funds.

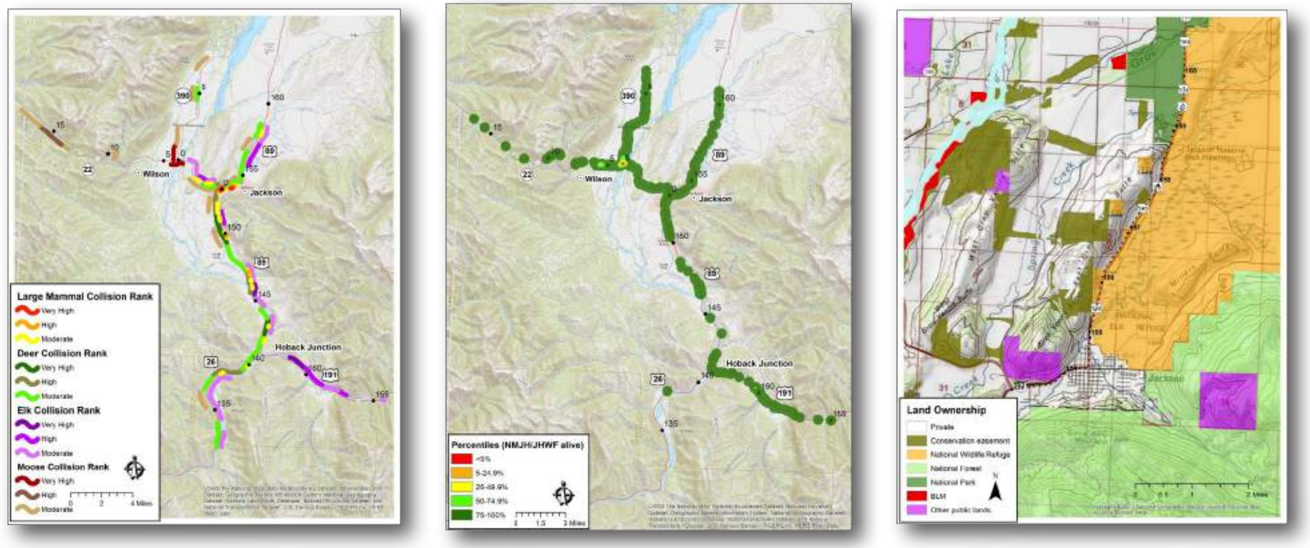


Figure 37. Collision rankings, live animal observations and land ownership (Huijser et al., 2018).

Cost-benefit Analysis:

While many mitigation efforts about wildlife crossings have been described, the effectiveness and costs of those measures differ and to understand the costs and benefits of each was important for the report. Researchers defined four distinct categories of mitigation efforts that combined different practices for analysis. These included:

1. **Fence and underpass (every 2 km) with jump-outs**
2. **Fence, under- and/or overpass (underpass every 2km, overpass every 24 km) with jump-outs**
3. **Fence, gap (once every 2 km), animal detections systems in gap, with jump-outs**
4. **Animal detection system only, no fencing**

For this analysis, the cost for a collision is considered the combination of the average costs due to vehicle damage, human injury, human fatality, and lost wildlife value to hunters. The passive use values, such as the value of wildlife for tourism was not included in cost estimates. The "benefits" of implementing mitigation measures was defined as the collisions costs that are avoided by having the crossing structures. This cost-benefit analysis was conducted over a 75-year period, which was defined as the average life span of a concrete structure and was based on the 2007 U.S. dollar. Costs for large mammal-vehicle collisions were articulated in terms of dollars per year per mile and were based on a divided four lane highway with two lanes of traffic in both directions. The findings showed that fencing with underpasses and jump outs decreased the costs by nearly half as much as the use of animal detection systems only (Figure 38).

The average cost per mile per year for each type of mitigation effort broke down as follows:

1. Fence with underpass and jump outs - $29,166/mi/year
2. Fence with under- and overpass with jump outs - $38,994/mi/year
3. Fence, gap, animal detection, with jump outs - $45,303/mi/year
4. Animal detection system - $59,568/mi/year

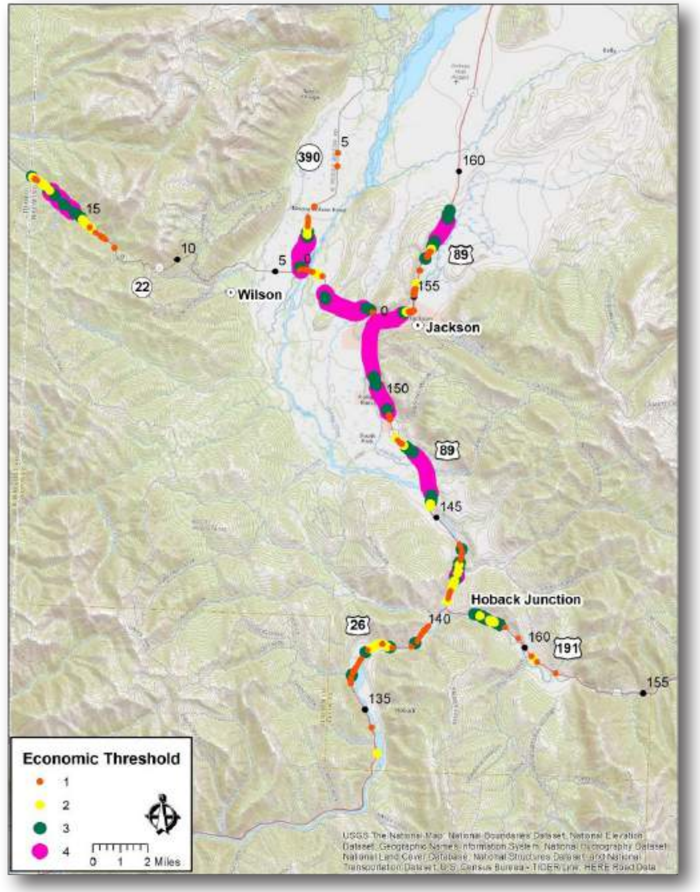


Figure 38. Economic threshold for crossing structures (Huijser et al., 2018).

Prioritization:

With the knowledge gained from the three parameters, human safety, biological conservation and economic impacts, a two-step process was followed to rank the road sections for mitigation efforts. The first step involved the calculation of a parameter based on a combination of human safety and economics, and calculation of a parameter based on biological conservation. To compute the parameter based on human safety and economics, the costs per mile per year associated with collisions were evaluated and weighted by large wild mammals based on body size because a larger animal was predicted to cause more damage. The highest calculated cost per mile per year was $113,660 and was set at the max threshold at 100%. The researchers then calculated the cost for each 0.1-mile road segments as a percentage of the threshold.

The second parameter based on biological conservation broken down into six sub-parameters which were combined into a single biological ranking factor. These sub-parameters included large mammal observation data, mule deer, elk, and moose movement, bighorn sheep presence, and large carnivore presence. Each category granted a road section 1 point, for a max total of six points, however no section of road scored more than three and thus a mark of three points was considered 100%. The biological conservation score was then calculated for each 0.1-mile road segment as a percentage of the maximum of three points.

The second step to decide priority areas included the calculation of a final overall ranking parameter based on the two parameters calculated in step 1. To do this, the human safety and economics parameter was combined with the biological conservation ranking by adding the values together and dividing by two. Road sections were broken down into three categories based on the highest score per 0.1-mile section of road, greater than 80%, 60-80%, and 40-60%. The total road length assigned a rank was 26.4 miles (30.2%) out of the 87.5 miles of road considered in the report (Figure 39).

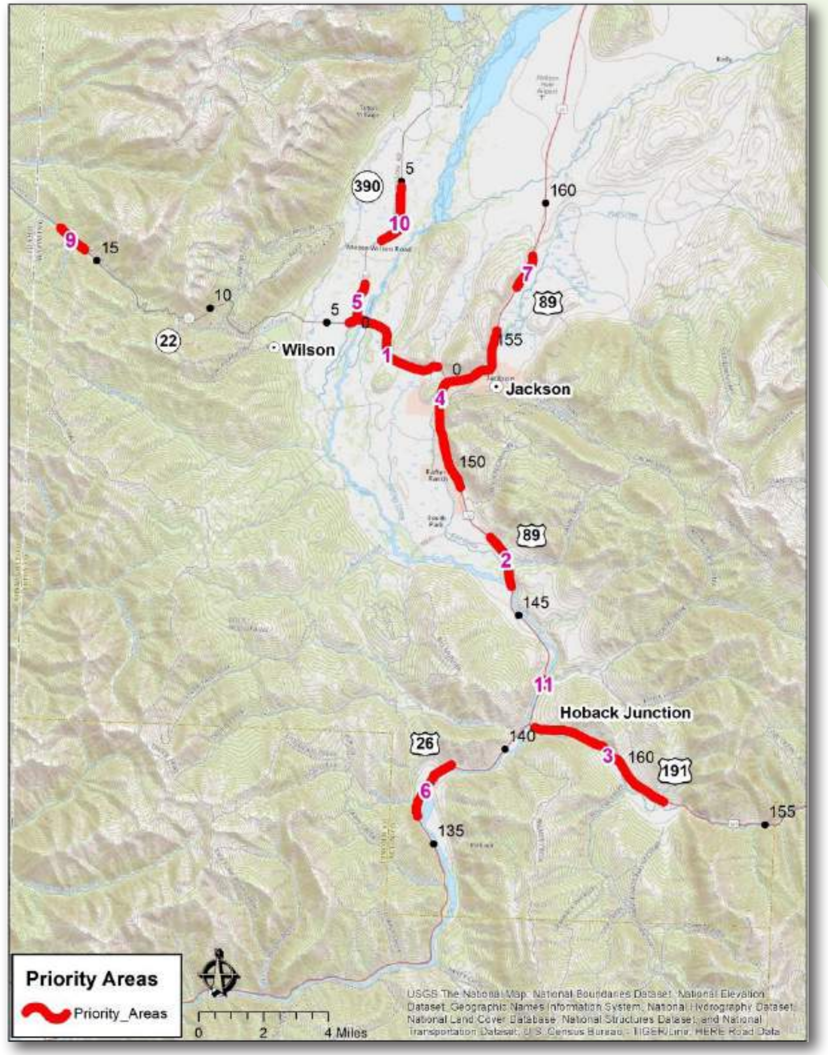


Figure 39. Priority Areas for crossing implementation (Huijser et al., 2018).

Mitigation Recommendations and Conceptual Designs:

Mitigation efforts along the road sections defined through the prioritization calculation were defined further based on the type of highway the section occupied. Roadways were broken down into four categories: high volume roads (10,000 vehicles/day or more) regardless of speed, medium volume roads (5,000 vehicles/day) with high design speed and limits, medium volume roads with low design speed and limits, and low volume roads (1,500 vehicles/day) with high design speed and limits. Each type of roadway was given site-specific recommendations including the types of crossings to be used and other visibility suggestions.

High volume roads would benefit from a combination of wildlife fences and crossing structures to keep animals off of the roadway (Figure 40). The type of crossing structure would be dependent on the target species. They also suggest improving visibility for drivers using streetlights to allow drivers greater reaction time to stopping for any wildlife on the road. High speed medium volume roadways would be improved with the use of fencing and crossing structures, however, in some locations this is not possible due to terrain and therefore, animal detection systems with fencing would suffice along with lowering the speed limits in those areas. They also suggest the use of lights to deter wildlife from the road, however, the use of lights is untested for the effectiveness of keeping wildlife away and should be used with caution. With low-speed medium volume roadways, researchers note that with the speed and visibility range, around 50% of drivers should be able to stop in time to avoid any collisions meaning no added measures need to be implemented. Finally, with low volume roads that have high speeds, drivers are often not able to stop in time and they suggest the use of animal detection systems where crossing structures are unsuitable and increased lighting.

Once priority road sections were established, and types of mitigation measures were determined for each road section, conceptual drawings were developed to provide an example of how these structures could look on the landscape. Researchers were clear in the section to note that just because these conceptual drawings were in specific places that did not mean it was the best location for the structure. They note that there are many diverse types of structures that could be used at varying points within the defined road sections and a further analysis into site specific locations would enhance the location decisions. For example, they mentioned how at the road section along U.S. highway 189/191 at the Hoback-Camp Creek location, the conceptual designs show an animal detection system with use of lighting because it is considered a low volume road, however, researchers on the study say that fencing combined with a crossing structure would be preferred in this location to the high frequency of collisions with elk along a critical migration corridor as well as issues with bighorn sheep licking salt laid on the road in the winter months (Figure 41).

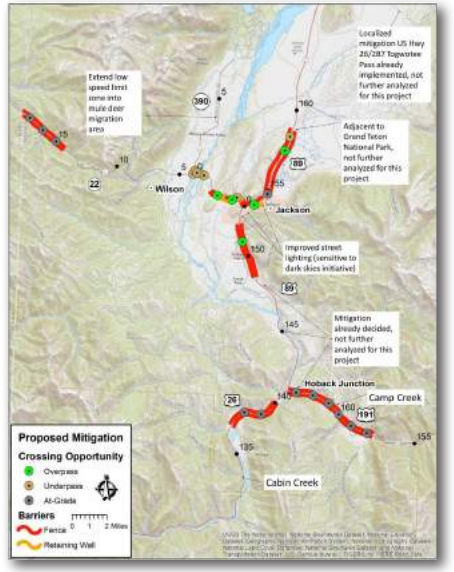


Figure 40. Proposed mitigation opportunities (Huijser et al., 2018). et al., 2018).

Draft Conceptual Mitigation Suggestion

US Hwy 189/191, Hoback - Camp Creek

Situation
- High concentration of elk-vehicle collisions.
- Important movement/migration area for mule deer and elk.
- Bighorn sheep licking road salt is a concern.
- 2, lanes, low traffic volume (1,600 vehicles/day), high percentage of semi-trucks.
- Relatively flat terrain immediately adjacent to road.

Draft Suggestions
- Wildlife fences and wildlife crossing structures are preferred (typically more reliable, effective and less risky than detection systems). However, the low traffic volume may allow for experiments with at-grade crossing opportunities.
- Consider at-grade crossing opportunities that are lighted when a vehicle approaches. This is aimed at improving visibility of large mammals to drivers in selected crossing locations and at hazing the animals off the highway when traffic approaches.
- Provide multiple crossing locations (perhaps one per mile or so).
- Keep large mammals from entering US Hwy 189/191 and reduce collisions through wildlife fences.
- Encourage wildlife to cross the highway and keep them from entering the fenced road corridor through electric mats or electric concrete embedded in the travel lanes at the crossing areas.
- When a vehicle is detected (induction loops) approaching a crossing area, activate signs that inform the driver they are approaching a crossing area and advertise a lower speed (35 MPH). At the end of the crossing area have a sign that says "End Wildlife Crossing Area). When no traffic is present, the signs do not display any information (black).
- The lights at the crossing area are only "on" when a vehicle approached. The lights are directed down towards road surface, minimizing light pollution.

Note: This is a suggestion. It illustrates the design principles and design concepts. This is not an official planning or zoning document. In addition, the suggestions are not necessarily tied to a specific parcel, but they do relate to recognizable road sections.

Figure 41. Example of a draft mitigation suggestion (Huijser et al., 2018).

Monitoring:

To understand if these mitigation efforts are effective, the researchers suggest a basic framework for post construction monitoring programs. Monitoring efforts were broken down into two categories, wildlife-vehicle collisions rates and wildlife use of crossings. To evaluate collisions, they suggested the use of a before-after-control-impact (BACI) approach which involves the collection of collision data before and after the implementation of the crossing structures. Data along a "control" road, or a section that received no mitigation measures, is also collected to measure against. More data collected over a longer period and at multiple sites will allow for more correct analysis and conclusions. Measuring effective use of wildlife crossings is more complicated because simply tallying the number of animals that use the crossing only illustrates use. To figure out effectiveness, objectives must be outlined prior to data collection. This can take the form of many types of research questions related to target species, or the number of individuals within a target species that use the crossing, as well as genetic connectivity, and habitat connectivity. Each of these questions would come with their own research methods and analysis, but would include the use of remote cameras, tracking beds, and/or GPS tracking collars to monitor any animals that use the crossing. Monitoring the effectiveness of crossing structures allows for a greater understanding of how and when to use different mitigation types.

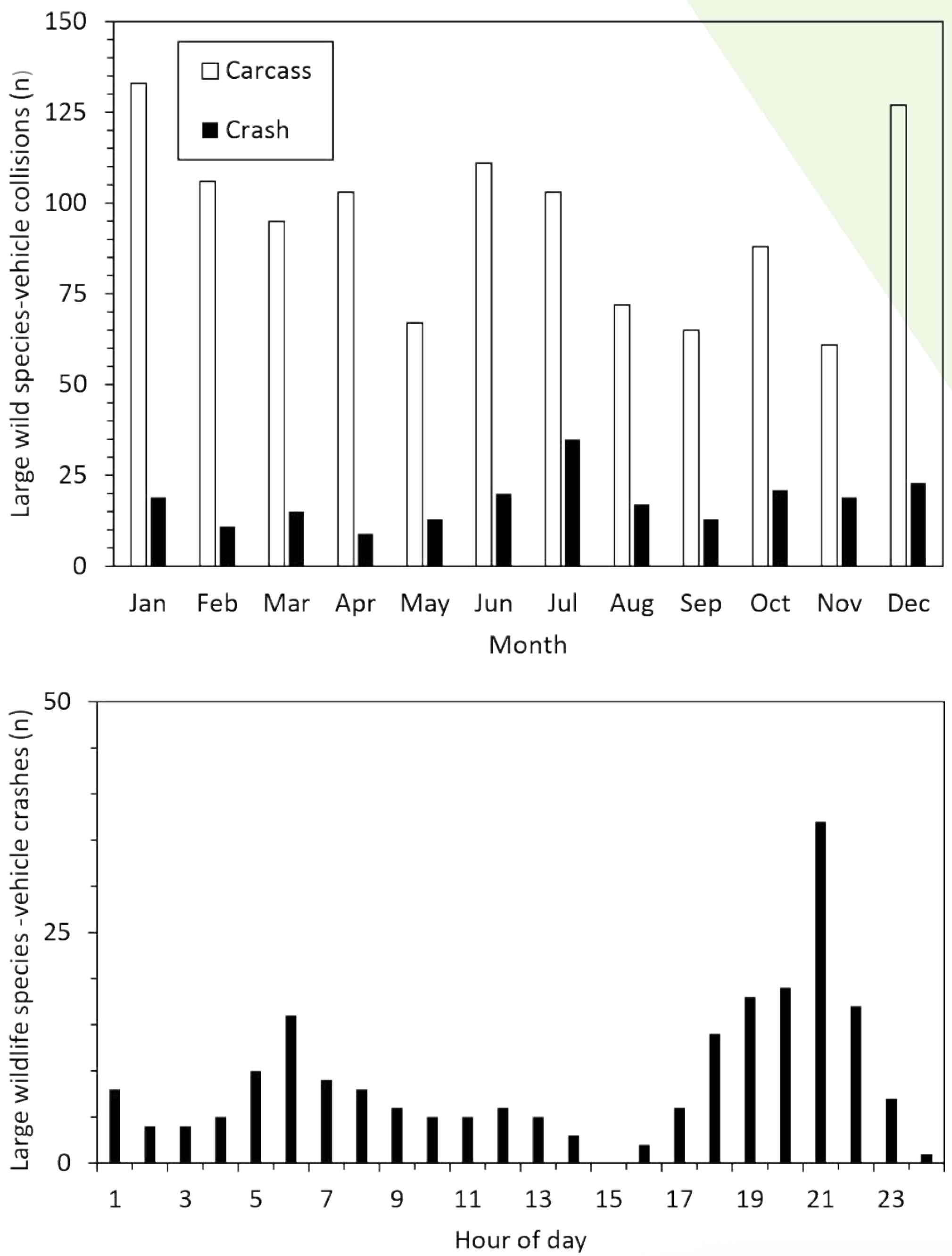


Figure 42. Time of year and hour of day collisions prior to study (Huijser et al., 2018).

2.4 Target species selection

As mentioned previously, crossing designs are roadway and species dependent. It would not make sense to implement a small culvert crossing for an area dominated by moose. It is therefore important to identify and consider the target species, or multiple species, of the study area and design in accordance to their specific needs. Clevenger and Huijser (2009) provide a detail list of species and the crossing types that are suitable for each species as a guide for design.

2.4.1 Species presence

First and foremost, it is key to understand what species use the area and which of them are considered important for that area. For this, most local fish and game agencies will have reports of key wildlife for given areas. Idaho Fish and Game has a summary of key fish and wildlife species for the Teton county region. For the purpose of their report they considered key species that are important for social, ecological and economic benefit to the area. They define ‘flagship’ species as those with economic importance as harvestable species, ‘species of greatest conservation need’ as designated by the Idaho Comprehensive Wildlife Conservation Strategy (ICWCS, IDFG 2005), and keystone species that represent a conservation benefit to other species in similar habitats (IDFG, 2012). There are three species that are considered the primary ungulates for the area because of their importance to the hunting communities and huge economic impacts to the area; elk, mule deer, and moose (IDFG, 2012). In 2006, mule deer hunting alone brought $42 million dollars to the area in direct expenses related to fuel, meals, and lodging within the Teton region (IDFG, 2012). Additionally, license and tag sales for mule deer brought nearly $6.3 trillion dollars to IDFG with 20% of those revenues going directly to wildlife conservation efforts, monitoring and management programs (IDFG, 2012).

Other species present in the Teton region that are considered key focal species include mountain lions, black and grizzly bears, Canada lynx, and wolverine (IDFG, 2012). These carnivores tend to spend their time in higher-elevation areas away from human disturbance, however, between 2009 and 2011, IDFG had to relocate some of these animals due to conflict with humans along the edges of urban areas (IDFG, 2012). Most commonly, carnivores may use the creek corridors for movement from the forested areas into the basin. Avian species present in the Teton region include the Columbian sharp-tailed grouse, greater sandhill crane, and bald eagles (IDFG, 2012). These species are most impacted by habitat loss due to fragmentation and land conversion or degradation of the native grasslands or forested habitats they rely on for mating (IDFG, 2012). For a full list of species within the Teton region, refer to the report “A Summary of Key Fish and Wildlife Resources of Low Elevation Lands in Teton County, Idaho” from Idaho Fish and Game. For the purpose of this project, the focus species will include the large game animals important for socio-economic growth, at-risk species, and those that pose the greatest threat to human life due to collisions.

2.4.2 At risk species

Federal delineation of threatened and endangered species is the primary source of determining if and animal is at risk of becoming extinct. A threatened species is defined as “likely to become endangered within the foreseeable future” and endangered species are “in danger of extinction throughout all or a significant part of its range” (USGS, 2021). Roadway mortality plays a major role in survivability for 21 species identified in the 2008 Report to Congress. However, it is noted that there are other factors contributing to the endangerment of these species including habitat loss due to fragmentation, urbanization, mining and agriculture, live stock grazing, logging, fire suppression, invasive species, water pollution, competition with non-native species, poaching, and loss of genetic diversity due to small meta populations from fragmentation (Huijser et al., 2018). Of the species identified, one is located within the Teton region, the Canada lynx. It is therefore important to consider areas of critical habitat for lynx survival in the overall planning process for mitigation efforts.

In addition to the designated species from the Report to Congress, species identified as federal, or state species of concern will also be considered in the greater planning process to identify critical habitats for protection. This study will include amphibian and mammal species designated as a Species of Greatest Conservation Need under the ICWC, US Fish and Wildlife listed threatened or endangered species, and Bureau of Land Management (BLM) type 3 (regional/state imperiled species) species. Bird and fish species will not be considered as they are not likely to be hit by vehicles and pose any major threat to human safety on road corridors. Additionally, only mammal species larger than foxes will be considered as small species such as mice, shrews, and squirrels also pose little threat to human safety. This includes the following species:

1. Amphibians
   a. Columbia spotted frog (*Rana pretiosa*)
   b. Western toad (*Anaxyrus boreas boreas*)

2. Mammals
   a. Big horn sheep (*Ovis canadensis*)
   b. Canada lynx (*Lynx canadensis*)
   c. Gray wolf (*Canis lupus*)
   d. Grizzly bear (*Ursus arctos*)
   e. Wolverine (*Gulo gulo*)

2.4.3 Greatest threat to human safety

Species survival and connectivity of habitats is equally as important as human safety and reducing fatal accidents as a result of collisions with wildlife. In general, the larger the animal, the greater threat it poses to increasing the severity of the injuries sustained as a result of a collision. Moose, elk, and grizzly bears are the largest species within the Teton basin that would be the greatest threat to human safety. In a study conducted in Newfoundland, it was found that of all the collisions with moose, 0.6% resulted in fatality and 26% resulted in serious injury (Huijser et al., 2008a). The Report to Congress (2018) also looked at various data records and found, for example, in Maine that while deer account for 81% of all WVCs, moose and bears make up 16% of all crashes. Within the Teton County Wildlife Crossings Master Plan, species larger than coyotes were used to define species that were considered a greater risk to safety. They delineated severe crashes to be associated with large mammals that cause over $1,000 in damages to vehicles (Huijser et al, 2018(1)). Therefore, for the purpose of this study, large mammals, greater than fox in size (25 pounds), will be considered as a threat to human safety.

2.4.4 Wildlife Habitat Maps

The following species will be considered in the regional habitat connectivity assessments and aid in the selection of critical corridors for wildlife movement and ultimately the locations for mitigation implementation. See appendix A for all habitat maps. Species considered were: mule deer, white-tailed deer, elk, moose, grizzly bear, black bear, and Canada lynx.

Chapter 3: Methods for Roadway Identification

This chapter explains the specific methods used in this project to identify priority zones along the major highways in the Teton Watershed and a cost-benefit analysis of each crossing type under two different stakeholder driven scenarios.

To locate priority areas for mitigation measures, areas with high concentrations of wildlife related collisions need to be identified as well as some of the characteristics of WVCs that could be contributing to those crashes. By evaluating factors that may be causing crashes, smaller, less expensive interventions to mitigation might be possible to reduce collisions. A density analysis of collisions with wildlife and carcass removals provided the locations in which wildlife crossing mitigation measures are warranted for the reduction of collisions.

Data used for Analysis

Data	Source	Method	Outcome
Average Daily Trips Approaches (driveways) Barrier Presence Barrier Height Bridge Presence Month Day of Week Time of Day Lane Type Lane Width Light Presence Shoulder Type Shoulder Width Speed Limit Adjacent Terrain	Idaho Transporation Department open GIS Data	Multivariate Regression	Characteristics that explain where collisions with wildlife are occuring: Month, Speed Limit, Barrier Height, Adjacent Terrain, and Shoulder Type.
Wildlife Collisions Carcass Removals	Idaho Fish and Game	Kernel Density - "Hot Spot" Analysis	Low, Moderate, High, and Very High densities of collisions with wildlife and carcass removals along major highways.
GAP Habitat Idaho Critical Habitat Mule Deer Habitat White-tailed deer Habitat Moose Habitat Elk Habitat Canada lynx Habitat Grizzly bear Habitat Black bear Habitat	USGS GAP Program Idaho Fish and Game USGS GAP Species Range and Predicted Habitat Data	Biological Conservation Value	Low, Moderate and High values for conservation of habitat.
Collision Costs	Huijser et al., 2008b Average cost of a collision with a deer in 2007$	Cost-Benefit Analysis	Cost of colliisons per 0.1 mile section of roadway

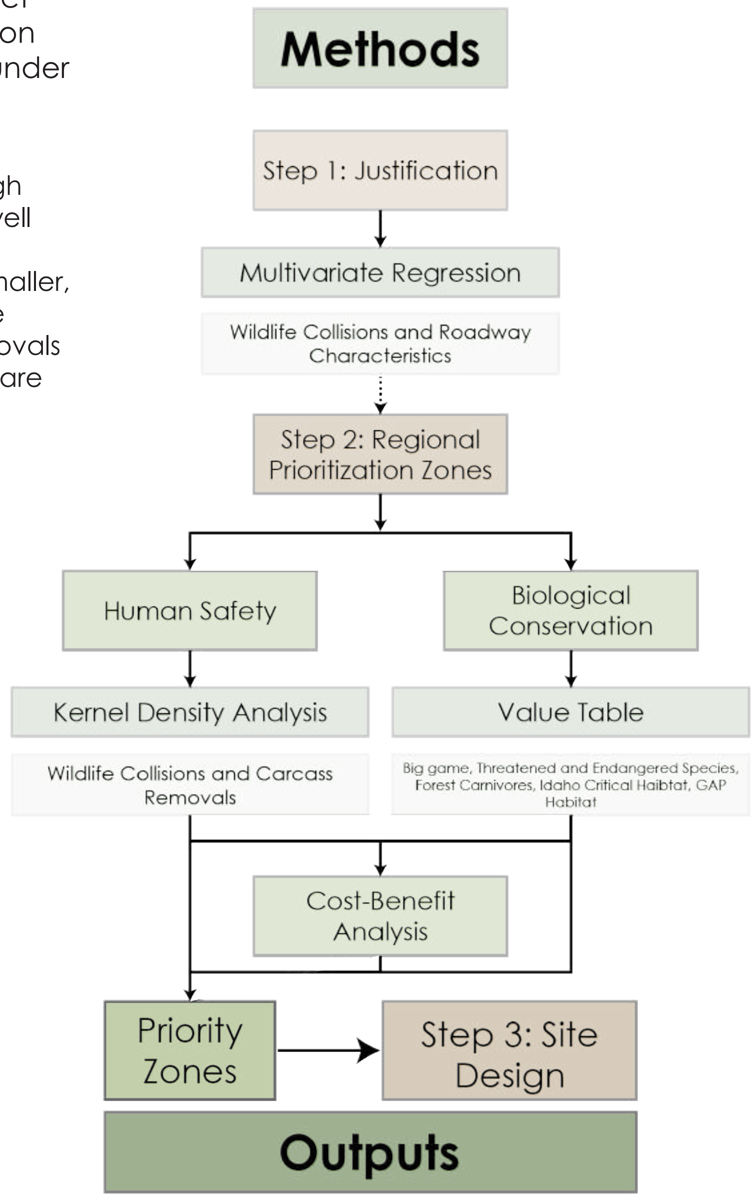
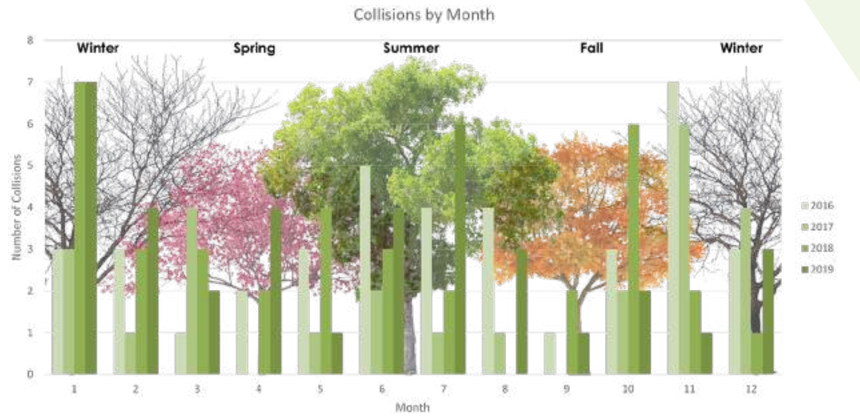


Figure 43. Process diagram for the methods section of this project.

3.1 Multivariate Linear Regression – Characteristics of wildlife-vehicle collisions

In the 2008 Report to Congress, an extensive review of literature related to wildlife collisions and the conditions in which they occurred led to the designation of key characteristics of collisions involving wildlife. They included variables such as population growth, time of day and year, roadway type, traffic density, weather, and landscape adjacent to the roadway (Huijser et al., 2008). To determine how these characteristics, and others, influence WVCs in Teton, roadway traits were evaluated through a multivariate linear regression tool in ArcGIS Pro called "Exploratory Regression" where all possible combinations of the input variables are evaluated to find the ones that best explain the dependent variable (collisions with wildlife). Data was limited to what was available through ITD and IDFG. Variables included the following:

- o Average Daily Trips (ADT)
- o Approaches (driveways and side roads)
- o Barrier presence, height and length
- o Bridge presence
- o Carcass removal
- o Month
- o Time of day
- o Lane type and width
- o Shoulder type and width
- o Speed limit
- o Adjacent terrain
- o Light presence



The top five variables that influenced collisions reported between 2009 and 2019 were month (winter months), speed limits (higher speeds), lower guardrail heights, terrain type (flat), and shoulder type (paved) with an r-squared value of 0.03. These characteristics could be considered in roadway development and renovations to minimize the chances of increased collisions with wildlife (Figure 44).

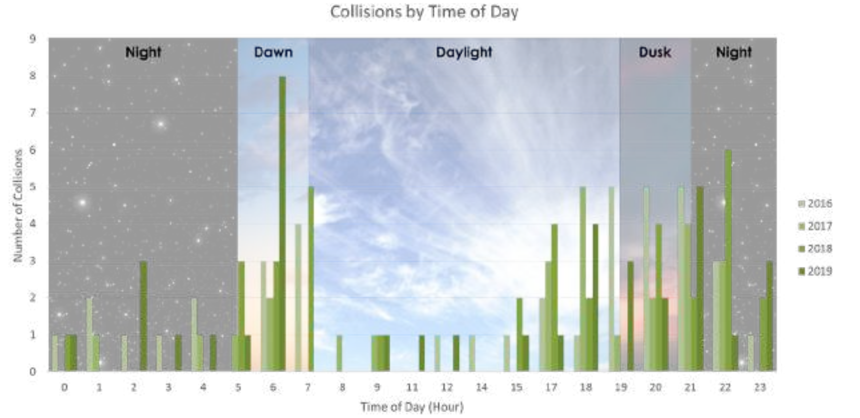
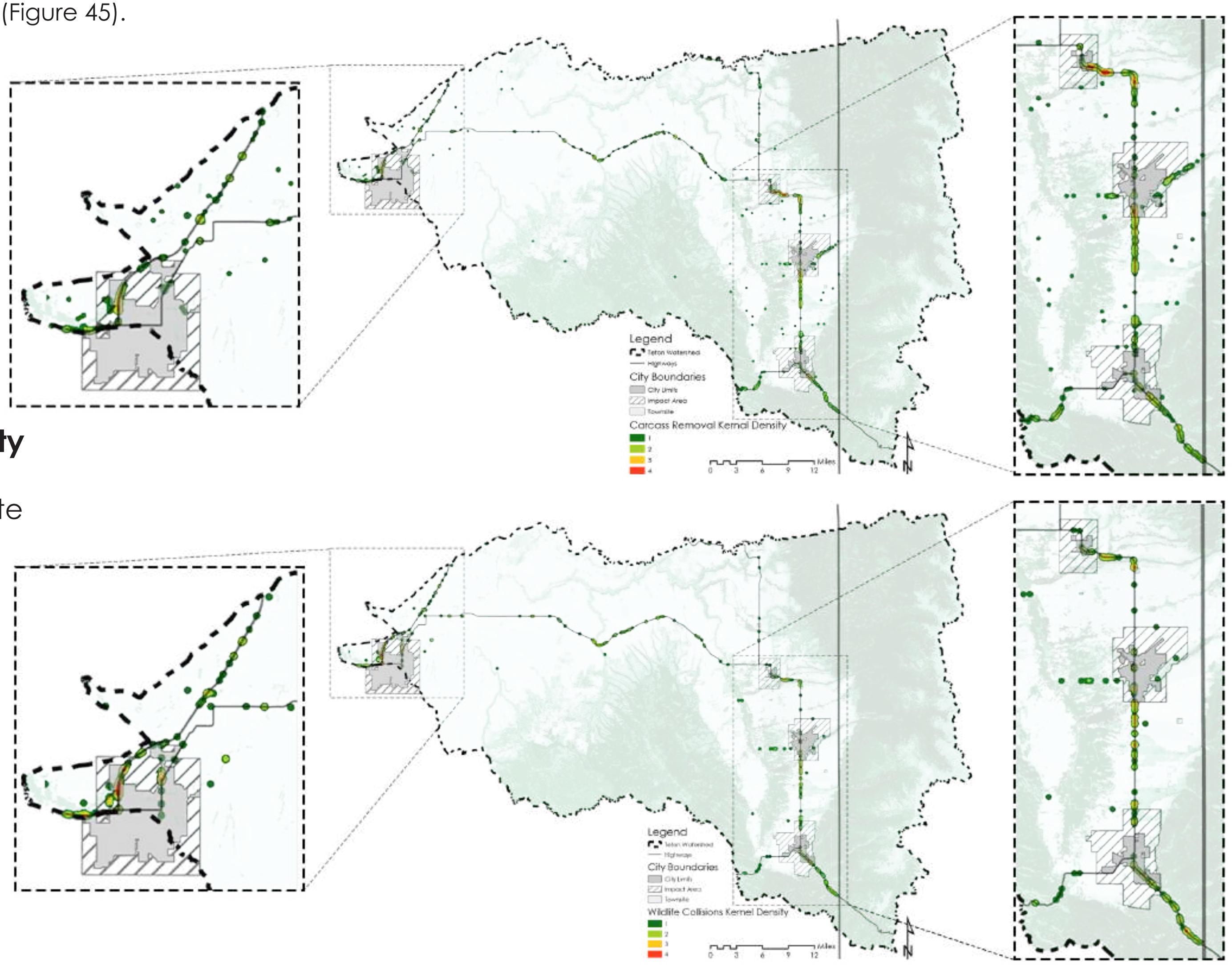


Figure 44. Time of year and hour of day for collisions in the Teton Watershed.

3.2 Kernel Density – "Hot Spot" analysis

The locations of areas with higher proportions of collisions with wildlife were found using a kernel density analysis in ArcGIS Pro using the tool "Kernel Density". This tool calculates a "magnitude-per-unit area from points using a kernel density function to fit a smooth surface to each point" (ESRI, 2021). The search radius used was 500 m. Hot spot analyses were conducted for wildlife collisions and target species (elk, moose, mule deer, white-tailed deer, moose, black bear, Canada lynx, and grizzly bear) carcass removals between 2010 and 2019. Densities were broken down into 4 categories: low, moderate, high, and very high by natural jenks which separate data into "natural groupings in the data to maximize the differences between classes" (ESRI, 2021). Low values are areas where there is a low density of collisions within the 500 m radius and very high values are areas with high densities of collisions. Values were recorded per 0.1 mi sections of road on all major highways in the watershed (Figure 45).

Kernel Density
- Low
- Moderate
- High



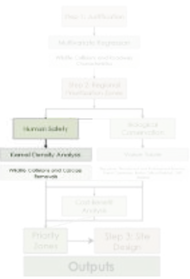
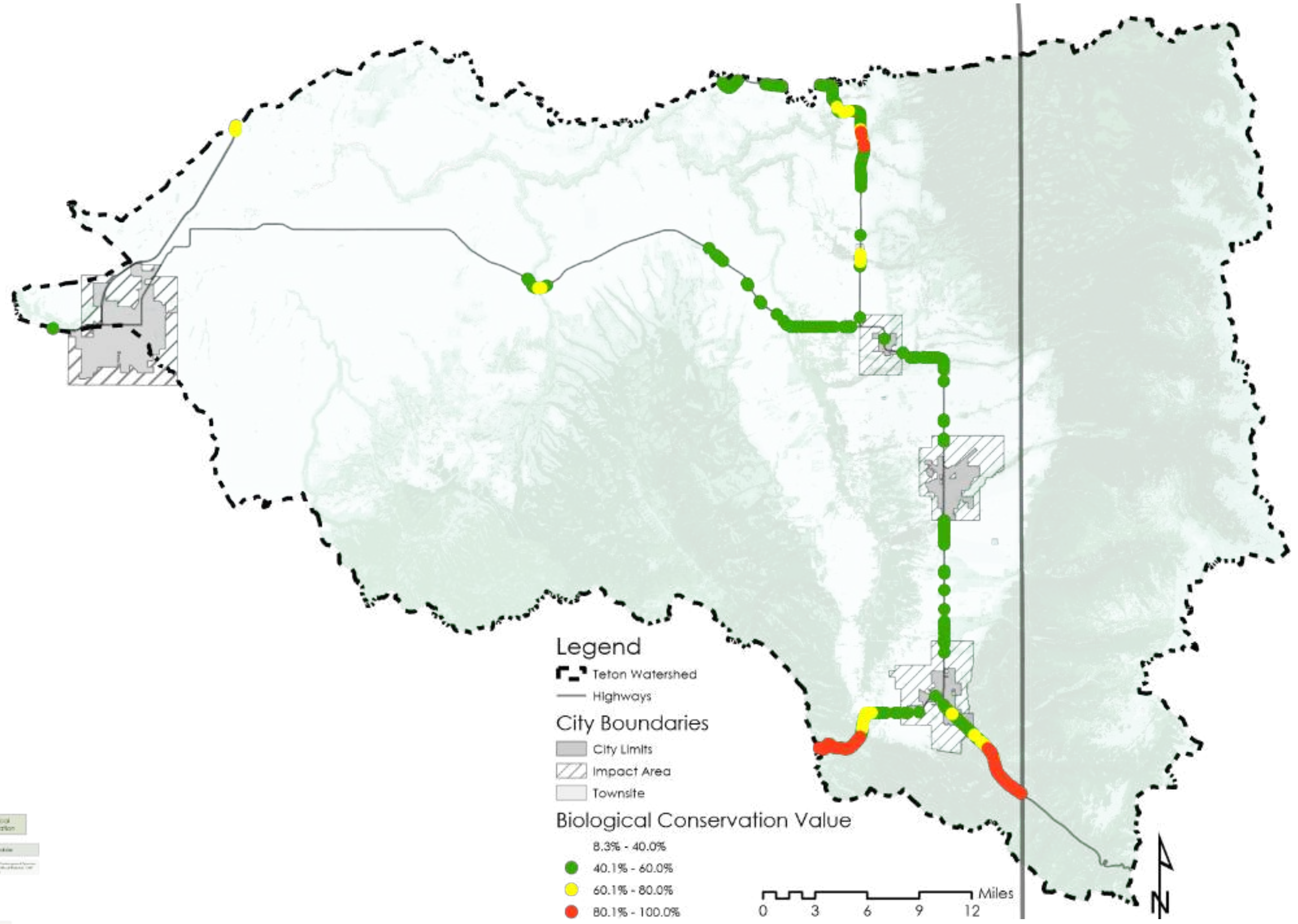


Figure 45. Kernel density analysis for collisions with wildlife and carcass removals in the Teton Watershed.

3.3 Biological Conservation Value

To give value to natural features beyond the bounds of the roadway, biological conservation items were defined based on the target game species identified by IDFG, the presence of threatened and endangered (T&E) species, presence of forest carnivores, GAP analysis habitats, and Idaho critical habitats (Figure 46). Species presence was defined by the GAP habitat analysis outlined by the United State Geological Survey (USGS) for each species as set to a binary value, 1 for presence, 0 for absence. Key game species were mule deer, elk, moose, and white-tailed deer (IDFG, 2012). Two species were identified as threatened or endangered within the watershed, Canada lynx and grizzly bear (IDFG, 2012). Forest carnivores were considered as any species greater than fox in size that had potential habitat within the watershed. These species included black bears in addition to lynx and grizzlies. The choice to include lynx and grizzly bears into both categories was to give them more weight for protection as T&E species. Values were recorded per 0.1 mi sections of road on all major highways. To find the total value of each section of road, the total value of the section was divided by the total points possible. While there was a possibility of 13 points, the highest value achieved for any section was 12 and thus was set as the maximum possible score.



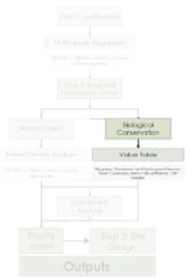


Figure 46. Biological conservation values.

3.4 Cost-Benefit Analysis

Collision densities are useful to find where crashes are occurring, but more importantly, knowing how much those collisions are costing the community can put a value on attempting to mitigate those collisions. The average number of collisions per 0.1 mi section of roadway between 2015 and 2019 were multiplied by the estimated cost of a collision with a deer $8,999 (Figure 47). This value was determined by using the inflation rate between 2007 and now, 36%, and adding that to the 2007 cost of collisions with wildlife, $6,617, according to the 2008 Report to Congress (Huijser et al., 2008b). This is the cost of vehicle repairs, human injuries or fatalities, towing, monetary value of the animal, and disposal of the carcass. In other words, it is the amount of money spent by the individuals and agencies within the community after a wildlife-vehicle collision. This value was then divided by the highest cost per 0.1 mi section ($77,391.40).

			Human Safety					Biological Conservation									All Collisions and Carcass Removals within 1 mile of each Mile Marker						Economics		
ID	Milepost Reference	Highway	Fatal Collisions (ITD) (Presence/Absence)	Collisions with Wildlife (ITD)	All Collisions (ITD)	Carcass Removal (IDFG)	Wildlife Collisions + All Collisions + Carcass Removal KD	Mule Deer Habitat	Elk Habitat	Moose Habitat	White tail deer Habitat	Threatened/Endagered Species Habitat	Forest Carnivore Habitat	GAP Analysis Habitat (GAP Code - max 3)	Idaho Critical Habitat (Rank - max 4)	Percent (of highest section value - 12)	2019	2018	2017	2016	2015	AVERAGE # Collisions Annually	Collision Cost (AVG $/Collision with Deer)	Collision per 0.1 mile as a percentages of the highest cost ($35,220.61)	HIGHWAY PRIORITY ZONE (Human Safety and Economics + Biological Conservation)/2
1	14.3	31				Low	Low	1	1	0	1	1	1	3	3	92%	2	0	0	0	3	1	$8,999.00	12%	52%
2	14.4	31			Low	Low	Low	1	1	0	1	1	1	3	3	92%	2	0	0	0	3	1	$8,999.00	12%	52%
3	14.5	31	1		Low	Low	Low	1	1	0	1	1	1	3	2	83%	2	0	0	0	3	1	$8,999.00	12%	47%
4	14.6	31			Low	Low	Low	1	1	0	1	1	1	3	2	83%	2	0	0	0	3	1	$8,999.00	12%	47%
5	14.7	31		Low	Low	Low	Moderate	1	1	0	1	1	1	3	2	83%	2	0	0	0	3	1	$8,999.00	12%	47%
6	14.8	31		Low		Low	Low	1	1	0	1	1	1	3	2	83%	2	0	0	0	3	1	$8,999.00	12%	47%
7	14.9	31		Low		Low	Low	1	1	0	1	1	1	3	2	83%	2	1	0	0	3	1.2	$10,798.80	14%	49%
8	15	31		Moderate		Moderate	Moderate	1	1	0	1	1	1	3	2	83%	2	2	0	1	3	1.6	$14,398.40	19%	51%
9	15.1	31		Low		Moderate	Moderate	1	1	0	1	1	1	3	2	83%	2	2	0	1	3	1.6	$14,398.40	19%	51%
10	15.2	31		Low		Low	Low	1	1	0	1	1	1	3	2	83%	2	2	1	1	3	1.8	$16,198.20	21%	52%
11	15.3	31						1	1	0	1	1	1	3	2	83%	2	2	2	1	4	2.2	$19,797.80	26%	54%
12	15.4	31						1	1	0	1	1	1	3	2	83%	1	2	3	1	4	2.2	$19,797.80	26%	54%
13	15.5	31						1	1	0	1	1	1	3	2	83%	1	2	3	1	4	2.2	$19,797.80	26%	54%
14	15.6	31						1	1	0	1	1	1	3	2	83%	2	2	3	1	4	2.4	$21,597.60	28%	56%
15	15.7	31				Low	Low	1	1	0	1	1	1	3	2	83%	2	2	4	1	4	2.6	$23,397.40	30%	57%
16	15.8	31				Low	Low	1	1	0	1	1	1	3	2	83%	2	2	4	1	4	2.6	$23,397.40	30%	57%
17	15.9	31		Low		Moderate	Moderate	1	1	0	1	1	1	3	2	83%	1	2	4	1	4	2.4	$21,597.60	28%	56%
18	16	31		Low		High	Moderate	1	1	0	1	1	1	3	2	83%	1	2	4	1	4	2.4	$21,597.60	28%	56%
19	16.1	31		Low		High	Moderate	1	1	0	1	1	1	3	2	83%	1	2	4	1	4	2.4	$21,597.60	28%	56%
20	16.2	31		Low		Moderate	Moderate	1	1	0	1	1	1	3	2	83%	1	2	4	1	3	2	$17,998.00	23%	53%
21	16.3	31		Low		Moderate	Moderate	1	1	0	1	1	1	3	2	83%	1	2	4	1	1	1.8	$16,198.20	21%	52%
22	16.4	31		Low		Moderate	Moderate	1	1	0	1	1	1	3	2	83%	1	2	4	1	1	1.8	$16,198.20	21%	52%
23	16.5	31		Low		Moderate	Moderate	1	1	0	1	1	1	0	2	58%	1	2	5	1	1	2	$17,998.00	23%	41%
24	16.6	31		Low		Low	Low	1	1	0	1	1	1	0	2	58%	1	2	5	1	1	2	$17,998.00	23%	41%
25	16.7	31		Low		Low	Low	1	1	0	1	0	1	0	3	58%	1	2	5	1	1	2	$17,998.00	23%	41%
26	16.8	31		Low			Low	1	1	0	1	1	1	0	3	67%	1	2	5	1	1	2	$17,998.00	23%	45%
27	16.9	31		Low		Low	Low	1	1	0	1	0	1	0	3	58%	2	2	5	1	1	2.2	$19,797.80	26%	42%
28	17	31				Low	Low	1	1	0	1	1	1	0	3	67%	2	2	5	1	1	2.2	$19,797.80	26%	46%
29	17.1	31				Low	Low	1	1	0	1	1	1	0	3	67%	2	0	5	1	1	1.8	$16,198.20	21%	44%
30	17.2	31						1	1	0	1	1	1	0	3	67%	2	0	5	0	1	1.6	$14,398.40	19%	43%
31	17.3	31						1	1	0	1	1	1	0	3	67%	2	0	4	0	1	1.4	$12,598.60	16%	41%
32	17.4	31				Low	Low	1	1	0	1	1	1	0	3	67%	2	0	3	0	1	1.2	$10,798.80	14%	40%
33	17.5	31				Low	Low	1	1	0	1	1	1	0	3	67%	2	0	3	0	0	1	$8,999.00	12%	39%
34	17.6	31				Low	Low	1	1	0	1	0	1	0	3	58%	2	0	2	0	0	0.8	$7,199.20	9%	34%
35	17.7	31		Low		Low	Low	1	1	1	1	1	1	0	3	75%	2	0	2	0	0	0.8	$7,199.20	9%	42%
36	17.8	31		Low		Low	Low	1	1	0	1	0	1	0	3	58%	2	0	2	0	0	0.8	$7,199.20	9%	34%
37	17.9	31	1	Low			Low	1	0	0	0	0	1	0	3	42%	1	0	2	0	0	0.6	$5,399.40	7%	24%
38	18	31		Low			Low	1	0	0	0	0	1	0	3	42%	1	0	1	0	0	0.4	$3,599.60	5%	23%
39	18.1	31		Low			Low	1	1	0	1	0	1	0	3	58%	1	0	1	0	0	0.4	$3,599.60	5%	31%
40	18.2	31		Low			Low	1	0	0	0	0	1	0	3	42%	1	0	1	0	0	0.4	$3,599.60	5%	23%

Table 3. Example of analysis used to identify priority areas using cost analysis.

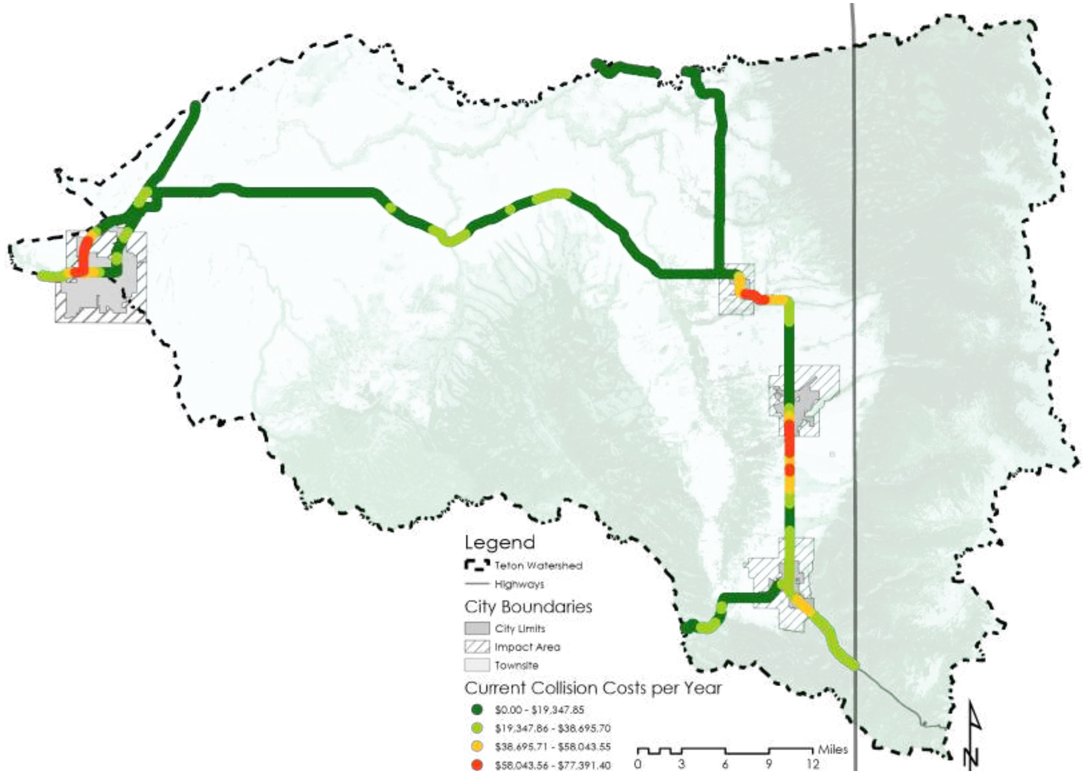


Figure 47. Current collision costs per year (2021).

3.5 RESULTS

The final determination of highway priority zones for wildlife crossing mitigation measures combines the human factor, the cost of collisions, with the biological conservation value of the road section. For each 0.1 mi section of road, the percent of cost of collisions calculated in section 4.3 was added to the percent of biological conservation calculated in section 4.4 and divided by two to find the overall priority percent of the road (Figure 48). Values less than 39% were considered non-priority, 40-59% were low priority, 60-79% were moderate priority, and those above 80% were considered high priority. No single section of road exceeded 78%.

$$\frac{\text{BIOLOGICAL CONSERVATION VALUE (\%)} + \text{COLLISION COST (\%)}}{2} = \text{PRIORITY ZONE VALUE (\%)}$$

3.6.1 *Business-as-Usual circa 2050 Priority Zones*

There were four distinct sections of roadway that were considered moderate priority for mitigation measures. Those areas are:

1. Idaho State Highway 33: mile markers 132.5 – 135.6
2. Idaho State Highway 33: mile markers 141.4 – 145.2
3. Idaho State Highway 33: mile markers 150 – 155
4. US Interstate 20: mile markers 333.4 – 335.1

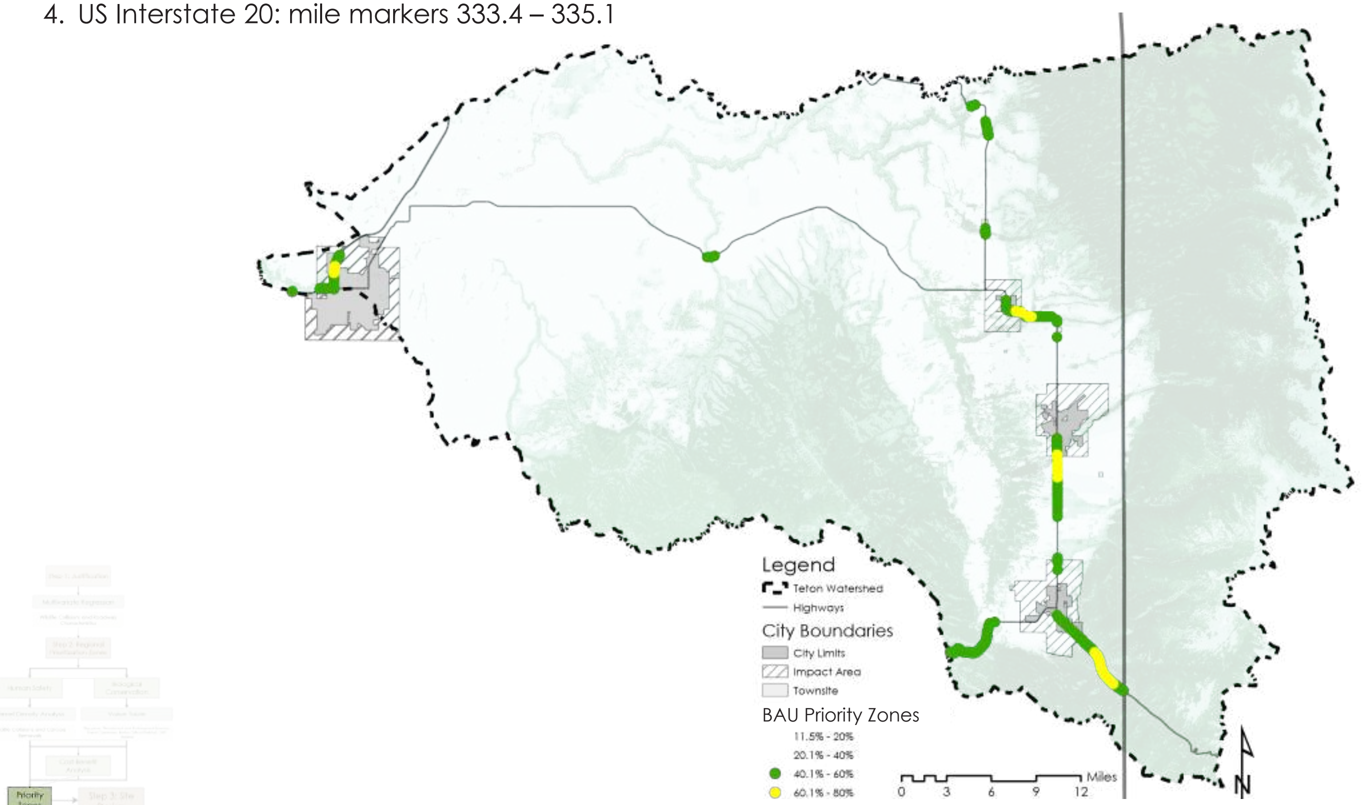


Figure 48. Priority zone locations for the scenario Business as Usual

3.6.2 *Recreation Sprawl circa 2050 Priority Zones*

Evaluation of the impacts of growth in the Teton region on wildlife collisions were aligned with the scenario "Recreation Sprawl - 2050" from the stakeholder driven scenarios within the GEM3 project. Population growth and increased roadway use were run through the model to illustrate how collisions might increase over time if no mitigation measure were implemented. Between 2010 and 2020 there was a growth in population within the area of nearly 12%. This value was used as a proxy to estimate the increased number of collisions. Current collision averages were multiplied by 30% to account for growth between 2020 and 2050. All habitat biological conservation factors stayed the same. All Idaho Critical Habitats were given a value one greater than current conditions, assuming within the scenario that habitat is further degraded due to increased recreational use of the land and conversion of natural land types to developed land or agriculture to accommodate increased population. With this assumed collision count for 2050, priority areas were reassigned and evaluated against the current model. Under this scenario, priority areas were as follows:

1. Idaho State Highway 31: mile markers 14.3 – 17.7
2. Idaho State Highway 33: mile markers 76.1 – 78.7
3. Idaho State Highway 33: mile markers 132.2 – 136.2
4. Idaho State Highway 33: mile markers 141 – 145.3
5. Idaho State Highway 33: mile markers 149.9 – 155
6. US Interstate 20: mile markers 333.4 – 335.3

While the sections of roadway did not change, they expanded slightly, and the priority levels were higher overall (Figure 49). The highest priority seen under this scenario was 94% within the 4th priority zone. There were also new areas that emerged as being low priority compared to the current model. This suggests that over time, as population increases, current priority areas will become increasingly important to mitigate crashes and there is the potential for new conflict zones to arise that will need attention.

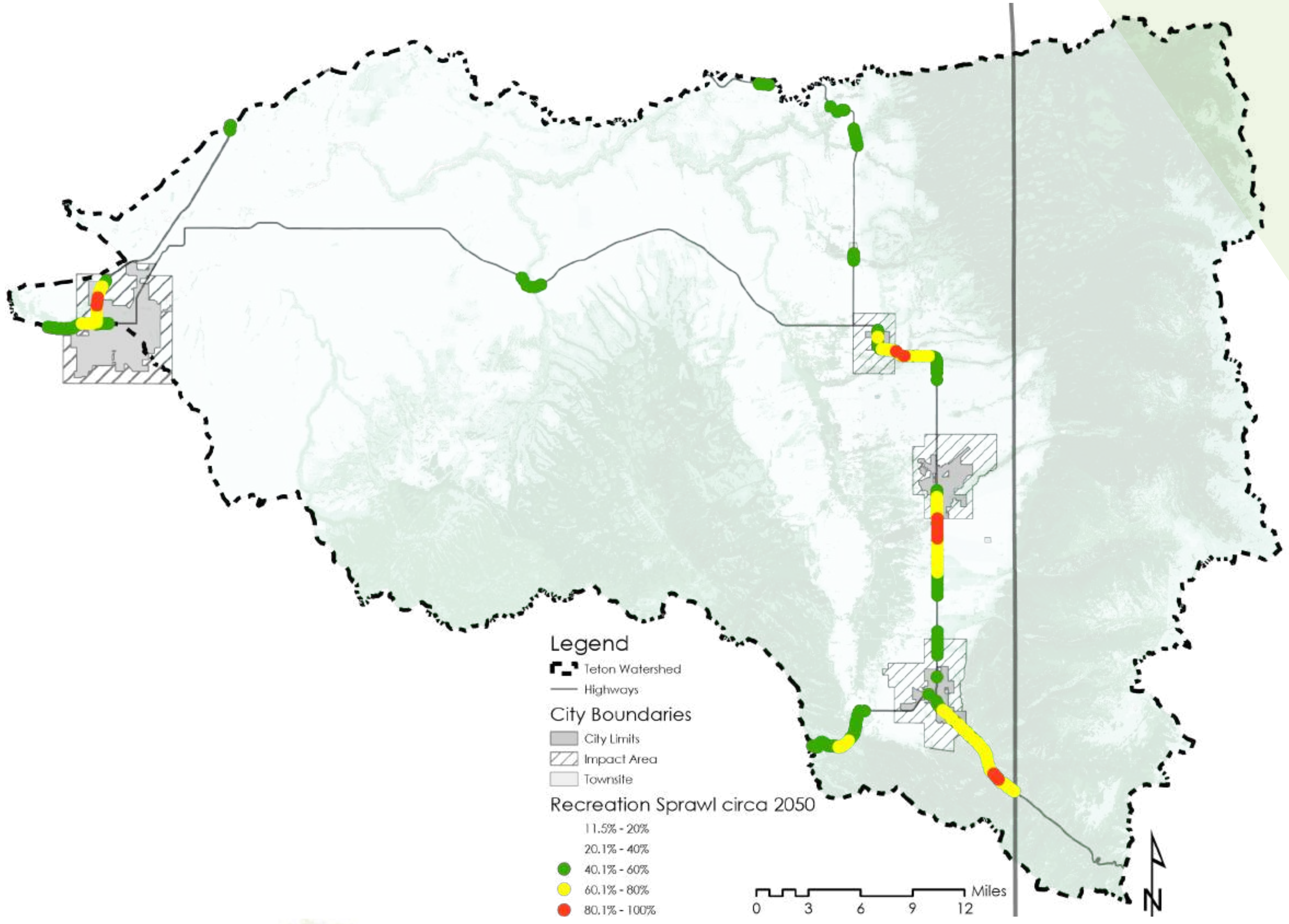


Figure 49. Priority zone locations under the scenario Recreation Sprawl circa 2050.

Chapter 4: Crossing Design Implimentation

This chapter examines the two priority zones that were selected for a site-scale evaluation of possible crossing structures and what those solutions could look like on the landscape.

4.1 Determine crossing type

Through review of the literature surrounding crossing structures, 21 different mitigation measures were evaluated for their economic feasibility within each of the defined priority zones. Four of the options were not economically possible at any location. These included Animal Detection Systems (functioning alone), Anti-fertility treatments, long bridges, and long tunnels. The remaining solutions were broken down into a cost per mile per year needed to pay for the implementation of that system. This was set as the threshold value for each mitigation type. The benefit of the crossing solution was defined as the total savings, represented by the cost of collisions minus the threshold cost, divided by the threshold value. Then, to account for the efficacy of each solution, the original savings was then multiplied by the known efficacy of the structure, allowing for an adjusted benefit in relation to how many collisions would be avoided. For any structure that had an "unknown" efficacy, it was given a 1% efficacy rate, and any structures with a known 0% efficacy were kept that way. This ruled out standard wildlife signs, deer reflectors and mirrors, and fence with gap and warning signs as options.

The adjusted benefit was used to determine how long it would take for each solution to "monetarily break-even" over time after implementation. The percentages were defined as follows:

- < 0% - Monetary Loss
- 0.1 – 10% - More than 10 Years to break-even
- 10.1 – 20% - 6 – 10 years
- 20.1 – 25% - 5 years
- 25.1 – 33% - 4 years
- 33.1 – 50% - 3 years
- 50.1 – 100% - 2 years
- > 100% - Less than 1 Year

This process was run for both the current collision data and the predicted collisions under the scenario Recreation Sprawl to see how certain crossing measures might change overtime in their economic feasibility to prevent collisions. While this shows all the possible solutions for each zone, it does not take into consideration terrain or site-specific limitations that could impact the implementation of any of the mitigation measures.

For example, while vegetation removal is highly possible across all zones (Figure 50), because of the landscape within the Teton Basin, there may not been any vegetation to be removed (Image 4). Therefore, site-specific characteristics will be evaluated for each zone to better determine which of the solutions would be possible. Only solutions that showed the potential to "break-even" in 3 or less years will be considered in design.

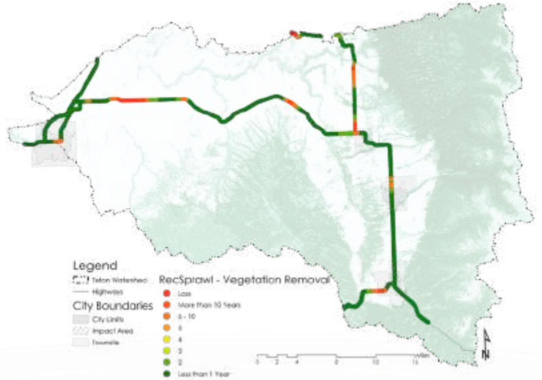


Figure 50. Cost-Benefit analysis of vegetation removal.

Image 4. Example of landscape showing that removal of vegetation, though economically feasible, is not physically possible.

4.2 Site-Specific Design

To evaluate crossing efforts at the site scale, two zones were selected to further look at the site-specific characteristics surrounding the roadway and how that will influence the types of mitigation measures provided as solutions (Figure 51). The first zone is on the south side of Driggs along highway 33. This area encompasses the south side of town and the Teton Creek drainage consisting of mainly private land which limits the practical solutions due to placement constraints. This area is defined by IDFG as an important corridor for wildlife movement, specifically for big game animals like mule deer (IDFG, 2012). The second zone is Teton Pass, heading towards Wyoming to the southeast of Victor, also on highway 33. This area included more public land and forested land which opens the opportunity for use of wildlife fencing. These two sites pose different limits and opportunities for mitigation implementation.

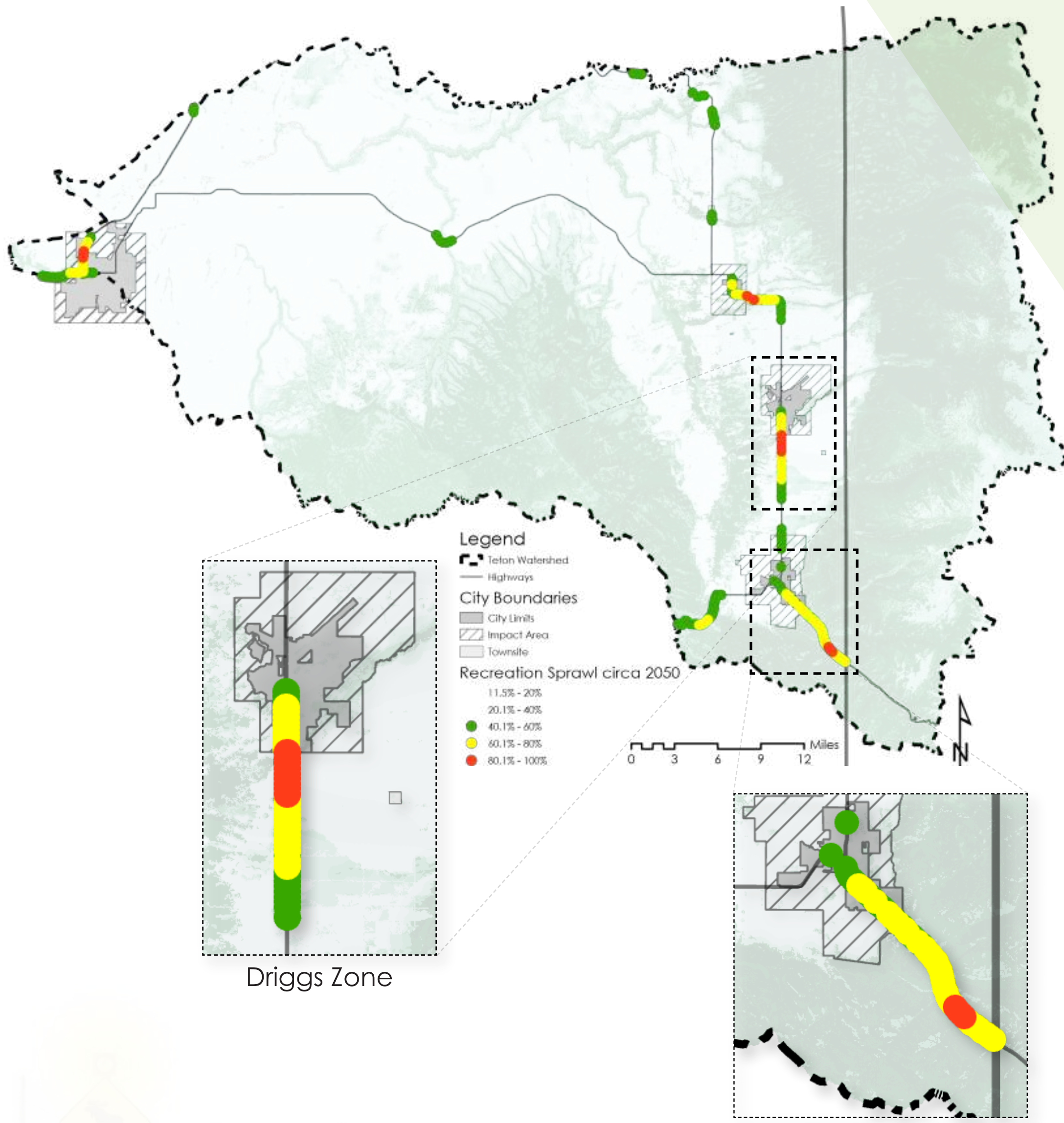


Figure 51. Zones chosen for further site-specific analysis, Driggs Zone and Teton Pass Zone. possible.

4.2.1 Highway 33 MP 141 – 145.3 (Driggs Zone)

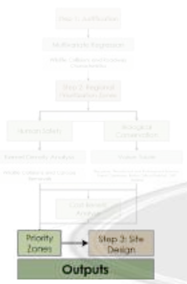
This zone is characterized by an urban area between mile marker 141 – 142, a creek crossing at marker 142.3 and then open agricultural fields between markers 142.4 and 145.3. Within the urban zone, there is no need for any interventions. At Teton Creek, there is already a small underpass to accommodate water flow. Without knowing the exact dimensions of the structure, it is difficult to determine what species are able to use this structure. It was assumed that the structure functions solely for water flow and therefore it could benefit from modifications for walkways to allow for small- and medium-sized animals to use, however, it is unlikely to be useful for large mammals like moose and mule deer. This is also the only section that has larger vegetation near the roadway. It would be beneficial to thin or remove vegetation in this area between 40 and 80 m from the roadway to allow greater visibility for drivers to see any wildlife approaching the road. Finally, beyond the creek crossing, most of the land next to the roadway is private agriculture and therefore is limited in the interventions allowed. For this section, the use of seasonal or enhanced warning signs would be most beneficial (Figure 52).

Viable Solutions and their Limitations (Huijser et al., 2008; Clevenger and Huijser, 2009):

1. Seasonal Signs
2. Enhanced Warning Signs
3. Vegetation Removal
   a. Cover within 40 m to 80 m of roadway should be removed
4. Fence with Underpass (Difficult with private landownership in this area)
   a. Fence placed at the edge of the ROW at property boundaries
   b. Partial Fencing to be used in mixed-land ownership
   c. Underpass is dependent on the target species
   d. Must include escape opportunities
   e. Must be within cross-highway habitat linkage zone

Priority Zones
- Low
- Moderate
- High

Mitigation "Breakeven" Point
- Monetary Loss
- More than 10 Years
- 6 - 10
- 5
- 4
- 3
- 2
- Less than 1 Year



Driggs Zone

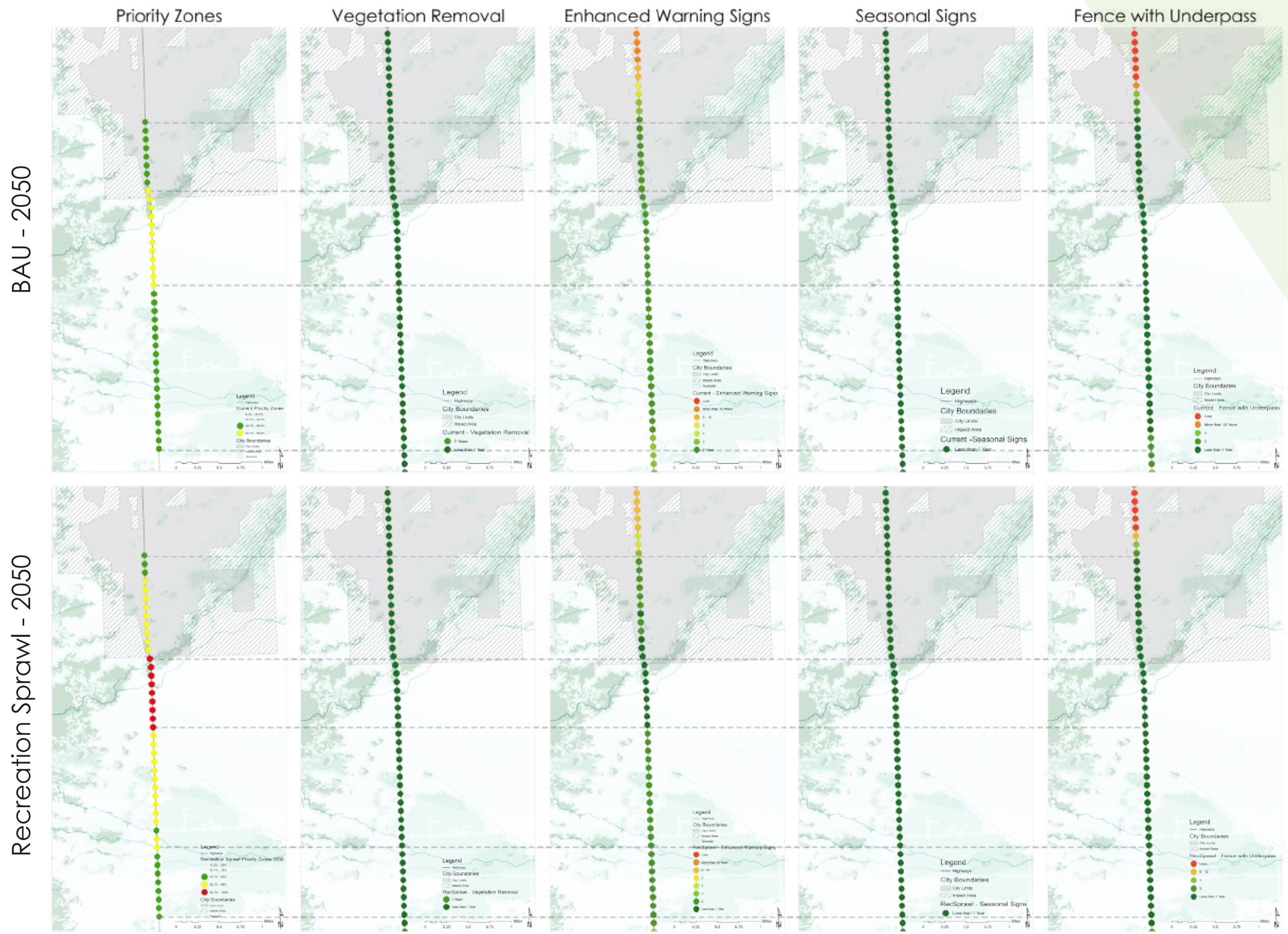


Figure 52. Monetary "Breakeven" points for solutions within the Driggs Zone.

Driggs Zone

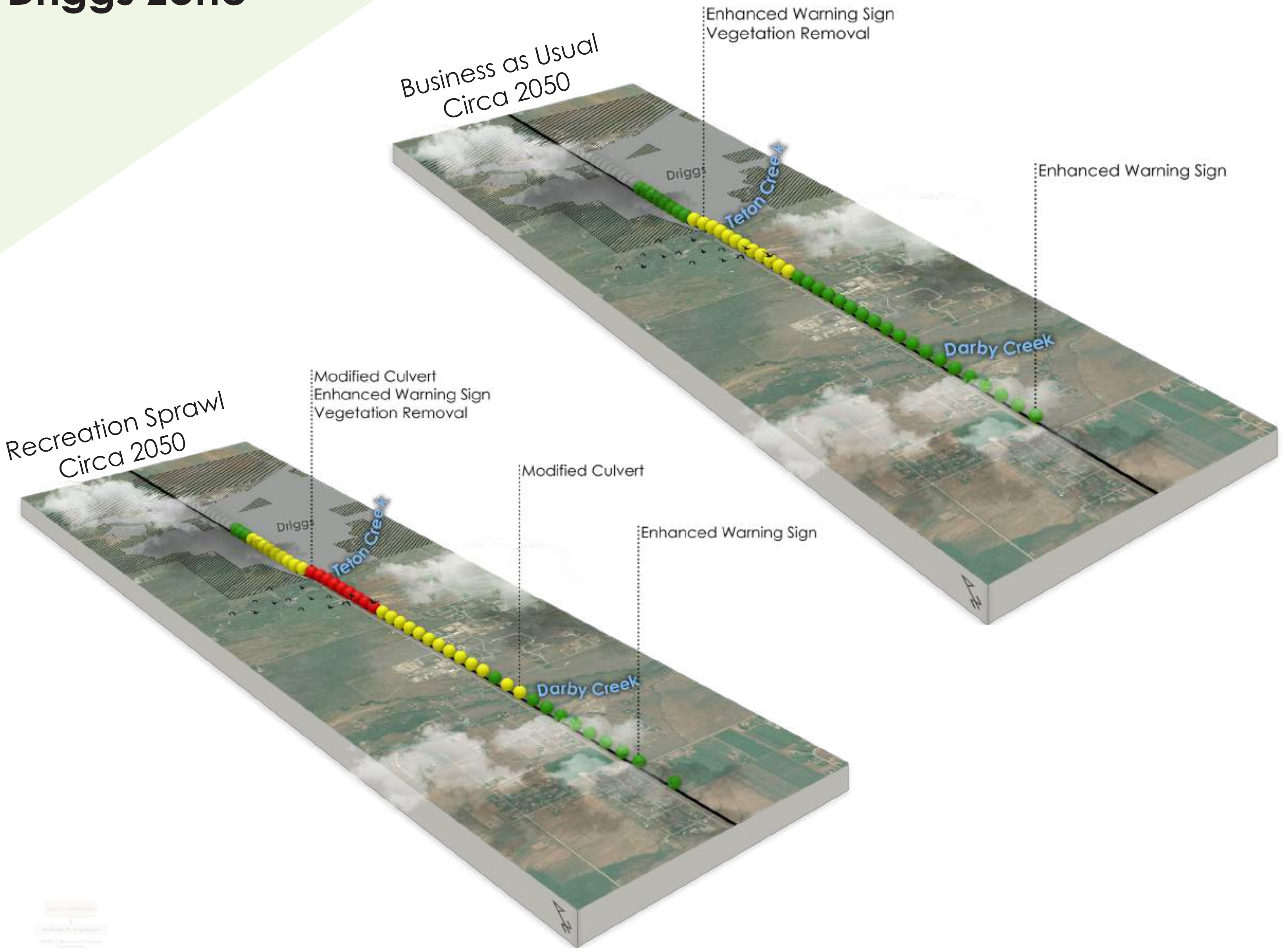
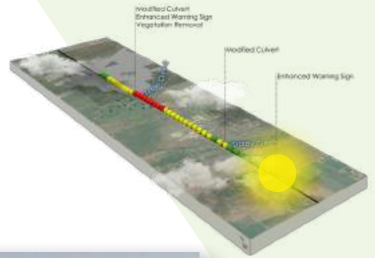


Figure 53. Landscape scale solutions for the Driggs Zone under Business as Usual and Recreation Sprawl Scenarios circa 2050.

Driggs Zone



Enhanced Warning Sign

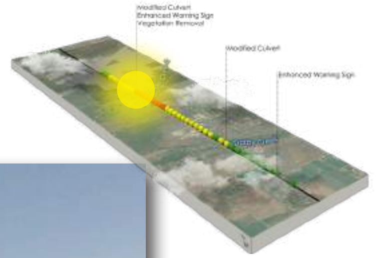
Before

After

Figure 54. Site-scale perspective of solutions under the Recreation Sprawl Scenario circa 2050.

Driggs Zone

Enhanced Warning Sign and Vegetation Removal



Before

After

Figure 54. Site-scale perspective of solutions under the Recreation Sprawl Scenario circa 2050.

4.2.2 *Highway 33 MP 149.9 – 155 (Teton Pass Zone)*

Similar to the zone south of Driggs, this area has a combination of private land and agricultural zones between mile marker 149.9 and 153.2 which limits solutions to seasonal and enhanced warning signs. In this section there is little to no vegetation near the roadway and therefore would not benefit from removal actions. Between markers 153.2 and 155 at the Wyoming border, the property on either side of the roadway is public land, owned by the United States Forest Service. This opens the opportunity for options with wildlife fencing. Additionally, as this section has more vegetation, the thinning and removal of vegetation within 40 – 80 m of the road would be beneficial for increased visibility. There are currently two low bridges in this zone that allow for water flow at Trail Creek and Moose Creek.

Much like Teton Creek, without knowing the exact dimensions of these bridges it is difficult to determine what species might be able to use them. However, in this case, it is possible to retrofit them to allow for small- and medium-sized mammal usage and use fencing to funnel wildlife to those crossings. Any fencing in this area should include escape points and crossing zones dependent on the target species. Finally, the use of seasonal and enhanced warning signs in this entire zone would be beneficial to notify drivers of constant and seasonal fluctuations in wildlife crossing attempts (Figure 56).

Viable solutions and their limitations (Huijser et al., 2008; Clevenger and Huijser, 2009):

1. Seasonal Signs
2. Enhanced Warning Signs
3. Vegetation Removal
    a. Cover within 40 m to 80 m of roadway should be removed

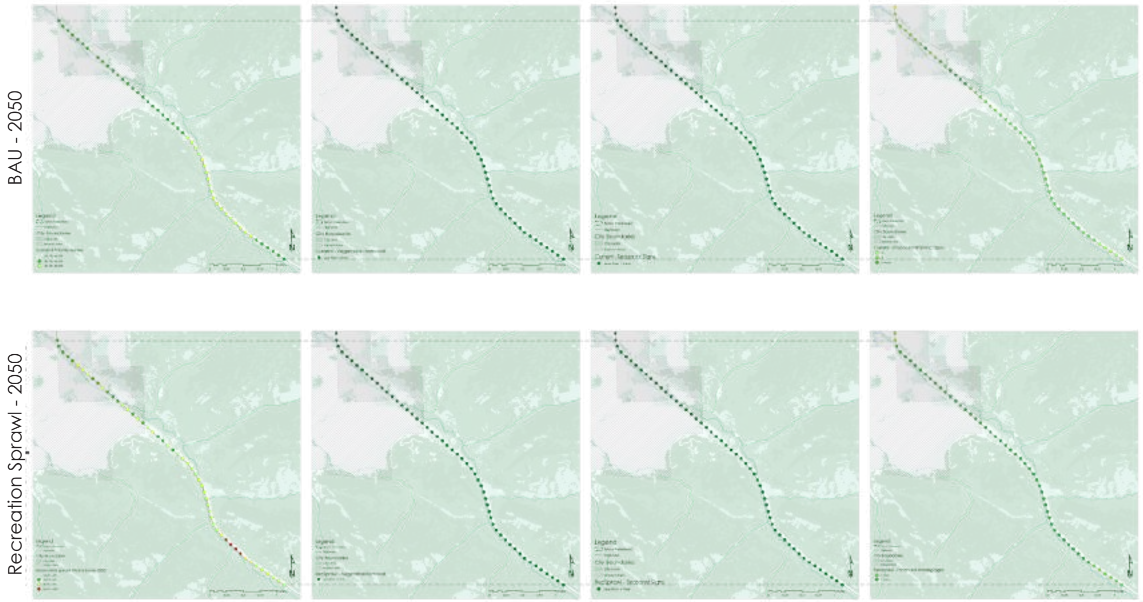
Fencing options would only be workable between mile markers 153.2 - 155 due to private land ownership up the roadway in the other sections.

1. Fence with Dig Barrier
    a. Placed at the edge of the ROW at property boundaries
    b. Partial Fencing to be used in mixed-land ownership
    c. Must include escape opportunities
2. Fence with Gap and Crosswalk
    a. Fence placed at the edge of the ROW at property boundaries
    b. Partial Fencing to be used in mixed-land ownership
    c. Gaps are dependent on the target species
    d. Must include escape opportunities
3. Fence with Gap and ADS (Figure 58)
    a. Fence placed at the edge of the ROW at property boundaries
    b. Partial Fencing to be used in mixed-land ownership

Teton Pass Zone

Priority Zones
- Low
- Moderate
- High

Mitigation "Breakeven" Point
- Monetary Loss
- More than 10 Years
- 6 - 10
- 5
- 4
- 3
- 2
- Less than 1 Year



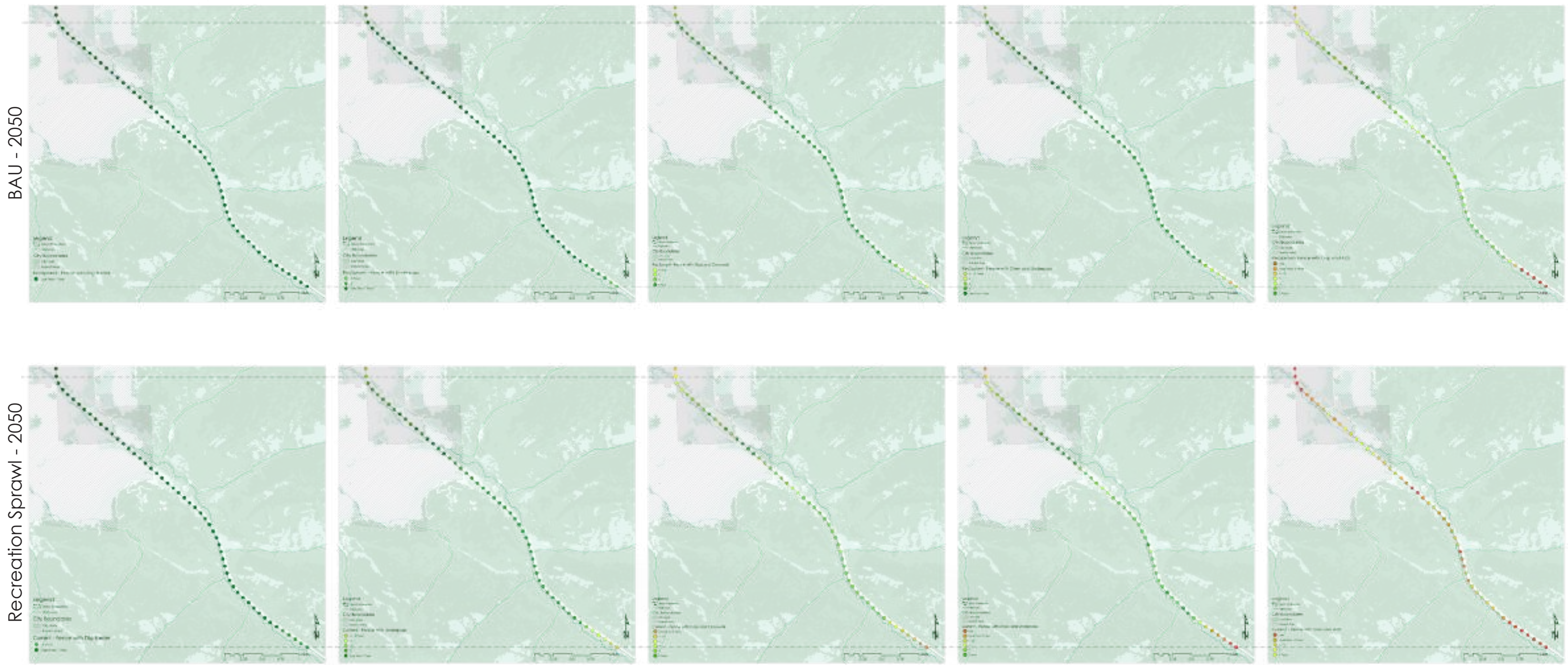


Figure 56. Monetary "Breakeven" points for solutions within the Teton Pass Zone.

Teton Pass Zone

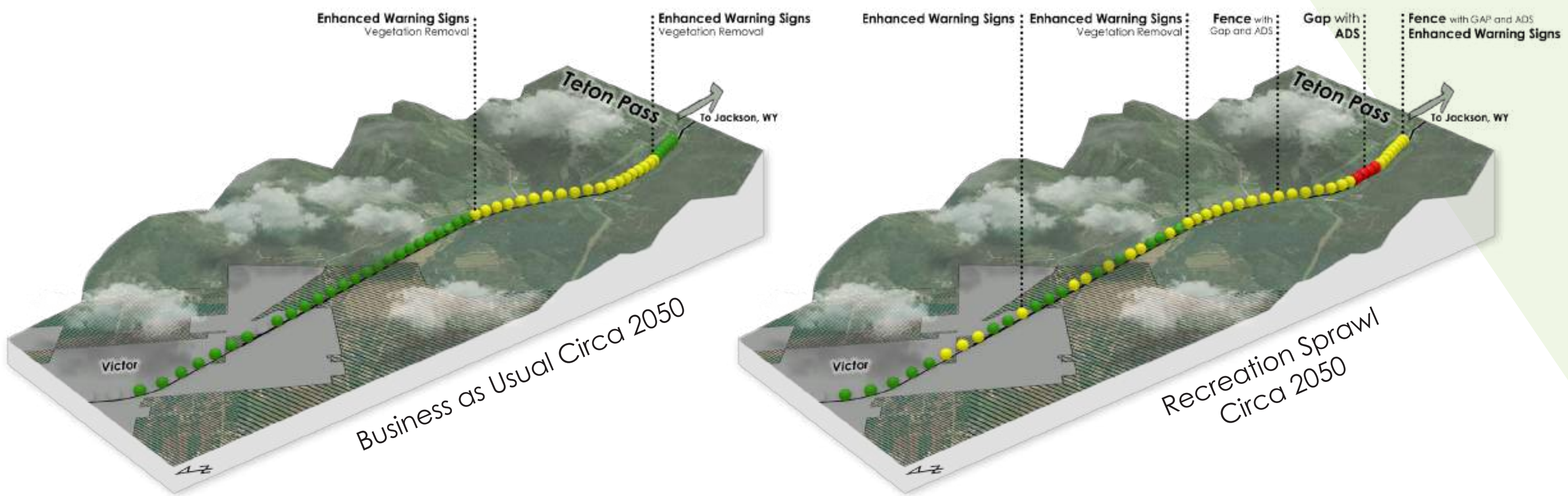


Figure 57. Landscape scale solutions for the Driggs Zone under Business as Usual and Recreation Sprawl Scenarios circa 2050.

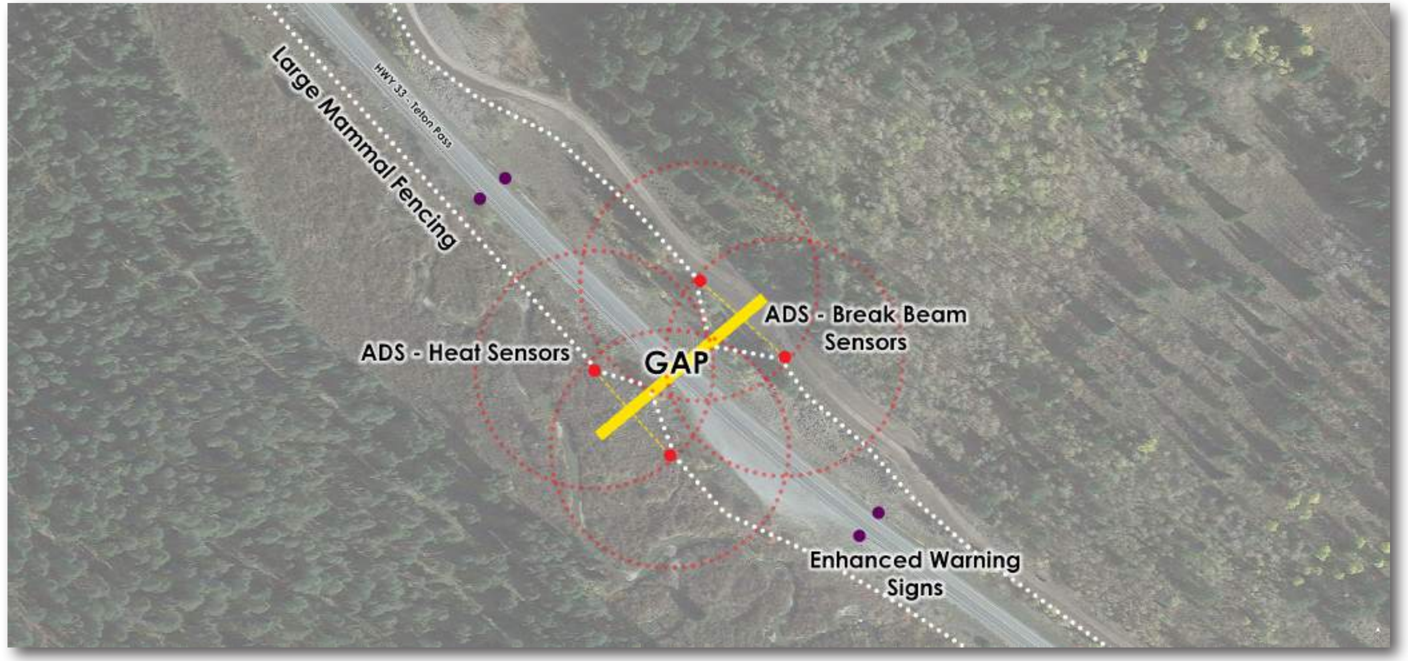
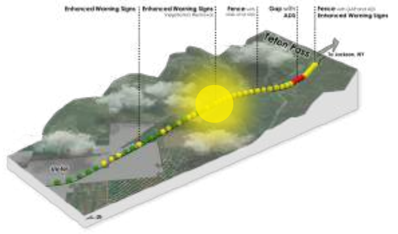


Figure 58. Aerial view of how an Animal Detection System could work using both Break Beam Sensors and Infrared/Heat Sensors.

Teton Pass Zone



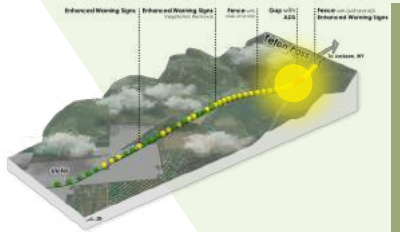
Enhanced Warning Sign and Vegetation Removal

Before

After

Figure 59. Site-scale perspective of solutions under the Recreation Sprawl Scenario circa 2050.

Teton Pass Zone



Before

Fence with Gap and ADS

After

Figure 60. Site-scale perspective of solutions under the Recreation Sprawl Scenario circa 2050.

Chapter 5: Discussion

This final chapter discusses the overall conclusions about this process and the applicability of this framework at other locations within Idaho as well as possible innovations in design that could further assist in reducing wildlife-vehicle collisions.

5.1 Conclusions about the Teton Watershed Crossing Plan

Through this process of identifying areas in the Teton Valley that experience high densities of collisions with wildlife and where important wildlife movement corridors are located there were 4 sections until the Business-as-Usual scenario and 6 sections under the Recreation Sprawl scenario for the year 2050 that show a need for mitigation measures to reduce WVCs. Given the general open landscape of the Valley and the location of private lands next to the major highways, many solutions would include the use of enhanced signs and removal of vegetation at creek crossings to improve visibility. Only in the southern areas of the watershed, including Teton Pass, where public lands are found would the use of fencing and animal detection systems be feasible.

Overall, solutions for this region are economically possible and would pay for themselves in less than 2 years and reduce collisions up to 20% in the valley floor and up to 87% where fencing could be used in the forested areas.

Moving forward, site visits at each priority area and continued discussion with stakeholders in the region working with the greater GEM3 project would be crucial for determining exactly which mitigation techniques would be the best option for the people of the place.

5.2 Applications to other locations

The framework set forth by this project allows for an easy-to-follow method to determining potential wildlife crossing locations in Idaho with minimal data collection required. For any given location, all that is needed is wildlife collision and carcass removal information which, in the state of Idaho, can be gathered from either (or both) Idaho Fish and Game and Idaho Transportation Department via their online portal through ArcGIS Pro. Some locations may have most specific information regarding wildlife movements but, in general, GAP habitat maps show where viable habitat for the given target species is located and that can be used as a proxy for wildlife movements. This method was quickly applied to Valley County, Idaho near the town of McCall along State Highway 55 (Figure 61).

This quick study used collision data, carcass removal data and biological data for mule deer, white-tailed deer, elk and moose with GAP habitats and Idaho critical habitats to see if there were areas of highway that showed a high priority for wildlife crossing mitigation. Preliminary results showed the only high priority zone to be near the town of McCall with low priority zones scattered across Highway 55 (Figure 62). This only considered a business-as-usual scenario. This shows how the methodology created in this project could be easily applied to other locations for an all to quick view into motorist safety and conservation of local wildlife.

Figure 61. Location of Valley County, Idaho

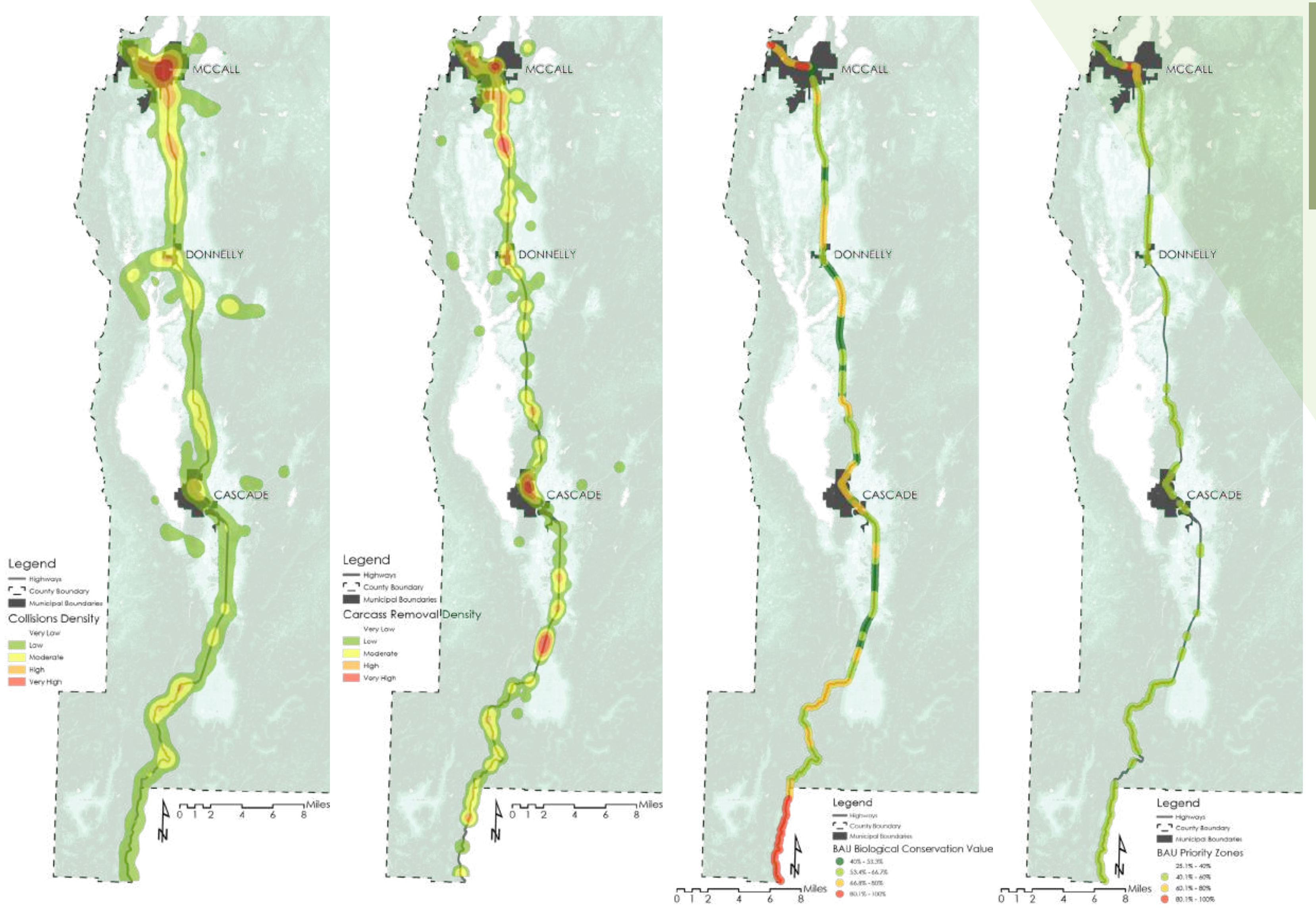


Figure 62. Example of the applicability of this framework to define priority zones in Valley County, Idaho under a business-as-usual scenario.

5.3 Innovations in design

Through studies of the literature surrounding wildlife detection systems one option, on-board wildlife detection, came up as a possibility for the future as technology in newer vehicles could support such a system. On-boarding systems work by alerting drivers in their vehicles with a warning signal that they are approaching an area where a large animal has been detected by an external system (Huijser et al., 2008b). This type of system has not been tested yet so the exact benefits are still unknown, however, it is estimated that the efficacy would be similar to basic animal detection systems and reduce collisions by up to 82% (Huijser et al., 2008b). There are two types of on-board detectors that are being explored, one uses an external GPS signal to detect wildlife and the other is fully incorporated within the vehicle and uses infrared sensors to locate large animals within a certain range of the vehicle (Huijser et al., 2008). In either case, these methods still rely on drivers to be fully alert and aware of their surrounds and should be used in conjunction with signs and other mitigation techniques to have the most direct benefit to human safety.

Some vehicle companies are already testing these types of systems, generally used currently to detect pedestrians, on large wildlife. Volvo uses a Pedestrian Detection System to aid the identification of wildlife through infrared cameras and radar systems (Read, 2011). If the vehicle finds anything it alerts the driver and, in an emergency, can apply the brakes on the car on its own (Read, 2011). This system also takes into consideration the surrounding environment to determine the best way to minimize the impact of the collision (Read, 2011). While this technology is still a work in progress, it is a huge step in vehicle safety and may help in the reduction of serious injuries from collisions with wildlife.

Photo Credit: Volvo (Read, 2011)

Image 5. Volvo car uses innovative technology to detect large wildlife on the road.

5.4 Lessons learned

For this project, limitations of data availability were an issue. As is the case in many other states, inconsistencies with collision reports made it difficult to determine which collisions were caused by wildlife and by which species of wildlife. Collisions with wildlife were not reported directly in Idaho until 1997, however, exact locations were not included with that data until 2007 and even today, the species involved in those collisions are not reported and only collisions costing over $1,500 in damages are reported. These limitations in the data restricted this project in its accuracy for target species collision reduction. However, in general, the solutions provided would still improve safety and reduce collisions overall in the priority zones identified.

Idaho Fish and Game have created a new Road kill/ Wildlife Salvage Reporting system with upgrades that make the reporting process more user friendly (Figure 63). This is a start in the right direction as ease of use of such a tool is imperative. However, a tool like this needs to be used widely by IDFG employees and ITD employees whenever they see road kill or are on the site of a WVC in order for the data to be reliable.

Additionally, the importance of land ownership and stakeholder buy-in proved to be significant. Land ownership next to roadways restrict crossing mitigation devices down to only a few motorist behavior techniques instead of physical barriers. The literature was explicit about not using fencing or major crossings, like over and underpasses, on or near private property because the lifetime of that structure cannot be guaranteed due to changes in ownership or development that could occur in the future. Stakeholders that were exposed to this project showed a general interest in the need for corridor protection and preventing collisions with wildlife and were interested in future research on this topic.

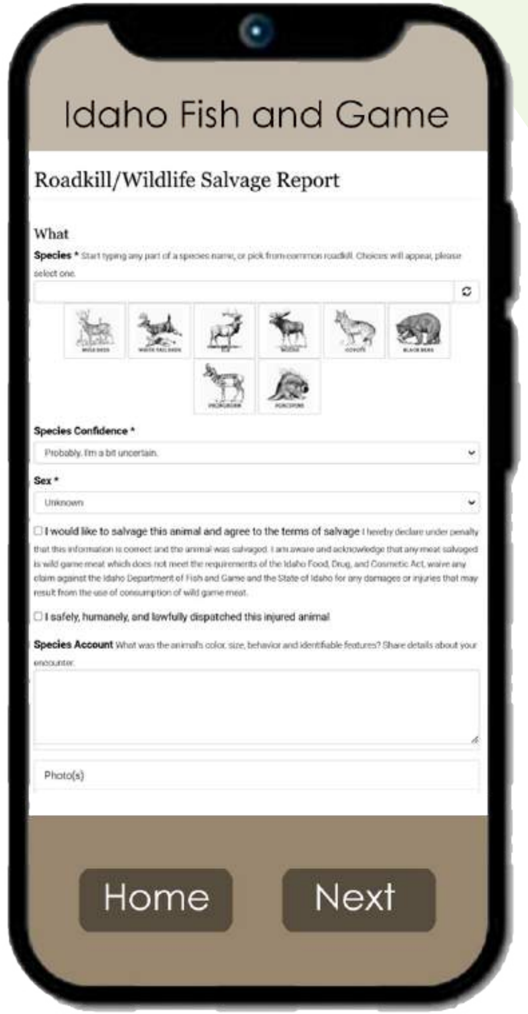


Figure 63. Screenshots of the roadkill reporting system through Idaho Fish and Game.

5.5 Further questions and research

Further research into wildlife crossing mitigation techniques should be focused on ways to improve the recording methods used for wildlife-vehicle collisions and how to apply this knowledge into roadway design and retrofitting projects at the site-scale. The literature today is comprehensive enough to guide planners to locate areas that have the greatest need for intervention but there are still some techniques that have unknown efficacies. A nation wide standard for reporting collisions should be implemented in a way that is user friendly and comprehensive enough to be used in regional projects like this one. Additionally, if able, species-specific information should be included in those reporting bodies so that managers and planners can more easily identify the target species and therefore the best crossing option to facilitate movements for the most at-risk species. Finally, innovations in design and safety, like on-board detection systems, should be reviewed further, developed, and tested to determine if that solution is viable across varying landscapes.

Beyond the roadway, adjacent land management practices should be included in studies like this one. Focusing on the crossing point puts up blinders to the conditions surrounding the road. For example, near town centers there may be need for zoning changes to conserve habitat corridors in critical habitat areas (Figure 64). Driggs is a good example of this phenomenon where proposed future zoning around Teton Creek is slated for residential development while previous zoning near this area is set for conservation. Post priority zone identification, future land use changes need to be considered to truly implement the most effective and robust mitigation measures to reduce WVCs and provide safe roads for all motorists.

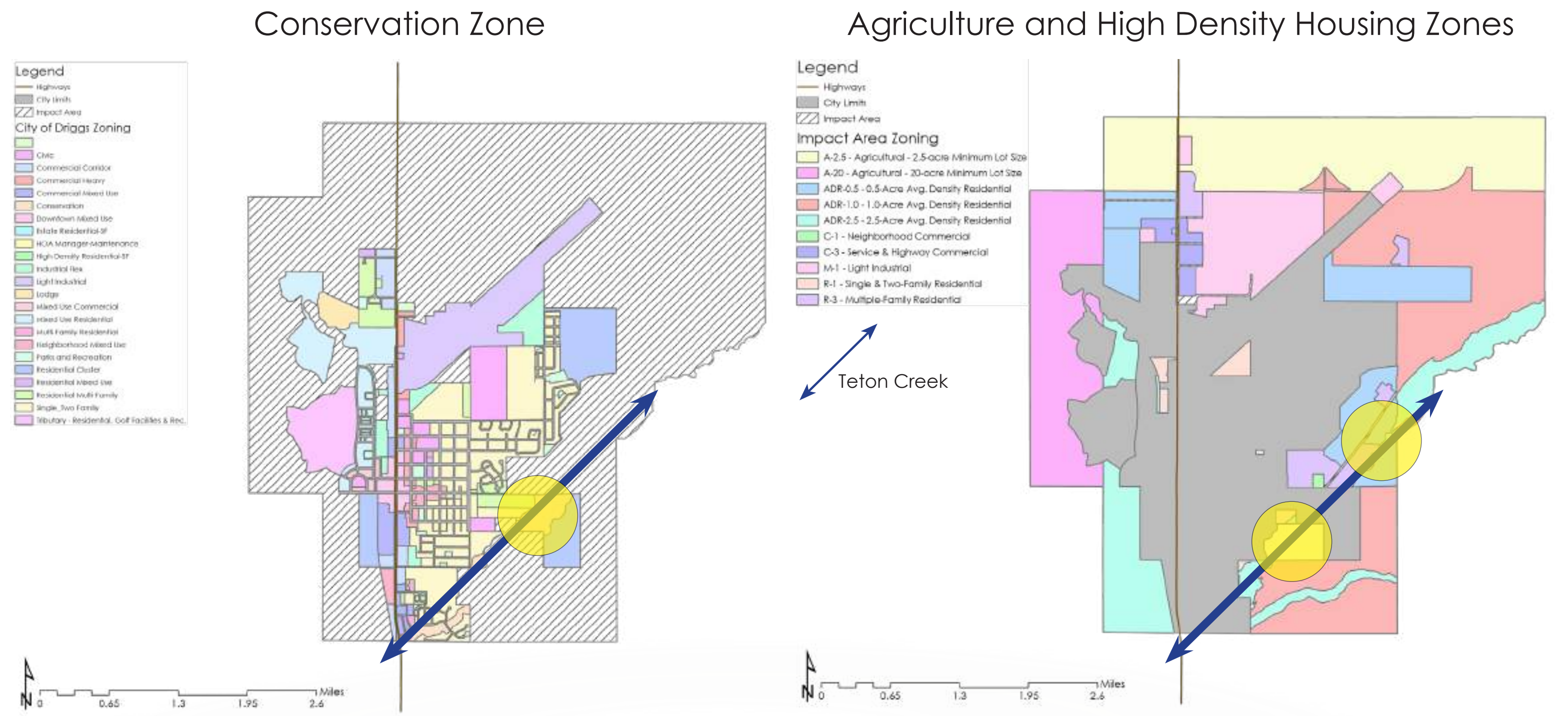


Figure 64. Current and proposed zoning for Driggs Idaho future growth.

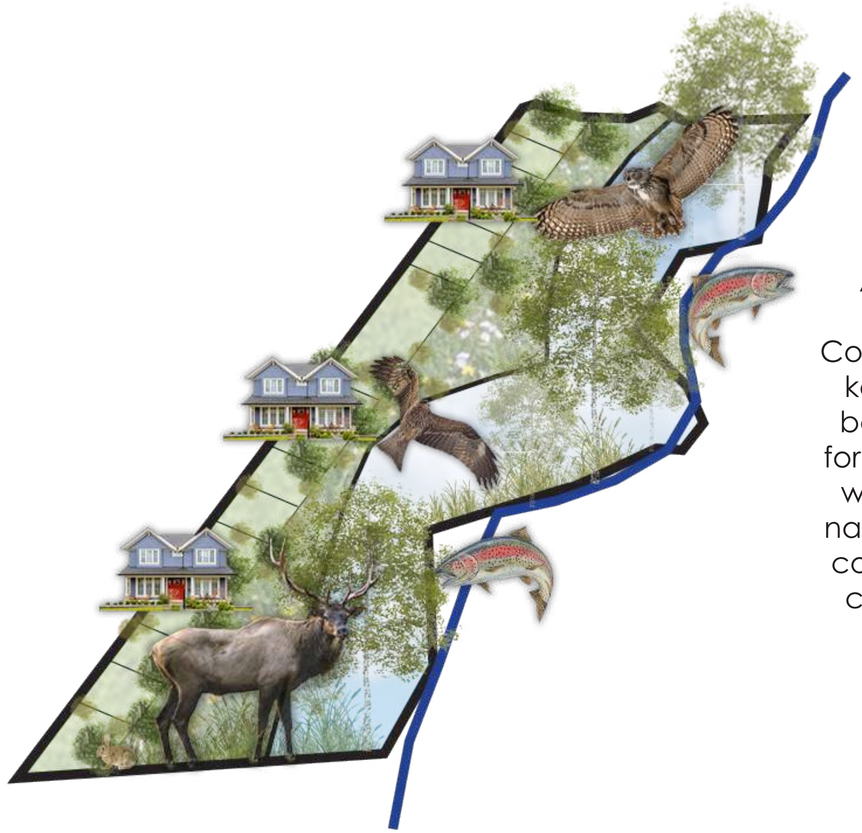


Figure 65. Example of Conservation Subdivision zoning along Teton Creek in Driggs, Idaho.

As an example, residential zoning along critical movement corridors could be zoned for Conservation Subdivisions only (Figure 65). This would keep major developments away from the stream banks and keep the native habitat intact to allow for free movement of wildlife and provide residence with their own park-like area to explore and enjoy nature. This would allow for wildlife already using this corridor to continue doing so and make managing collisions where this corridor crossing the highway more feasible in the long term.

Additionally, stream bank preservation and conservation zones within Agricultural Zones would benefit wildlife and the stream flow (Figure 66). Reducing large equipment and livestock access to the stream prevents bank erosion keeping the waterway as pristine as possible. This also provides a buffer zone for wildlife to move through the area with less hurdles.

Figure 66. Example of a stream buffer zone within an Agricultural Zone along Teton Creek in Driggs, Idaho.

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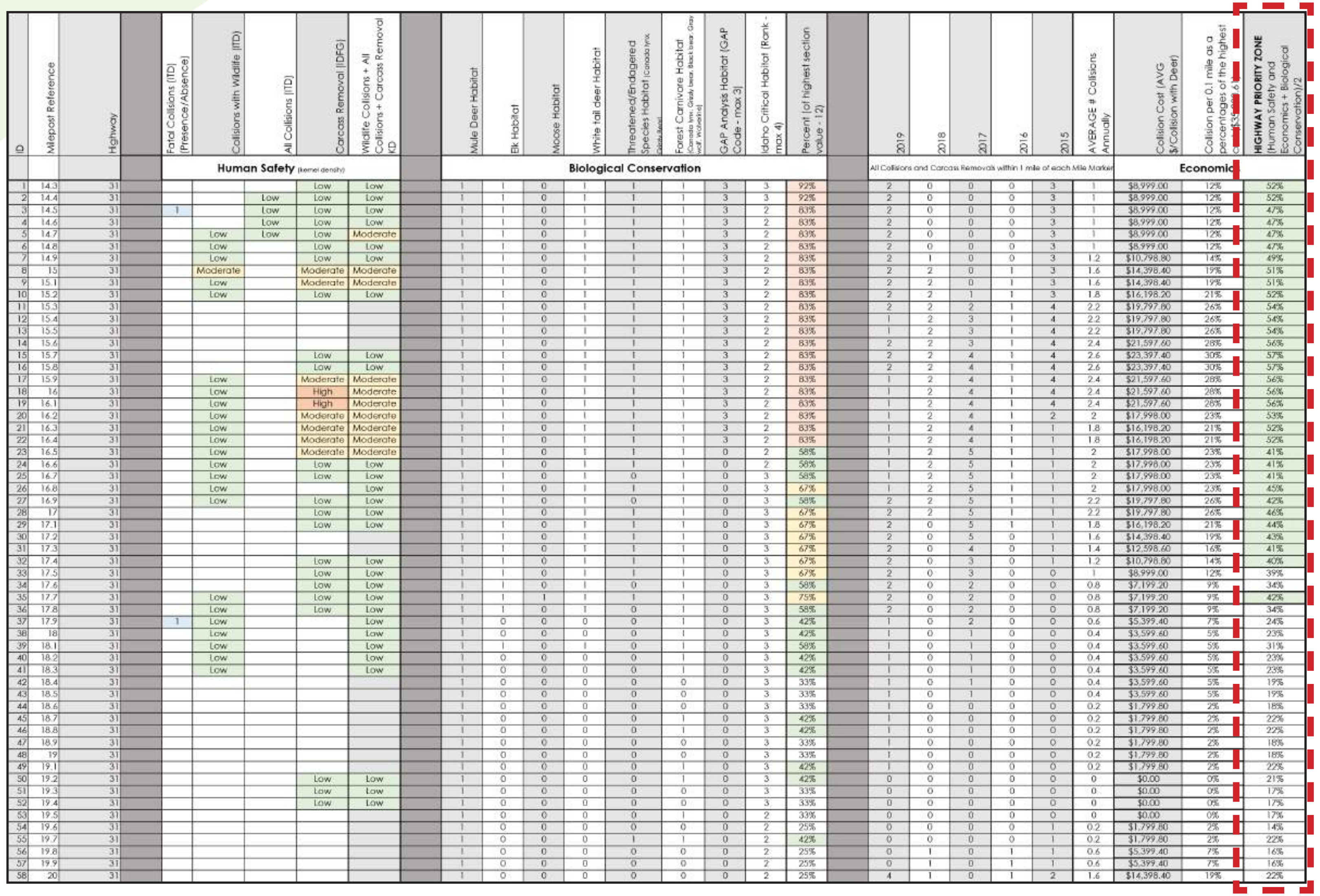
Appendix A: Tables

BUSINESS-AS-USUAL CIRCA 2050 PRIORITY ZONES

EXAMPLE SECTION OF LARGE SPREAD SHEET

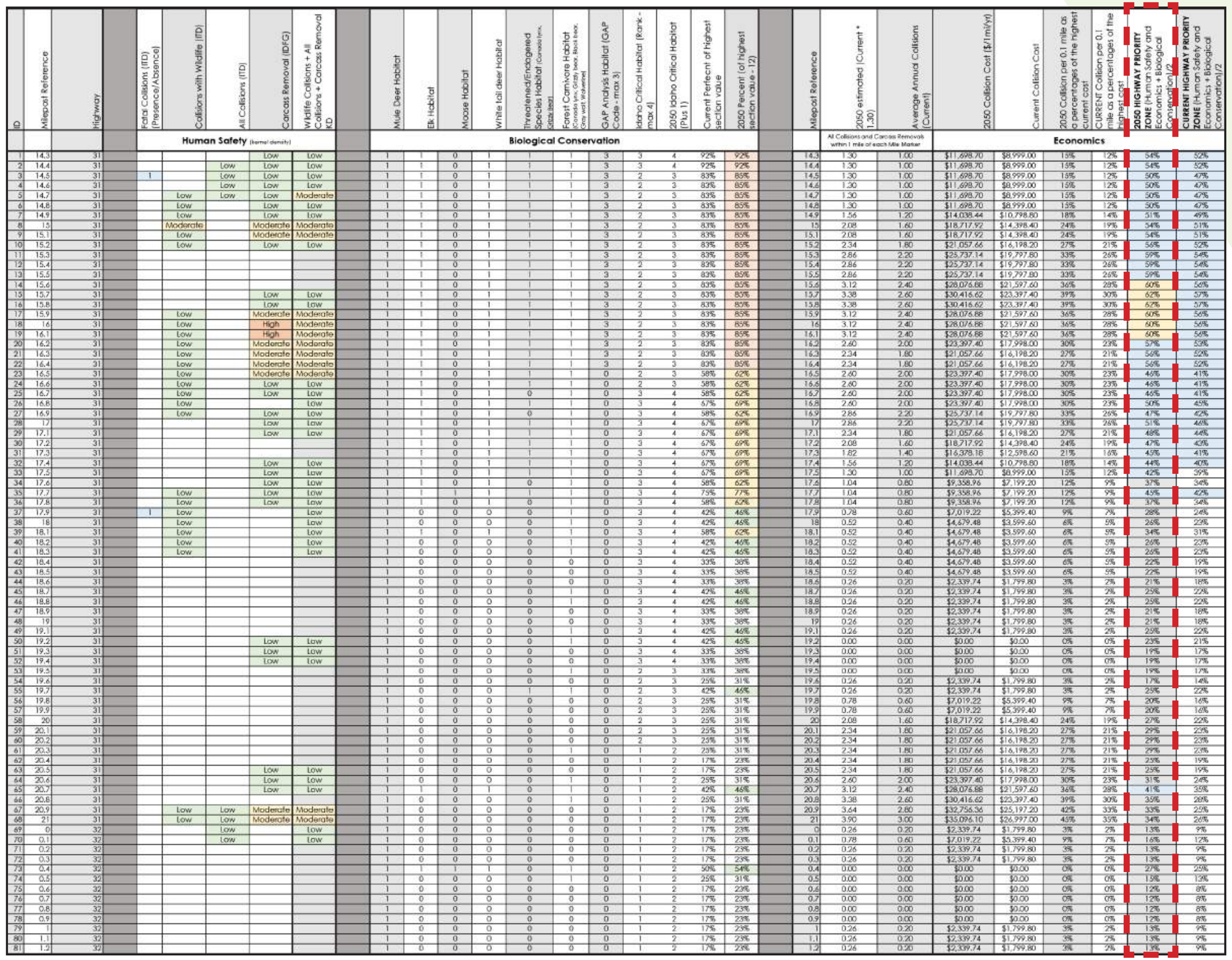


$$\frac{\text{BIOLOGICAL CONSERVATION VALUE (\%)} + \text{COLLISION COST (\%)}}{2} = \text{PRIORITY ZONE VALUE (\%)}$$

Appendix A: Tables

RECREATION SPRAWL CIRCA 2050 PRIORITY ZONES

EXAMPLE SECTION OF LARGE SPREAD SHEET



Appendix A: Tables

BUSINESS-AS-USUAL CIRCA 2050 COST-BENEFIT ANALYSIS

EXAMPLE SECTION OF LARGE SPREAD SHEET

OBJECTID	SegCode	RouteNo	RouteType	MP	RouteName	AvgAnnCollision	CollisionCost	BioConsValue	PriorityLevel	SWS_Savings	SWS_Threshold	SWS_Benefit	SWS_Efficacy	SWS_Adj_Savings	SWS_Adj_Benefit	DW_Savings	DW_Threshold	DW_Benefit	DW_Efficacy	DW_Adj_Savings	DW_Adj_Benefit	SeaSign_Savings	SeaSign_Threshold	SeaSign_Benefit	SeaSign_Efficacy	SeaSign_Adj_Savings	SeaSign_Adj_Benefit	EWS_Savings	EWS_Threshold	EWS_Benefit	EWS_Efficacy	EWS_Adj_Savings	EWS_Adj_Benefit
										Standard Warning Signs						Deer Whistles						Seasonal Signs						Enhanced Warning Signs					
166	002070	20	Main	333.4	20-Main	5.6	$50,394.40	17%	41%	$50,338.48	$55.92	$900.13	0%	0	0	$50,321.39	$73.01	$689.23	Unknown	$503.21	689%	$50,310.51	$83.89	$599.76	26%	$13,080.73	15594%	$49,620.79	$773.61	$64.14	Unknown	$496.21	64%
196	002070	20	Main	333.5	20-Main	6.6	$59,393.40	33%	55%	$59,337.48	$55.92	$1,061.05	0%	0	0	$59,320.39	$73.01	$812.48	Unknown	$593.20	812%	$59,309.51	$83.89	$707.03	26%	$15,420.47	18383%	$58,619.79	$773.61	$75.77	Unknown	$586.20	76%
115	002070	20	Main	333.6	20-Main	7.4	$66,592.60	25%	56%	$66,536.68	$55.92	$1,189.78	0%	0	0	$66,519.59	$73.01	$911.09	Unknown	$665.20	911%	$66,508.71	$83.89	$792.85	26%	$17,292.27	20614%	$65,818.99	$773.61	$85.08	Unknown	$658.19	85%
155	002070	20	Main	333.7	20-Main	7.6	$68,392.40	17%	53%	$68,336.48	$55.92	$1,221.97	0%	0	0	$68,319.39	$73.01	$935.74	Unknown	$683.19	936%	$68,308.51	$83.89	$814.31	26%	$17,760.21	21172%	$67,618.79	$773.61	$87.41	Unknown	$676.19	87%
112	002070	20	Main	333.8	20-Main	7.4	$66,592.60	17%	51%	$66,536.68	$55.92	$1,189.78	0%	0	0	$66,519.59	$73.01	$911.09	Unknown	$665.20	911%	$66,508.71	$83.89	$792.85	26%	$17,292.27	20614%	$65,818.99	$773.61	$85.08	Unknown	$658.19	85%
17	002070	20	Main	333.9	20-Main	7.6	$68,392.40	17%	53%	$68,336.48	$55.92	$1,221.97	0%	0	0	$68,319.39	$73.01	$935.74	Unknown	$683.19	936%	$68,308.51	$83.89	$814.31	26%	$17,760.21	21172%	$67,618.79	$773.61	$87.41	Unknown	$676.19	87%
893	002070	20	Main	334	20-Main	8.2	$73,791.80	17%	56%	$73,735.88	$55.92	$1,318.52	0%	0	0	$73,718.79	$73.01	$1,009.69	Unknown	$737.19	1010%	$73,707.91	$83.89	$878.68	26%	$19,164.06	22846%	$73,018.19	$773.61	$94.39	Unknown	$730.18	94%
152	002070	20	Main	334.1	20-Main	8.6	$77,391.40	17%	58%	$77,335.48	$55.92	$1,382.88	0%	0	0	$77,318.39	$73.01	$1,058.99	Unknown	$773.18	1059%	$77,307.51	$83.89	$921.59	26%	$20,099.95	23961%	$76,617.79	$773.61	$99.04	Unknown	$766.18	99%
136	002070	20	Main	334.2	20-Main	8.6	$77,391.40	25%	63%	$77,335.48	$55.92	$1,382.88	0%	0	0	$77,318.39	$73.01	$1,058.99	Unknown	$773.18	1059%	$77,307.51	$83.89	$921.59	26%	$20,099.95	23961%	$76,617.79	$773.61	$99.04	Unknown	$766.18	99%
1	002070	20	Main	334.3	20-Main	8.6	$77,391.40	33%	67%	$77,335.48	$55.92	$1,382.88	0%	0	0	$77,318.39	$73.01	$1,058.99	Unknown	$773.18	1059%	$77,307.51	$83.89	$921.59	26%	$20,099.95	23961%	$76,617.79	$773.61	$99.04	Unknown	$766.18	99%
45	002070	20	Main	334.4	20-Main	8.6	$77,391.40	33%	67%	$77,335.48	$55.92	$1,382.88	0%	0	0	$77,318.39	$73.01	$1,058.99	Unknown	$773.18	1059%	$77,307.51	$83.89	$921.59	26%	$20,099.95	23961%	$76,617.79	$773.61	$99.04	Unknown	$766.18	99%
169	002070	20	Main	334.5	20-Main	8.4	$75,591.60	33%	66%	$75,535.68	$55.92	$1,350.70	0%	0	0	$75,518.59	$73.01	$1,034.34	Unknown	$755.19	1034%	$75,507.71	$83.89	$900.13	26%	$19,632.01	23403%	$74,817.99	$773.61	$96.71	Unknown	$748.18	97%
97	002070	20	Main	334.6	20-Main	8	$71,992.00	17%	55%	$71,936.08	$55.92	$1,286.33	0%	0	0	$71,918.99	$73.01	$985.04	Unknown	$719.19	985%	$71,908.11	$83.89	$857.22	26%	$18,696.11	22288%	$71,218.39	$773.61	$92.06	Unknown	$712.18	92%
162	002070	20	Main	334.7	20-Main	7.8	$70,192.20	17%	54%	$70,136.28	$55.92	$1,254.15	0%	0	0	$70,119.19	$73.01	$960.39	Unknown	$701.19	960%	$70,108.31	$83.89	$835.77	26%	$18,228.16	21730%	$69,418.59	$773.61	$89.73	Unknown	$694.19	90%
85	002070	20	Main	334.8	20-Main	7.8	$70,192.20	25%	58%	$70,136.28	$55.92	$1,254.15	0%	0	0	$70,119.19	$73.01	$960.39	Unknown	$701.19	960%	$70,108.31	$83.89	$835.77	26%	$18,228.16	21730%	$69,418.59	$773.61	$89.73	Unknown	$694.19	90%
116	002070	20	Main	334.9	20-Main	7.8	$70,192.20	17%	54%	$70,136.28	$55.92	$1,254.15	0%	0	0	$70,119.19	$73.01	$960.39	Unknown	$701.19	960%	$70,108.31	$83.89	$835.77	26%	$18,228.16	21730%	$69,418.59	$773.61	$89.73	Unknown	$694.19	90%
886	002070	20	Main	335	20-Main	7.6	$68,392.40	17%	53%	$68,336.48	$55.92	$1,221.97	0%	0	0	$68,319.39	$73.01	$935.74	Unknown	$683.19	936%	$68,308.51	$83.89	$814.31	26%	$17,760.21	21172%	$67,618.79	$773.61	$87.41	Unknown	$676.19	87%
33	002070	20	Main	335.1	20-Main	6.2	$55,793.80	17%	44%	$55,737.88	$55.92	$996.68	0%	0	0	$55,720.79	$73.01	$763.18	Unknown	$557.21	763%	$55,709.91	$83.89	$664.12	26%	$14,484.58	17267%	$55,020.19	$773.61	$71.12	Unknown	$550.20	71%
156	002070	20	Main	335.2	20-Main	5.2	$46,794.80	17%	39%	$46,738.88	$55.92	$835.77	0%	0	0	$46,721.79	$73.01	$639.93	Unknown	$467.22	640%	$46,710.91	$83.89	$556.84	26%	$12,144.84	14478%	$46,021.19	$773.61	$59.49	Unknown	$460.21	59%
66	002070	20	Main	335.3	20-Main	4.6	$41,395.40	17%	35%	$41,339.48	$55.92	$739.22	0%	0	0	$41,322.39	$73.01	$565.97	Unknown	$413.22	566%	$41,311.51	$83.89	$492.48	26%	$10,740.99	12804%	$40,621.79	$773.61	$52.51	Unknown	$406.22	53%
187	002070	20	Main	335.4	20-Main	3.4	$30,596.60	17%	28%	$30,540.68	$55.92	$546.12	0%	0	0	$30,523.59	$73.01	$418.07	Unknown	$305.24	418%	$30,512.71	$83.89	$363.74	26%	$7,933.31	9457%	$29,822.99	$773.61	$38.55	Unknown	$298.23	39%
183	002070	20	Main	335.5	20-Main	3.2	$28,796.80	17%	27%	$28,740.88	$55.92	$513.93	0%	0	0	$28,723.79	$73.01	$393.42	Unknown	$287.22	393%	$28,712.91	$83.89	$342.29	26%	$7,465.36	8900%	$28,023.19	$773.61	$36.22	Unknown	$280.23	36%
5	002070	20	Main	335.6	20-Main	2.6	$23,397.40	17%	23%	$23,341.48	$55.92	$417.38	0%	0	0	$23,324.39	$73.01	$319.46	Unknown	$233.24	319%	$23,313.51	$83.89	$277.92	26%	$6,061.51	7226%	$22,623.79	$773.61	$29.24	Unknown	$226.24	29%
137	002070	20	Main	335.7	20-Main	2	$17,998.00	25%	24%	$16,142.28	$55.92	$288.65	0%	0	0	$16,125.19	$73.01	$220.86	Unknown	$161.25	221%	$16,114.31	$83.89	$192.10	26%	$4,189.72	4995%	$15,424.59	$773.61	$19.94	Unknown	$154.25	20%
34	002070	20	Main	335.8	20-Main	1.8	$16,198.20	17%	19%	$16,142.28	$55.92	$288.65	0%	0	0	$16,125.19	$73.01	$220.86	Unknown	$161.25	221%	$16,114.31	$83.89	$192.10	26%	$4,189.72	4995%	$15,424.59	$773.61	$19.94	Unknown	$154.25	20%
170	002070	20	Main	335.9	20-Main	2	$17,998.00	17%	20%	$16,142.28	$55.92	$288.65	0%	0	0	$16,125.19	$73.01	$220.86	Unknown	$161.25	221%	$16,114.31	$83.89	$192.10	26%	$4,189.72	4995%	$15,424.59	$773.61	$19.94	Unknown	$154.25	20%
882	002070	20	Main	336	20-Main	1.8	$16,198.20	25%	23%	$16,142.28	$55.92	$288.65	0%	0	0	$16,125.19	$73.01	$220.86	Unknown	$161.25	221%	$16,114.31	$83.89	$192.10	26%	$4,189.72	4995%	$15,424.59	$773.61	$19.94	Unknown	$154.25	20%
201	002070	20	Main	336.1	20-Main	1.2	$10,798.80	25%	19%	$16,142.28	$55.92	$288.65	0%	0	0	$16,125.19	$73.01	$220.86	Unknown	$161.25	221%	$16,114.31	$83.89	$192.10	26%	$4,189.72	4995%	$15,424.59	$773.61	$19.94	Unknown	$154.25	20%
87	002070	20	Main	336.2	20-Main	0.8	$7,199.20	17%	13%	$16,142.28	$55.92	$288.65	0%	0	0	$16,125.19	$73.01	$220.86	Unknown	$161.25	221%	$16,114.31	$83.89	$192.10	26%	$4,189.72	4995%	$15,424.59	$773.61	$19.94	Unknown	$154.25	20%
202	002070	20	Main	336.3	20-Main	0.6	$5,399.40	25%	16%	$16,142.28	$55.92	$288.65	0%	0	0	$16,125.19	$73.01	$220.86	Unknown	$161.25	221%	$16,114.31	$83.89	$192.10	26%	$4,189.72	4995%	$15,424.59	$773.61	$19.94	Unknown	$154.25	20%
70	002070	20	Main	336.4	20-Main	0.6	$5,399.40	25%	16%	$16,142.28	$55.92	$288.65	0%	0	0	$16,125.19	$73.01	$220.86	Unknown	$161.25	221%	$16,114.31	$83.89	$192.10	26%	$4,189.72	4995%	$15,424.59	$773.61	$19.94	Unknown	$154.25	20%
123	002070	20	Main	336.5	20-Main	0.8	$7,199.20	17%	13%	$7,143.28	$55.92	$127.73	0%	0	0	$7,126.19	$73.01	$97.60	Unknown	$71.26	98%	$7,115.31	$83.89	$84.82	26%	$1,849.98	2205%	$6,425.59	$773.61	$8.31	Unknown	$64.26	8%
122	002070	20	Main	336.6	20-Main	0.8	$7,199.20	17%	13%	$7,143.28	$55.92	$127.73	0%	0	0	$7,126.19	$73.01	$97.60	Unknown	$71.26	98%	$7,115.31	$83.89	$84.82	26%	$1,849.98	2205%	$6,425.59	$773.61	$8.31	Unknown	$64.26	8%
171	002070	20	Main	336.7	20-Main	1	$8,999.00	17%	14%	$8,943.08	$55.92	$159.92	0%	0	0	$8,925.99	$73.01	$122.26	Unknown	$89.26	122%	$8,915.11	$83.89	$106.28	26%	$2,317.93	2763%	$8,225.39	$773.61	$10.63	Unknown	$82.25	11%
53	002070	20	Main	336.8	20-Main	1.2	$10,798.80	33%	24%	$10,742.88	$55.92	$192.10	0%	0	0	$10,725.79	$73.01	$146.91	Unknown	$107.26	147%	$10,714.91	$83.89	$127.73	26%	$2,785.88	3321%	$10,025.19	$773.61	$12.96	Unknown	$100.25	13%
72	002070	20	Main	336.9	20-Main	1.2	$10,798.80	25%	19%	$10,742.88	$55.92	$192.10	0%	0	0	$10,725.79	$73.01	$146.91	Unknown	$107.26	147%	$10,714.91	$83.89	$127.73	26%	$2,785.88	3321%	$10,025.19	$773.61	$12.96	Unknown	$100.25	13%
888	002070	20	Main	337	20-Main	1.4	$12,598.60	17%	16%	$12,542.68	$55.92	$224.28	0%	0	0	$12,525.59	$73.01	$171.56	Unknown	$125.26	172%	$12,514.71	$83.89	$149.19	26%	$3,253.83	3879%	$11,824.99	$773.61	$15.29	Unknown	$118.25	15%
102	002070	20	Main	337.1	20-Main	1.4	$12,598.60	17%	16%	$12,542.68	$55.92	$224.28	0%	0	0	$12,525.59	$73.01	$171.56	Unknown	$125.26	172%	$12,514.71	$83.89	$149.19	26%	$3,253.83	3879%	$11,824.99	$773.61	$15.29	Unknown	$118.25	15%
158	002070	20	Main	337.2	20-Main	1.2	$10,798.80	17%	15%	$10,742.88	$55.92	$192.10	0%	0	0	$10,725.79	$73.01	$146.91	Unknown	$107.26	147%	$10,714.91	$83.89	$127.73	26%	$2,785.88	3321%	$10,025.19	$773.61	$12.96	Unknown	$100.25	13%
139	002070	20	Main	337.3	20-Main	1.2	$10,798.80	17%	15%	$10,742.88	$55.92	$192.10	0%	0	0	$10,725.79	$73.01	$146.91	Unknown	$107.26	147%	$10,714.91	$83.89	$127.73	26%	$2,785.88	3321%	$10,025.19	$773.61	$12.96	Unknown	$100.25	13%
141	002070	20	Main	337.4	20-Main	1.2	$10,798.80	17%	15%	$10,742.88	$55.92	$192.10	0%	0	0	$10,725.79	$73.01	$146.91	Unknown	$107.26	147%	$10,714.91	$83.89	$127.73	26%	$2,785.88	3321%	$10,025.19	$773.61	$12.96	Unknown	$100.25	13%
79	002070	20	Main	337.5	20-Main	1.8	$16,198.20	17%	19%	$16,142.28	$55.92	$288.65	0%	0	0	$16,125.19	$73.01	$220.86	Unknown	$161.25	221%	$16,114.31	$83.89	$192.10	26%	$4,189.72	4995%	$15,424.59	$773.61	$19.94	Unknown	$154.25	20%
89	002070	20	Main	337.6	20-Main	1.8	$16,198.20	17%	19%	$16,142.28	$55.92	$288.65	0%	0	0	$16,125.19	$73.01	$220.86	Unknown	$161.25	221%	$16,114.31	$83.89	$192.10	26%	$4,189.72	4995%	$15,424.59	$773.61	$19.94	Unknown	$154.25	20%
190	002070	20	Main	337.7	20-Main	1.8	$16,198.20	17%	19%	$16,142.28	$55.92	$288.65	0%	0	0	$16,125.19	$73.01	$220.86	Unknown	$161.25	221%	$16,114.31	$83.89	$192.10	26%	$4,189.72	4995%	$15,424.59	$773.61	$19.94	Unknown	$154.25	20%
144	002070	20	Main	337.8	20-Main	1.8	$16,198.20	17%	19%	$16,142.28	$55.92	$288.65	0%	0	0	$16,125.19	$73.01	$220.86	Unknown	$161.25	221%	$16,114.31	$83.89	$192.10	26%	$4,189.72	4995%	$15,424.59	$773.61	$19.94	Unknown	$154.25	20%
26	002070	20	Main	337.9	20-Main	1.4	$12,598.60	17%	16%	$12,542.68	$55.92	$224.28	0%	0	0	$12,525.59	$73.01	$171.56	Unknown	$125.26	172%	$12,514.71	$83.89	$149.19	26%	$3,253.83	3879%	$11,824.99	$773.61	$15.29	Unknown	$118.25	15%
890	002070	20	Main	338	20-Main	1.4	$12,598.60	17%	16%	$12,542.68	$55.92	$224.28	0%	0	0	$12,525.59	$73.01	$171.56	Unknown	$125.26	172%	$12,514.71	$83.89	$149.19	26%	$3,253.83	3879%	$11,824.99	$773.61	$15.29	Unknown	$118.25	15%
121	002070	20	Main	338.1	20-Main	2	$17,998.00	17%	20%	$17,942.08	$55.92	$320.83	0%	0	0	$17,924.99	$73.01	$245.51	Unknown	$179.25	246%	$17,914.11	$83.89	$213.56	26%	$4,657.67	5552%	$17,224.39	$773.61	$22.26	Unknown	$172.24	22%
22	002070	20	Main	338.2	20-Main	2	$17,998.00	17%	20%	$17,942.08	$55.92	$320.83	0%	0	0	$17,924.99	$73.01	$245.51	Unknown	$179.25	246%	$17,914.11	$83.89	$213.56	26%	$4,657.67	5552%	$17,224.39	$773.61	$22.26	Unknown	$172.24	22%
120	002070	20	Main	338.3	20-Main	2.2	$19,797.80	17%	21%	$19,741.88	$55.92	$353.02	0%	0	0	$19,724.79	$73.01	$270.16	Unknown	$197.25	270%	$19,713.91	$83.89	$235.01	26%	$5,125.62	6110%	$19,024.19	$773.61	$24.59	Unknown	$190.24	25%

ADJUSTED BENEFIT VALUES OF EACH MITGATION TYPE REPRESENT HOW MONETARLY BENEFITIAL EACH ONE IS, SIMPLY PUT, IF THE STRUCTURE OR DEVICE WILL PAY FOR ITS SELF IN SAVED COLLISION COSTS OVER IT'S LIFETIME.

Appendix A: Tables

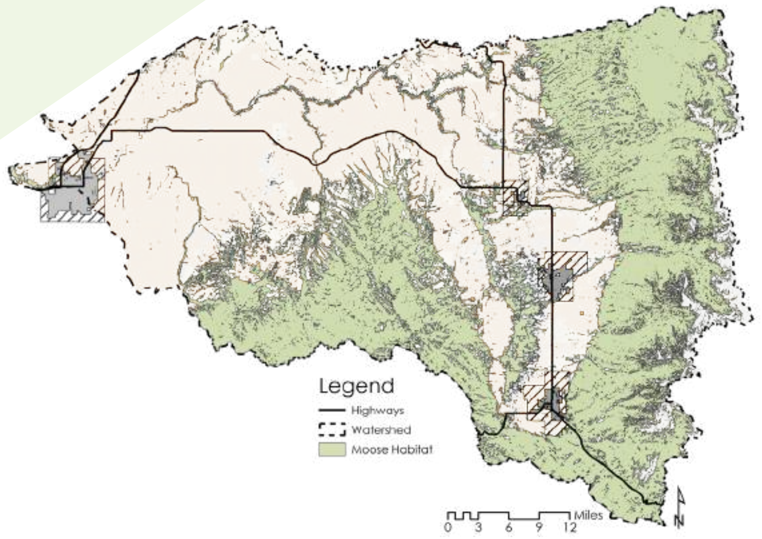
RECREATION SPRAWL CIRCA 2050 COST-BENEFIT ANALYSIS

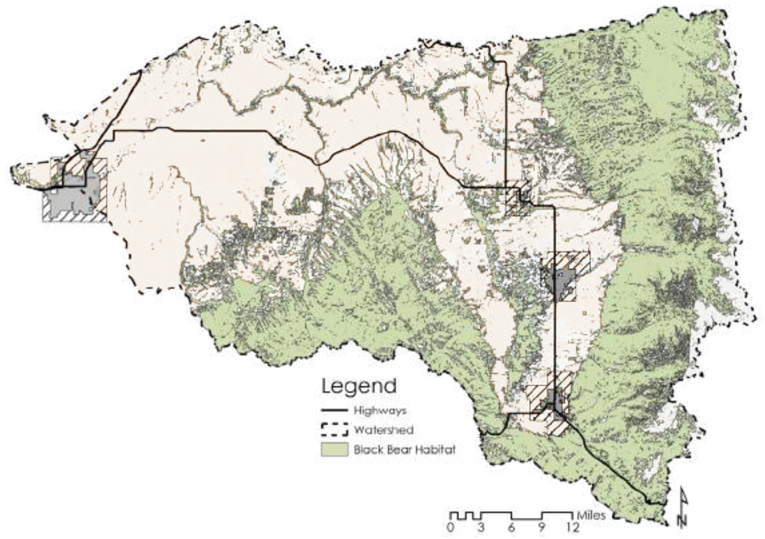
EXAMPLE SECTION OF LARGE SPREAD SHEET

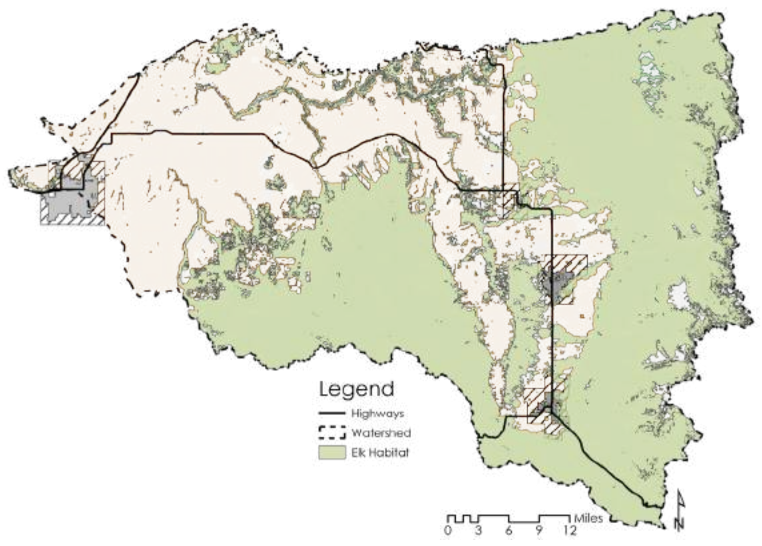
OBJECTID	SegCode	RouteNo	RouteType	MP	RouteName	AvgAnnCollision	CollisionCost	BioConsValue	PriorityLevel	SWS_Savings	SWS_Threshold	SWS_Benefit	SWS_Efficacy	SWS_Adj_Savings	SWS_Adj_Benefit	DW_Savings	DW_Threshold	DW_Benefit	DW_Efficacy	DW_Adj_Savings	DW_Adj_Benefit	SeaSign_Savings	SeaSign_Threshold	SeaSign_Benefit	SeaSign_Efficacy	SeaSign_Adj_Savings	SeaSign_Adj_Benefit	EWS_Savings	EWS_Threshold	EWS_Benefit	EWS_Efficacy	EWS_Adj_Savings	EWS_Adj_Benefit
										Standard Warning Signs						Deer Whistles						Seasonal Signs						Enhanced Warning Signs					
1	002070	20	Main	334.3	20-Main	11.18	$100,608.82	38%	84%	$100,552.90	$55.92	$1,798.05	0%	$0.00	0%	$100,535.81	$73.01	$1,376.99	Unknown	$1,005.36	1377%	$100,524.93	$83.89	$1,198.36	26%	$26,136.48	31157%	$99,835.21	$773.61	$129.05	Unknown	$998.35	129%
2	002460	33	Main	109.2	33-Main	1.04	$9,358.96	23%	18%	$9,303.04	$55.92	$166.35	0%	$0.00	0%	$9,285.95	$73.01	$127.19	Unknown	$92.86	127%	$9,275.07	$83.89	$110.57	26%	$2,411.52	2875%	$8,585.35	$773.61	$11.10	Unknown	$85.85	11%
3	002460	33	Main	109.5	33-Main	1.04	$9,358.96	23%	18%	$9,303.04	$55.92	$166.35	0%	$0.00	0%	$9,285.95	$73.01	$127.19	Unknown	$92.86	127%	$9,275.07	$83.89	$110.57	26%	$2,411.52	2875%	$8,585.35	$773.61	$11.10	Unknown	$85.85	11%
4	002460	33	Main	110.5	33-Main	0.52	$4,679.48	23%	15%	$4,623.56	$55.92	$82.68	0%	$0.00	0%	$4,606.47	$73.01	$63.09	Unknown	$46.06	63%	$4,595.59	$83.89	$54.78	26%	$1,194.85	1424%	$3,905.87	$773.61	$5.05	Unknown	$39.06	5%
5	002070	20	Main	335.6	20-Main	3.38	$30,416.62	23%	31%	$30,360.70	$55.92	$542.90	0%	$0.00	0%	$30,343.61	$73.01	$415.60	Unknown	$303.44	416%	$30,332.73	$83.89	$361.60	26%	$7,886.51	9402%	$29,643.01	$773.61	$38.32	Unknown	$296.43	38%
6	002450	31	Main	17.2	31-Main	2.08	$18,717.92	69%	47%	$18,662.00	$55.92	$333.71	0%	$0.00	0%	$18,644.91	$73.01	$255.37	Unknown	$186.45	255%	$18,634.03	$83.89	$222.14	26%	$4,844.85	5776%	$17,944.31	$773.61	$23.20	Unknown	$179.44	23%
7	002450	31	Main	17.7	31-Main	1.04	$9,358.96	77%	45%	$9,303.04	$55.92	$166.35	0%	$0.00	0%	$9,285.95	$73.01	$127.19	Unknown	$92.86	127%	$9,275.07	$83.89	$110.57	26%	$2,411.52	2875%	$8,585.35	$773.61	$11.10	Unknown	$85.85	11%
8	002450	31	Main	15.3	31-Main	2.86	$25,737.14	85%	59%	$25,681.22	$55.92	$459.22	0%	$0.00	0%	$25,664.13	$73.01	$351.51	Unknown	$256.64	352%	$25,653.25	$83.89	$305.81	26%	$6,669.85	7951%	$24,963.53	$773.61	$32.27	Unknown	$249.64	32%
9	002450	31	Main	17.1	31-Main	2.34	$21,057.66	69%	48%	$21,001.74	$55.92	$375.54	0%	$0.00	0%	$20,984.65	$73.01	$287.42	Unknown	$209.85	287%	$20,973.77	$83.89	$250.03	26%	$5,453.18	6501%	$20,284.05	$773.61	$26.22	Unknown	$202.84	26%
10	002450	31	Main	19.5	31-Main	0	$0.00	38%	19%	-$55.92	$55.92	-$1.00	0%	$0.00	0%	-$73.01	$73.01	-$1.00	Unknown	-$0.73	-1%	-$83.89	$83.89	-$1.00	26%	-$21.81	-26%	-$773.61	$773.61	-$1.00	Unknown	-$7.74	-1%
11	002450	31	Main	20.4	31-Main	2.34	$21,057.66	23%	25%	$21,001.74	$55.92	$375.54	0%	$0.00	0%	$20,984.65	$73.01	$287.42	Unknown	$209.85	287%	$20,973.77	$83.89	$250.03	26%	$5,453.18	6501%	$20,284.05	$773.61	$26.22	Unknown	$202.84	26%
12	002070	20	Main	343.8	20-Main	1.04	$9,358.96	69%	41%	$9,303.04	$55.92	$166.35	0%	$0.00	0%	$9,285.95	$73.01	$127.19	Unknown	$92.86	127%	$9,275.07	$83.89	$110.57	26%	$2,411.52	2875%	$8,585.35	$773.61	$11.10	Unknown	$85.85	11%
13	002450	31	Main	18.5	31-Main	0.52	$4,679.48	38%	22%	$4,623.56	$55.92	$82.68	0%	$0.00	0%	$4,606.47	$73.01	$63.09	Unknown	$46.06	63%	$4,595.59	$83.89	$54.78	26%	$1,194.85	1424%	$3,905.87	$773.61	$5.05	Unknown	$39.06	5%
14	002450	31	Main	19.6	31-Main	0.26	$2,339.74	31%	17%	$2,283.82	$55.92	$40.84	0%	$0.00	0%	$2,266.73	$73.01	$31.05	Unknown	$22.67	31%	$2,255.85	$83.89	$26.89	26%	$586.52	699%	$1,566.13	$773.61	$2.02	Unknown	$15.66	2%
15	002070	20	Main	341.8	20-Main	1.3	$11,698.70	31%	23%	$11,642.78	$55.92	$208.19	0%	$0.00	0%	$11,625.69	$73.01	$159.23	Unknown	$116.26	159%	$11,614.81	$83.89	$138.46	26%	$3,019.85	3600%	$10,925.09	$773.61	$14.12	Unknown	$109.25	14%
16	002450	31	Main	20.9	31-Main	3.64	$32,756.36	23%	33%	$32,700.44	$55.92	$584.74	0%	$0.00	0%	$32,683.35	$73.01	$447.65	Unknown	$326.83	448%	$32,672.47	$83.89	$389.49	26%	$8,494.84	10127%	$31,982.75	$773.61	$41.34	Unknown	$319.83	41%
17	002070	20	Main	333.9	20-Main	9.88	$88,910.12	23%	69%	$88,854.20	$55.92	$1,588.86	0%	$0.00	0%	$88,837.11	$73.01	$1,216.76	Unknown	$888.37	1217%	$88,826.23	$83.89	$1,058.90	26%	$23,094.85	27531%	$88,136.51	$773.61	$113.93	Unknown	$881.37	114%
18	002460	33	Main	110.8	33-Main	0.26	$2,339.74	23%	13%	$2,283.82	$55.92	$40.84	0%	$0.00	0%	$2,266.73	$73.01	$31.05	Unknown	$22.67	31%	$2,255.85	$83.89	$26.89	26%	$586.52	699%	$1,566.13	$773.61	$2.02	Unknown	$15.66	2%
19	002450	31	Main	18.8	31-Main	0.26	$2,339.74	46%	25%	$2,283.82	$55.92	$40.84	0%	$0.00	0%	$2,266.73	$73.01	$31.05	Unknown	$22.67	31%	$2,255.85	$83.89	$26.89	26%	$586.52	699%	$1,566.13	$773.61	$2.02	Unknown	$15.66	2%
20	002450	31	Main	17.8	31-Main	1.04	$9,358.96	62%	37%	$9,303.04	$55.92	$166.35	0%	$0.00	0%	$9,285.95	$73.01	$127.19	Unknown	$92.86	127%	$9,275.07	$83.89	$110.57	26%	$2,411.52	2875%	$8,585.35	$773.61	$11.10	Unknown	$85.85	11%
21	002450	31	Main	19.9	31-Main	0.78	$7,019.22	31%	20%	$6,963.30	$55.92	$124.51	0%	$0.00	0%	$6,946.21	$73.01	$95.14	Unknown	$69.46	95%	$6,935.33	$83.89	$82.68	26%	$1,803.19	2150%	$6,245.61	$773.61	$8.07	Unknown	$62.46	8%
22	002070	20	Main	338.2	20-Main	2.6	$23,397.40	23%	27%	$23,341.48	$55.92	$417.38	0%	$0.00	0%	$23,324.39	$73.01	$319.46	Unknown	$233.24	319%	$23,313.51	$83.89	$277.92	26%	$6,061.51	7226%	$22,623.79	$773.61	$29.24	Unknown	$226.24	29%
23	002450	31	Main	16.1	31-Main	3.12	$28,076.88	85%	60%	$28,020.96	$55.92	$501.06	0%	$0.00	0%	$28,003.87	$73.01	$383.56	Unknown	$280.04	384%	$27,992.99	$83.89	$333.71	26%	$7,278.18	8676%	$27,303.27	$773.61	$35.29	Unknown	$273.03	35%
24	002450	31	Main	18.6	31-Main	0.26	$2,339.74	38%	21%	$2,283.82	$55.92	$40.84	0%	$0.00	0%	$2,266.73	$73.01	$31.05	Unknown	$22.67	31%	$2,255.85	$83.89	$26.89	26%	$586.52	699%	$1,566.13	$773.61	$2.02	Unknown	$15.66	2%
25	002070	20	Main	338.5	20-Main	3.12	$28,076.88	23%	30%	$28,020.96	$55.92	$501.06	0%	$0.00	0%	$28,003.87	$73.01	$383.56	Unknown	$280.04	384%	$27,992.99	$83.89	$333.71	26%	$7,278.18	8676%	$27,303.27	$773.61	$35.29	Unknown	$273.03	35%
26	002070	20	Main	337.9	20-Main	1.82	$16,378.18	23%	22%	$16,322.26	$55.92	$291.87	0%	$0.00	0%	$16,305.17	$73.01	$223.32	Unknown	$163.05	223%	$16,294.29	$83.89	$194.25	26%	$4,236.55	5050%	$15,604.57	$773.61	$20.17	Unknown	$156.05	20%
27	002450	31	Main	18.2	31-Main	0.52	$4,679.48	46%	26%	$4,623.56	$55.92	$82.68	0%	$0.00	0%	$4,606.47	$73.01	$63.09	Unknown	$46.06	63%	$4,595.59	$83.89	$54.78	26%	$1,194.85	1424%	$3,905.87	$773.61	$5.05	Unknown	$39.06	5%
28	002450	31	Main	16.5	31-Main	2.6	$23,397.40	62%	46%	$23,341.48	$55.92	$417.38	0%	$0.00	0%	$23,324.39	$73.01	$319.46	Unknown	$233.24	319%	$23,313.51	$83.89	$277.92	26%	$6,061.51	7226%	$22,623.79	$773.61	$29.24	Unknown	$226.24	29%
29	002450	31	Main	18.7	31-Main	0.26	$2,339.74	46%	25%	$2,283.82	$55.92	$40.84	0%	$0.00	0%	$2,266.73	$73.01	$31.05	Unknown	$22.67	31%	$2,255.85	$83.89	$26.89	26%	$586.52	699%	$1,566.13	$773.61	$2.02	Unknown	$15.66	2%
30	002450	31	Main	20.8	31-Main	3.38	$30,416.62	31%	35%	$30,360.70	$55.92	$542.90	0%	$0.00	0%	$30,343.61	$73.01	$415.60	Unknown	$303.44	416%	$30,332.73	$83.89	$361.60	26%	$7,886.51	9402%	$29,643.01	$773.61	$38.32	Unknown	$296.43	38%
31	002460	33	Main	110.4	33-Main	0.52	$4,679.48	23%	15%	$4,623.56	$55.92	$82.68	0%	$0.00	0%	$4,606.47	$73.01	$63.09	Unknown	$46.06	63%	$4,595.59	$83.89	$54.78	26%	$1,194.85	1424%	$3,905.87	$773.61	$5.05	Unknown	$39.06	5%
32	002460	33	Main	107.2	33-Main	0.52	$4,679.48	23%	15%	$4,623.56	$55.92	$82.68	0%	$0.00	0%	$4,606.47	$73.01	$63.09	Unknown	$46.06	63%	$4,595.59	$83.89	$54.78	26%	$1,194.85	1424%	$3,905.87	$773.61	$5.05	Unknown	$39.06	5%
33	002070	20	Main	335.1	20-Main	8.06	$72,531.94	23%	58%	$72,476.02	$55.92	$1,295.99	0%	$0.00	0%	$72,458.93	$73.01	$992.44	Unknown	$724.59	992%	$72,448.05	$83.89	$863.66	26%	$18,836.49	22455%	$71,758.33	$773.61	$92.76	Unknown	$717.58	93%
34	002070	20	Main	335.8	20-Main	2.34	$21,057.66	23%	25%	$21,001.74	$55.92	$375.54	0%	$0.00	0%	$20,984.65	$73.01	$287.42	Unknown	$209.85	287%	$20,973.77	$83.89	$250.03	26%	$5,453.18	6501%	$20,284.05	$773.61	$26.22	Unknown	$202.84	26%
35	002450	31	Main	15.1	31-Main	2.08	$18,717.92	85%	54%	$18,662.00	$55.92	$333.71	0%	$0.00	0%	$18,644.91	$73.01	$255.37	Unknown	$186.45	255%	$18,634.03	$83.89	$222.14	26%	$4,844.85	5776%	$17,944.31	$773.61	$23.20	Unknown	$179.44	23%
36	002450	31	Main	19.2	31-Main	0	$0.00	46%	23%	-$55.92	$55.92	-$1.00	0%	$0.00	0%	-$73.01	$73.01	-$1.00	Unknown	-$0.73	-1%	-$83.89	$83.89	-$1.00	26%	-$21.81	-26%	-$773.61	$773.61	-$1.00	Unknown	-$7.74	-1%
37	002460	33	Main	115.4	33-Main	3.64	$32,756.36	54%	48%	$32,700.44	$55.92	$584.74	0%	$0.00	0%	$32,683.35	$73.01	$447.65	Unknown	$326.83	448%	$32,672.47	$83.89	$389.49	26%	$8,494.84	10127%	$31,982.75	$773.61	$41.34	Unknown	$319.83	41%
38	002450	31	Main	15.4	31-Main	2.86	$25,737.14	85%	59%	$25,681.22	$55.92	$459.22	0%	$0.00	0%	$25,664.13	$73.01	$351.51	Unknown	$256.64	352%	$25,653.25	$83.89	$305.81	26%	$6,669.85	7951%	$24,963.53	$773.61	$32.27	Unknown	$249.64	32%
39	002450	31	Main	14.7	31-Main	1.3	$11,698.70	85%	50%	$11,642.78	$55.92	$208.19	0%	$0.00	0%	$11,625.69	$73.01	$159.23	Unknown	$116.26	159%	$11,614.81	$83.89	$138.46	26%	$3,019.85	3600%	$10,925.09	$773.61	$14.12	Unknown	$109.25	14%
40	002450	31	Main	19.8	31-Main	0.78	$7,019.22	31%	20%	$6,963.30	$55.92	$124.51	0%	$0.00	0%	$6,946.21	$73.01	$95.14	Unknown	$69.46	95%	$6,935.33	$83.89	$82.68	26%	$1,803.19	2150%	$6,245.61	$773.61	$8.07	Unknown	$62.46	8%
41	002070	20	Main	340.8	20-Main	1.3	$11,698.70	23%	19%	$11,642.78	$55.92	$208.19	0%	$0.00	0%	$11,625.69	$73.01	$159.23	Unknown	$116.26	159%	$11,614.81	$83.89	$138.46	26%	$3,019.85	3600%	$10,925.09	$773.61	$14.12	Unknown	$109.25	14%
42	002070	20	Main	343.2	20-Main	1.3	$11,698.70	31%	23%	$11,642.78	$55.92	$208.19	0%	$0.00	0%	$11,625.69	$73.01	$159.23	Unknown	$116.26	159%	$11,614.81	$83.89	$138.46	26%	$3,019.85	3600%	$10,925.09	$773.61	$14.12	Unknown	$109.25	14%
43	002460	33	Main	109.7	33-Main	1.3	$11,698.70	23%	19%	$11,642.78	$55.92	$208.19	0%	$0.00	0%	$11,625.69	$73.01	$159.23	Unknown	$116.26	159%	$11,614.81	$83.89	$138.46	26%	$3,019.85	3600%	$10,925.09	$773.61	$14.12	Unknown	$109.25	14%
44	002460	33	Main	108.7	33-Main	1.3	$11,698.70	23%	19%	$11,642.78	$55.92	$208.19	0%	$0.00	0%	$11,625.69	$73.01	$159.23	Unknown	$116.26	159%	$11,614.81	$83.89	$138.46	26%	$3,019.85	3600%	$10,925.09	$773.61	$14.12	Unknown	$109.25	14%
45	002070	20	Main	334.4	20-Main	11.18	$100,608.82	38%	84%	$100,552.90	$55.92	$1,798.05	0%	$0.00	0%	$100,535.81	$73.01	$1,376.99	Unknown	$1,005.36	1377%	$100,524.93	$83.89	$1,198.36	26%	$26,136.48	31157%	$99,835.21	$773.61	$129.05	Unknown	$998.35	129%
46	002460	33	Main	109.9	33-Main	1.3	$11,698.70	23%	19%	$11,642.78	$55.92	$208.19	0%	$0.00	0%	$11,625.69	$73.01	$159.23	Unknown	$116.26	159%	$11,614.81	$83.89	$138.46	26%	$3,019.85	3600%	$10,925.09	$773.61	$14.12	Unknown	$109.25	14%
47	002460	33	Main	110.7	33-Main	0.26	$2,339.74	23%	13%	$2,283.82	$55.92	$40.84	0%	$0.00	0%	$2,266.73	$73.01	$31.05	Unknown	$22.67	31%	$2,255.85	$83.89	$26.89	26%	$586.52	699%	$1,566.13	$773.61	$2.02	Unknown	$15.66	2%
48	002070	20	Main	349.9	20-Main																												
49	002450	31	Main	14.3	31-Main	1.3	$11,698.70	92%	54%	$11,642.78	$55.92	$208.19	0%	$0.00	0%	$11,625.69	$73.01	$159.23	Unknown	$116.26	159%	$11,614.81	$83.89	$138.46	26%	$3,019.85	3600%	$10,925.09	$773.61	$14.12	Unknown	$109.25	14%
50	002450	31	Main	19.3	31-Main	0	$0.00	38%	19%	-$55.92	$55.92	-$1.00	0%	$0.00	0%	-$73.01	$73.01	-$1.00	Unknown	-$0.73	-1%	-$83.89	$83.89	-$1.00	26%	-$21.81	-26%	-$773.61	$773.61	-$1.00	Unknown	-$7.74	-1%
51	002460	33	Main	115.1	33-Main	3.38	$30,416.62	31%	35%	$30,360.70	$55.92	$542.90	0%	$0.00	0%	$30,343.61	$73.01	$415.60	Unknown	$303.44	416%	$30,332.73	$83.89	$361.60	26%	$7,886.51	9402%	$29,643.01	$773.61	$38.32	Unknown	$296.43	38%
52	002450	31	Main	16.2	31-Main	2.6	$23,397.40	85%	57%	$23,341.48	$55.92	$417.38	0%	$0.00	0%	$23,324.39	$73.01	$319.46	Unknown	$233.24	319%	$23,313.51	$83.89	$277.92	26%	$6,061.51	7226%	$22,623.79	$773.61	$29.24	Unknown	$226.24	29%
53	002070	20	Main	336.8	20-Main	1.56	$14,038.44	38%	28%	$13,982.52	$55.92	$250.03	0%	$0.00	0%	$13,965.43	$73.01	$191.28	Unknown	$139.65	191%	$13,954.55	$83.89	$166.35	26%	$3,628.18	4325%	$13,264.83	$773.61	$17.15	Unknown	$132.65	17%

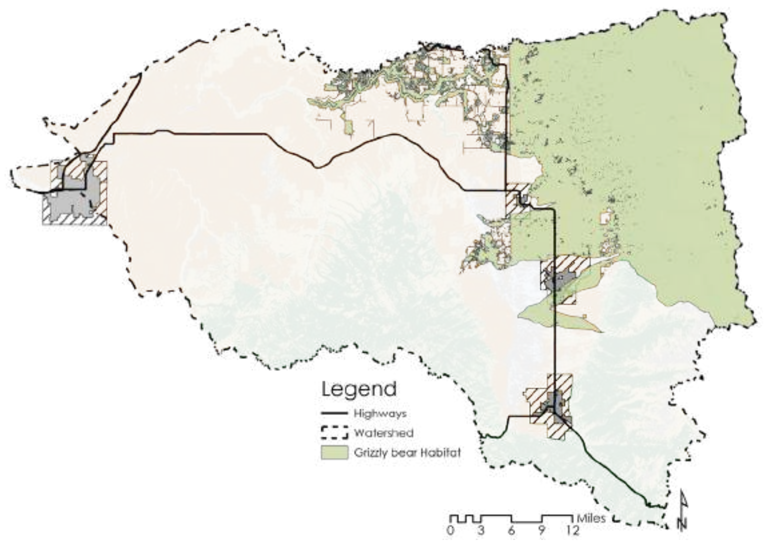
Appendix B: Habitat Maps

HABITAT MAPS WERE COLLECTED FROM USGS SPECIES RANGE AND PREDICTED HABITAT MAPS THROUGH THE GAP ANALYSIS PROGRAM. https://gapanalysis.usgs.gov/apps/species-data-download/

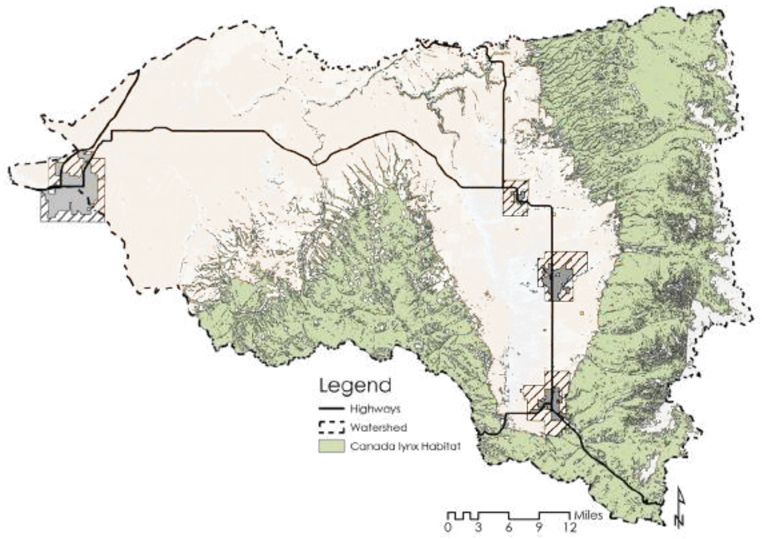


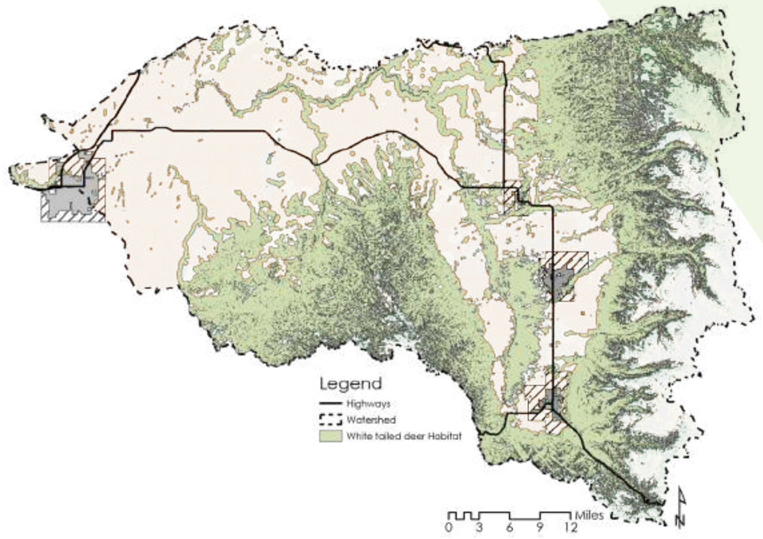


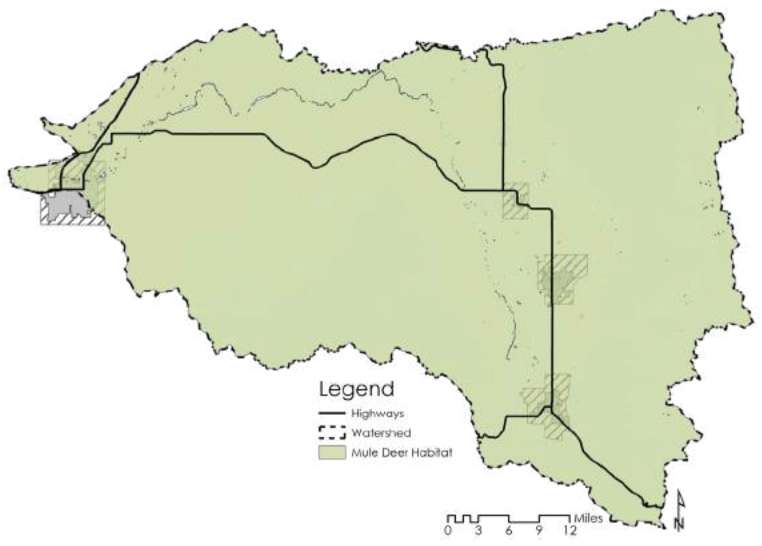


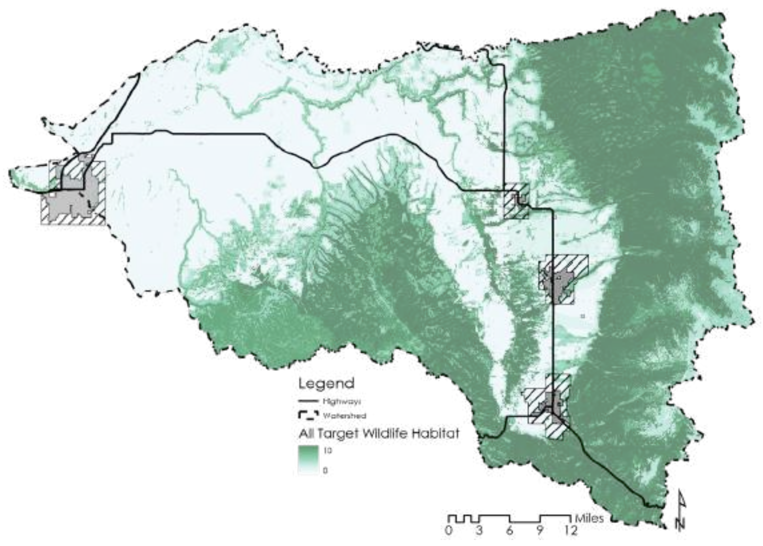


Appendix B: Habitat Maps









Appendix C: Data Processing

Step 1: Justification

- a) Data Transformations:
  - i) Data: Wildlife Collisions
    - (1) Data Range: January 1 2008 – December 31 2020
    - (2) Source: Idaho Transportation Department, Kelly Campbell – Principal Research Analyst
    - (3) Data acquired: November 16th 2021
      - (a) Excel to Table
        - (i) Row to use as sheet name: 6
        - (ii) Range: A7:F15784
        - (iii) Output: wildlifecollisiontable
      - (b) XY Table to Point
        - (i) X Field: Longitude
        - (ii) Y Field: Latitude
        - (iii) Output: wildlifecollisions
      - (c) Clip
        - (i) Input: wildlifecollisions
        - (ii) Clip Feature: Teton Watershed
        - (iii) Output: tet_wlf_collisions
      - (d) Add Field
        - (i) Field Name: Year
        - (ii) Type: Double
        - (iii) Number Format: Numeric
        - (iv) Calculate Field: Appropriate year via "accident_date" value
      - (e) Separate Layer by Year – Model Builder
        - (i) Select by Attribute – where "year" is equal to "xxxx"
        - (ii) Feature to Point – tet_wlf_coll_xx {yr}
  - ii) Data: FARS – Fatality Collisions
    - (1) Data range: 2008 – 2019
    - (2) Source: National Highway Traffic Safety Administration
    - (3) Data acquired: November 10th 2021
      - (a) XY Table to Point – for all years 2008 - 2019
        - (i) X Field: Longitude
        - (ii) Y Field: Latitude
        - (iii) Output: farsxxxx {year}
      - (b) Clip
        - (i) Input: farsxxxx {year}
        - (ii) Clip Feature: Teton Watershed
        - (iii) Output: farsxxxx{year}_clip
      - (c) Merge
        - (i) Input Datasets – all years fars 2008 – 2019
        - (ii) Output: fars_all
  - iii) Data: Idaho All Crashes
    - (1) Data range: 2005 – 2019
    - (2) Source: Idaho Transportation Department
    - (3) Data acquired: November 17th 2021
      - (a) Clip
        - (i) Input: Idaho Crash Data
        - (ii) Clip Feature: Teton Watershed
        - (iii) Output: crashdata
      - (b) Separate Layer by Year – Model Builder
        - (i) Select by Attribute – where "accident_year" is equal to "xxxx"
        - (ii) Feature to Point – tet_crash_xx {yr}
  - iv) Data: Roadkill
    - (1) Data range: 2002 – 2020
    - (2) Source: Idaho Fish and Game
    - (3) Data acquired: November 17th 2021
      - (a) Clip
        - (i) Input: Idaho Roadkill
        - (ii) Clip Feature: Teton Watershed
        - (iii) Output: teton_roadkill
      - (b) Remove non-target species
        - (i) Select by Attribute – where "species" is equal to "target" OR …
        - (ii) Target species:
          1. Deer
          2. Mule deer
          3. White tailed deer
          4. Elk
          5. Moose
        - (iii) Create Layer from Selection – tet_target_carcass
      - (c) Add Field
        - (i) Field Name: Year
        - (ii) Type: Double
        - (iii) Number Format: Numeric
        - (iv) Calculate Field: Appropriate year via "observed" value
      - (d) Separate Layer by Year – Model Builder
        - (i) Select by Attribute – where "year" is equal to "xxxx"
        - (ii) Feature to Point – tet_carcass_xx {yr}
      - (e) Separate Layer by Species – Model Builder
        - (i) Select by Attribute – where "species" is equal to "target species"
        - (ii) Target species:
          1. Deer
          2. Mule deer
          3. White tailed deer
          4. Elk
          5. Moose
        - (iii) Feature to Point – xxxx{species}_carcass
- a) Multivariate Regression
  - i) Prep Explanatory Variables:
    - (1) ADT
    - (2) Approaches
    - (3) Barrier (guardrail) Height
    - (4) Barrier (guardrail) Length
    - (5) Barriers (guardrail) Presence
    - (6) Bridge Presence
    - (7) Carcass Removal
    - (8) Lane Type
    - (9) Lane Width
    - (10) Light Presence
    - (11) Month
    - (12) Shoulder Type
    - (13) Shoulder Width
    - (14) Speed Limit
    - (15) Terrain Type
    - (16) Time of Day
  - ii) Clip to Teton Watershed
  - iii) Convert all Variables into Points
    - (1) Feature to Point
      - (a) Approaches
    - (2) Generate Points Along Lines
      - (a) Guardrails
        - (i) 10 meters and end points
      - (b) Terrain
        - (i) 500 meters and end points
      - (c) ADT
        - (i) 500 meters and end points
      - (d) Speed Limit
        - (i) 500 meters and end points
      - (e) Lanes
        - (i) 500 meters and end points
      - (f) Shoulders
        - (i) 500 meters and end points
  - iv) Add Fields to Teton Wildlife Crashes
    - (1) Unique ID = Object ID
    - (2) Time = Accident_time (HOUR ONLY)
    - (3) Month = Accident_date (MONTH ONLY)
  - v) Spatial Join: ALL VARIABLES joined to Wildlife Collisions
    - (1) Target Features: Wildlife Collisions
    - (2) Join Features: ALL VARIABLES
    - (3) Output: wlf_collisions_variables
    - (4) Join Operation: one to one
    - (5) Keep all Target Features: Yes
    - (6) Match Options: Within a distance: 500m
    - (7) ALL NULL VALUES = 0
  - vi) Exploratory Regression Tool – ArcGIS Pro
    - (1) Input Features:
      - (a) ADT
      - (b) Approaches
      - (c) Barrier presence, height, and length
      - (d) Bridge presence
      - (e) Carcass removal
      - (f) Month
      - (g) Time of day
      - (h) Land type and width
      - (i) Speed limit
      - (j) Adjacent terrain
      - (k) Light presence
    - (2) Dependent Variable:
      - (a) Wildlife Collisions

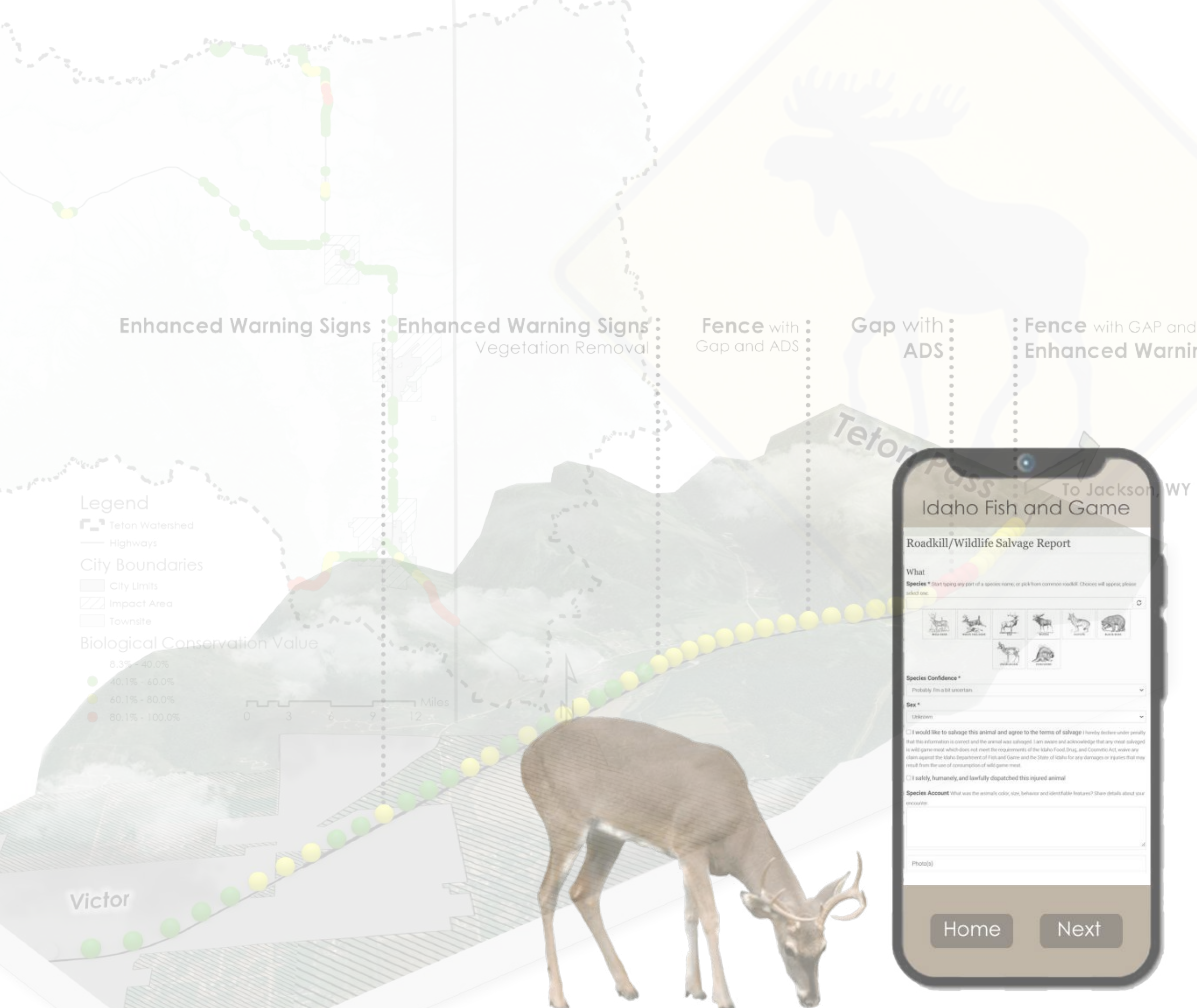
Step 2: Regional Prioritization Zones

- a) Human Safety
  - i) Wildlife Collision Data
    - (1) Obtained from Idaho Transportation Department – Kelly Campbell
      - (a) Includes all crashes and fatalities 2005 – 2019
    - (2) "Clip" to Teton Watershed
    - (3) Select for all collisions recorded between January 1, 2010, and December 31, 2019
    - (4) "Make layer from Selection" – Wildlife Collisions 2010 - 2019
    - (5) KERNEL DENSITY
      - (a) Pop field: OBJECTID
      - (b) Cell size: 30
      - (c) Radius: 1 mile (1609.344)
      - (d) Units: Square Miles
      - (e) Output Cells: Density
      - (f) Method: Planar
  - ii) Carcass Data
    - (1) Obtained from Idaho Fish and Game Roadkill Data Reports; 2005 - Current
      - (a) https://data-idfggis.opendata.arcgis.com/datasets/IDFGgis::idaho-roadkill-observations/about
    - (2) "Clip" to Teton Watershed
    - (3) Select for all carcasses recorded between January 1, 2010, and December 31, 2019
    - (4) "Make layer from Selection" – Roadkill 2010 – 2019
    - (5) KERNEL DENSITY
      - (a) Pop field: OBJECTID
      - (b) Cell size: 30
      - (c) Radius: 1 mile (1609.344)
      - (d) Units: Square Miles
      - (e) Output Cells: Density
      - (f) Method: Planar
  - iii) Reclass:
    - (1) Input: Kernel Density Output (Carcass and Collisions)
      - (a) 5 Natural Breaks (Jenks) Classes
        - (i) 0 = NODATA
        - (ii) Next = 1
        - (iii) Next = 2
        - (iv) Next = 3
        - (v) Next = 4
      - (b) NODATA = NODATA
      - (c) Output: wlf_coll_kd; fars_kd; crash_kd; carcass_kd
      - (d) Change all missing values to NODATA - Yes
- b) Biological Conservation Values – Table
  - i) Idaho Critical Habitat
  - ii) Federal GAP Habitat
  - iii) Species presence / absence
    - (1) FOR HABITAT
    - (2) Mule Deer, White tail Deer, Moose, Elk
      - (a) Match Option: Within a Distance
      - (b) Search Radius = 1 meter (these species use roadside habitats)
    - (3) Wolverine, Grizzly bear, Black bear, Lynx, Wolf, GAP Habitat Analysis
      - (a) When doing Raster to Polygon – Delete the "0" Value Polygon before doing Spatial Join
      - (b) Match Option: Within a Distance
        - (i) Search Radius = 100 meters (these species do not use roadside habitats regularly)
    - (4) Repeat for all Kernel Density and Biological Conservation Variables to place value to each tenth mile and full mile marker to be converted into table form.
    - (5) Merge:
      - (a) Input Datasets: {Wildlife Collisions Tenths and Wildlife Collisions Miles}
      - (b) Output Dataset: {wlf_collisions_allpoints}
      - (c) Merge Rule: Join_Count
    - (6) Repeat for all sets of variables in tenths and miles format to create a single layer with all mile markers in one layer
  - iv) ONLY APPLIES to T&E Species Habitat and Forest Carnivore Habitat
    - (1) T&E Species: Grizzly bear and Canada lynx
    - (2) Forest Carnivore Habitat: Grizzly bear, Canada lynx, Gray wolf, Wolverine, Black bear
      - (a) Input Features: Any TWO features to be joined
      - (b) Output: Name of two features
      - (c) Join Attributes: All Attributes
      - (d) Output Type: Same as Input
    - (3) Table to Excel
      - (a) Input: wlf_collisions_allpoints
      - (b) Output Excel File: wildlife collisions values
      - (c) Use Field Alias as Column Header: Yes
- c) Cost-Benefit Analysis
  - i) Cost of collisions – Average $8,999 per collision
  - ii) Average number of collisions per 0.1 mile marker
  - iii) Multiply number of collisions by the cost per collision
    - (1) Cost of collisions per 0.1 mile section of road annually
  - iv) Divide the cost of collisions per 0.1 mile by the highest cost across all roadways
    - (1) Proportion of the total cost of collisions per 0.1 mile section of road annually
  - v) Add together the Proportion of Collisions Costs (%) and Biological Conservation Value (%) and Divide by 2
    - (1) % Priority at each 0.1 mile section of road
      - (a) < 39.9% = No Priority
      - (b) 40 – 60% = Low Priority
      - (c) 60 – 80% = Moderate Priority
      - (d) 80 – 100% = High Priority
- d) Mitigation Measures – Monetary Benefit
  - i) Cost-Benefit analysis to figure out which crossing structures will pay for themselves within each priority zone
  - ii) "Threshold Value" ($)
    - (1) Cost per mile per year of each mitigation measure – Clevenger and Huijser (2009)
  - iii) Cost = Cost of collision per 0.1 mi of road / year
  - iv) "Savings" ($)
    - (1) Collision costs minus the threshold value
  - v) "Efficacy" (%)
    - (1) Effectiveness of each mitigation measure – Clevenger and Huijser (2009)
  - vi) "Adjusted Savings" ($)
    - (1) "Savings" X "Efficacy"
  - vii) "Adjusted Benefit" (%)
    - (1) "Adjusted Savings" / "Threshold Value"
  - viii) Monetary "Breakeven"
    - (1) Based on the "Adjusted Benefit ($)"
      - (a) < 0% - Monetary Loss
      - (b) 0.1 – 10% - More than 10 years to breakeven
      - (c) 10.1 – 20% - 6 – 10
      - (d) 20.1 – 25% - 5
      - (e) 25.1 – 33% - 4
      - (f) 33.1 – 50% - 3
      - (g) 50.1 – 100% - 2
      - (h) > 100.1% - Less than 1 year to breakeven

Data used for Analysis

Data	Source	Method	Outcome
Average Daily Trips Approaches (driveways) Barrier Presence Barrier Height Bridge Presence Month Day of Week Time of Day Lane Type Lane Width Light Presence Shoulder Type Shoulder Width Speed Limit Adjacent Terrain	Idaho Transporation Department open GIS Data	Multivariate Regression	Characteristics that explain where collisions with wildlife are occuring: Month, Speed Limit, Barrier Height, Adjacent Terrain, and Shoulder Type.
Wildlife Collisions Carcass Removals	Idaho Fish and Game	Kernel Density - "Hot Spot" Analysis	Low, Moderate, High, and Very High densities of collisions with wildlife and carcass removals along major highways.
GAP Habitat Idaho Critical Habitat Mule Deer Habitat White-tailed deer Habitat Moose Habitat Elk Habitat Canada lynx Habitat Grizzly bear Habitat Black bear Habitat	USGS GAP Program Idaho Fish and Game USGS GAP Species Range and Predicted Habitat Data	Biological Conservation Value	Low, Moderate and High values for conservation of habitat.
Collision Costs	Huijser et al., 2008b Average cost of a collision with a deer in 2007$	Cost-Benefit Analysis	Cost of collisons per 0.1 mile section of roadway

Appendix C: Data Processing



Enhanced Warning Signs
Enhanced Warning Signs
Vegetation Removal
Fence with
Gap and ADS
Gap with
ADS
Fence with GAP and
Enhanced Warnin
Teton Pass
To Jackson, WY
Legend
Teton Watershed
Highways
City Boundaries
City Limits
Impact Area
Townsite
Biological Conservation Value
8.3% - 40.0%
40.1% - 60.0%
60.1% - 80.0%
80.1% - 100.0%
0 3 6 9 12 Miles
Victor
Idaho Fish and Game
Roadkill/Wildlife Salvage Report
What
Species Confidence *
Sex *
Unknown
I would like to salvage this animal and agree to the terms of salvage
I safely, humanely, and lawfully dispatched this injured animal
Species Account
Photo(s)
Home
Next