Miistakis Institute

Improving Human and Wildlife Safety Along Alberta's Highway Network

March 2019

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Acknowledgements

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Executive Summary

Enhancing the efficiency, sustainability, and safety of Alberta's highways by systematically identifying priority road sections for mitigation measures to improve wildlife movement and reduce Animal Vehicle Collisions.

The intersection of wildlife and people on highways raises two critical issues: impacts of roads on the movement and mortality of wildlife, and risks to people from animal vehicle collisions (AVCs). In Alberta, as in many areas, these two issues are addressed by different government agencies, with Alberta Transportation (AT) mandated to address motorist safety and Alberta Environment and Parks (AEP) mandated to manage Alberta's wildlife. AVCs are responsible for ~50% of all vehicle collisions in rural areas, and therefore represent an important human safety concern. AEP has several policy objectives relating to maintaining wildlife connectivity in support of species recovery and biodiversity management goals.

There is a need to better understand wildlife connectivity in a regional context across the highway network in the South Saskatchewan Region, identify areas of human safety risk, and prioritize highway sections where mitigation solutions should be implemented to meet both human safety and wildlife conservation outcomes. To meet these needs, a coupled AEP-AT decision support tool was developed that incorporates wildlife issues into future road development and highway upgrade projects, and links transportation planning into Alberta's land use planning process.

We developed an AVC Risk Index using RCMP records of animal carcasses from AVCs along roads in the South Saskatchewan Region. This index enabled the identification of highway sections with a high human safety risk. We developed functional connectivity models for four focal species (pronghorn, rattlesnake, grizzly bear, and mule deer) and species-neutral structural connectivity model using ArcGIS Linkage Mapper software, and then derived Connectivity Value Indices for highway sections by extracting values from the connectivity model outputs. We compared AVC Risk Indices and Connectivity Value Indices to determine whether and where priority locations for these two factors overlap at two spatial scales: (1) traffic control sections (TCS) representing areas with similar traffic volumes that are created by AT and are useful for informing priority areas for highway upgrades and mitigation; and (2) kilometer sections, which could inform mitigation assessments occurring on specific sections of Alberta highways.

We explored different scenarios for combining the AVC Risk Indices and Connectivity Value Indices by using a weighted average approach that allowed greater emphasis on either human safety or wildlife connectivity value.

We hosted a stakeholder workshop in which we used an Analytical Hierarchy Process (AHP) to establish weights that reflected participants' collective opinions on the relative importance of AVC risk and wildlife connectivity value. Participants heavily weighted human safety risk over wildlife connectivity, with AHP weights of 88% and 13% respectively. In addition, workshop participants equated connectivity values with a heavy emphasis on structural connectivity (54%), which represents areas of flow between natural habitat patches remaining on the landscape, over functional connectivity for individual species of conservation concern, such as grizzly bear (17%), pronghorn (12%), and rattlesnake (5%).

Using the AHP-derived weights, we identified 129 TCSs (12% of the highway network in the South Saskatchewan Region) as priorities for mitigation.
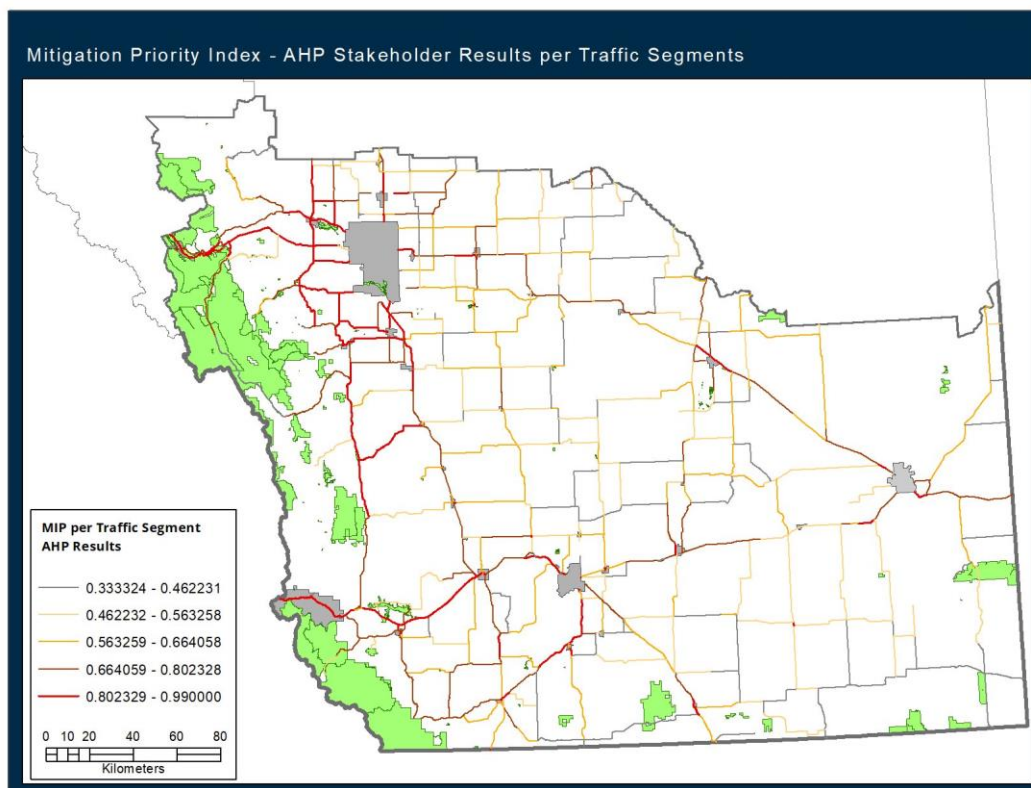
The process and results identified the following recommendations for consideration by AT and AEP:

> ➢ Road sections with the highest AVC Risk Index values were most common on the fringes of urban centers, where a combination of high traffic volume and abundant deer populations intersect to create a 'perfect storm' of risk to human safety. It is important to consider additional methods for prioritizing mitigation sections because these areas may not be important ecologically despite having many recorded AVCs.

➢ The AVC Risk Index, when normalized by traffic volume, identified road sections along the highway network where animals cross most frequently and may be important from an ecological perspective to maintaining biodiversity. In addition these areas represent sections of higher risk of each car being involved in an AVC.

➢ Road sections with high Ungulate Vehicle Collision Index and those with high Structural Connectivity Value Index exhibited minimal spatial overlap. This is an important consideration because mitigation decisions have traditionally been based on relative AVC risk of highway sections. AT does consider wildlife connectivity, but as a secondary factor once statistically-significant AVC clusters have been identified. This finding emphasizes the importance of AEP, with its policy objective of maintaining wildlife connectivity, being actively engaged in and pro-actively supporting transportation planning where wildlife management issues are impacted by Alberta's highway network.

➢ Workshop participants, through an Analytical Hierarchy Process, assigned much greater weight to human safety than to wildlife connectivity concerns, likely due to the impression that investment in mitigation will be driven primarily by AT's human safety mandate. However, roads may have a significant impact on wildlife via direct mortality or avoidance behavior by species sensitive to road disturbance. Thus, ensuring safe passage of wildlife across roads is an important strategy for maintaining biodiversity and protecting species at risk. Public education and science-policy translation regarding the need for investments in mitigation in support of biodiversity and species-at-risk recovery planning is urgently needed.

➢ Workshop participants identified structural connectivity as the most important connectivity component for wildlife conservation and management concerns, likely because this model is species-agnostic and represents areas important for biodiversity in highly fragmented landscapes. It may also be easier for the public to understand the concept of maintaining natural habitat than the concept of dispersal corridors for individual species. Participants suggested that the structural connectivity model be expanded to the provincial scale and incorporated into Alberta Wildlife Watch mapping products to help inform transportation planning.

➢ Further exploration is needed regarding mitigation investment for species at risk in areas where roads have been identified as a key impact. Products from this assessment may suggest where to focus finer-scale research to better inform transportation planning.

➢ The decision support tool should be integrated into existing planning processes by AT and AEP and updated as new data become available, new modeling methods are developed, or additional geographic areas are considered.

➢ Direct engagement among AT and AEP staff and the broader scientific and conservation communities would help to ensure that these goals are realized.

1.0 Introduction

Enhancing the efficiency, sustainability, and safety of Alberta's highways by systematically identifying priority road sections for mitigation measures to improve wildlife movement and reduce animal vehicle collisions.

Alberta supports an extensive network of transportation infrastructure consisting of 31,000 km of highway that enables the efficient movement of people and goods (Government of Alberta, 2013). Alberta is also home to the most diverse assemblage of large mammal species in Canada, including elk, moose, bighorn sheep, mule deer, white-tailed deer, black bear, cougar, wolf, wolverine, lynx, and the provincially-threatened grizzly bear. Most of these species require large areas for survival as they search for food, shelter, and mates. Inevitably, these movements bring animals into contact with roads and, too often, the vehicles driving on them.

The intersection of wildlife and people on highways raises two critical issues:
1. The impact of roads on the movement and mortality of wildlife; and
2. Risks to people and vehicles caused by collisions with wildlife.

Many species of wildlife avoid crossing roads, creating movement barriers across the landscape (Frissell & Trombulak, 2000). These barrier effects reduce the amount of habitat available to animals, alter predator-prey interactions, and can reduce the viability of populations through genetic and demographic isolation (Forman et al., 2003). For some taxa, such as large carnivores, mortality from vehicle collisions is often the leading cause of death (Alberta Environment and Parks, 2016a, 2016b). As such, roads can pose a major hurdle to wildlife management and conservation objectives.

Human safety is also compromised by animal-road interactions. Across Canada, approximately six large mammals are involved in an AVC every hour (L-P Tardif and Associates Inc., 2003). AVCs in Alberta represent approximately 50 percent of all reported vehicle accidents on provincial rural highways and result in an average of five human fatalities each year (Alberta Transportation, 2017). Alberta Transportation estimated that the annual cost of AVCs across the province may have surpassed $280 million per year (2015 dollars) (Alberta Transportation, 2017).

Highway mitigation is a widespread and highly effective means to resolve issues of road-wildlife interaction. Mitigation may involve making drivers more alert (e.g., animal detection systems, variable message signs), separating wildlife and motorists (e.g., exclusion fencing, crossing structures such as overpasses and underpasses), and modifying animal behavior near the road (large boulder fields, vegetation manipulation) (Bissonette & Rosa, 2012; Huijser et al., 2008). However, because mitigation measures are both expensive and often fixed (i.e., not portable), it is critical that they are strategically implemented to maximize

return on investment for both wildlife and transportation agencies (Ford, Clevenger, Huijser, & Dibb, 2011). It is not always clear when and where different government agencies share priorities. For example, a recent study in Montana found that highway sections with high value for wildlife connectivity (e.g., for rare carnivores) and highway sections with high risk of AVCs rarely occurred in the same place (McClure & Ament, 2014).

In Alberta, rural highway mitigation without a planned highway upgrade is in place or is planned for sections of Highway 3 in the Crowsnest Pass area, and Highway 1 near Canmore. These efforts are complementary to Parks Canada's effort to create over 90 km of highway mitigation (fencing and crossing structures) within Banff National Park. While these efforts demonstrate Alberta's leadership in resolving road-wildlife interactions, it is not clear if these specific highway sections are the most important priority at the province-wide scale. For example, collisions with deer may be more common on the fringes of urban centers, where a combination of high traffic volume and abundant deer populations intersect to create a 'perfect storm' of risk to human safety. Likewise, connectivity models often link patches of non-disturbed areas to identify areas that are important for wildlife movement. This 'structural' perspective of connectivity may approximate animal movement in areas with high amounts of human disturbance (i.e., southern Alberta), where the vast majority of the landscape has been transformed by agriculture and urban development. These rural landscapes are occupied by both people and a diverse array of carnivores, ungulates, and other wildlife. At the regional scale, measures of connectivity must account for the way animals actually use different types of habitats depending on the landscape context.

In spite of Alberta's demonstrated leadership in creating safer roads and more connected landscapes, there has been no systematic planning and prioritization of highway mitigation at the regional or province-wide scale. Indeed, to our knowledge, such comprehensive planning has not been undertaken anywhere in Canada. The timing is ideal for Alberta to continue leading Canada in the management of safe, efficient, and sustainable highways.

1.1 Alberta Perspective

The Government of Alberta has the responsibility and authority for the protection and management of wildlife on all land in Alberta, irrespective of whether these lands are owned by the Crown or by private interests. The Government of Alberta is also responsible for contributing to Albertans' economic prosperity and quality of life by providing a safe and efficient transportation network. As in most jurisdictions, the wildlife populations and transportation network of Alberta are managed by different government departments, which have distinct management priorities, planning areas, budgets, and expertise.

Alberta Environment and Parks (AEP) manage Alberta's wildlife, and recognize the key role connected habitats play in protecting biodiversity. For example, the South Saskatchewan Regional Plan indicates that wildlife habitat across and within land-use planning regions is

an important strategy for maintaining and protecting biodiversity (Alberta Government, 2014). In addition, maintaining wildlife connectivity has been identified as an important strategy in the recovery plans for threatened or endangered species. For example, the grizzly bear recovery plan highlights the importance of maintaining regional connectivity between designated grizzly bear population areas (Alberta Environment and Parks, 2016a). Recently, AEP released a draft Biodiversity Management Framework for the South Saskatchewan Region and identified a fragmentation index as one of their indicators to monitor biodiversity. Lastly, AEP has developed 'Recommended Land Use Guidelines' for specified wildlife and biodiversity zones in Alberta. These guidelines argue for the protection of locally- and provincially-significant wildlife movement corridors (Environment and Sustainable Resource Development 2015). Our report will help meet several of these policy objectives by identifying where connectivity across Alberta's road network is needed to support AEP's biodiversity management goals.

Alberta Transportation (AT) manages highways, with a top priority to enhance human safety. Animal vehicle collisions (AVCs) are responsible for 50% of all vehicle collisions in rural areas, and represent an important motorist safety concern (Alberta Transportation, 2017). In addition to considering AVC hotspots (areas of high AVC risk), Alberta Transportations Business Plan 2015-2020 identified as a policy initiative to "create and implement a Transportation Strategy to develop a multi-modal system that will support a strong economy, a high quality of life and a healthy environment for all Albertans to meet growing urban and regional transportation needs." We suggest that a healthy environment includes maintaining wildlife connectivity, reducing AVCs, and enhancing the safety of people.

There is a need to better understand habitat connectivity in a regional context across Alberta, identify highway sections with high AVC rates, and prioritize highway sections where mitigation solutions should be implemented. To meet these needs, a coupled AEP-AT decision support tool was developed that incorporated wildlife issues into future road development and highway upgrade projects and linked transportation planning into Alberta's land use planning process and wildlife management priorities.

1.2 Project Purpose and Objectives

Our overall goal was to provide a decision support tool to improve wildlife connectivity, increase motorist safety, and reduce wildlife mortality throughout Alberta's highway network in the South Saskatchewan Region. We sought to identify priority traffic control sections and kilometer sections where mitigation could help meet the distinct and shared management objectives of AT and AEP. Meeting this goal required an assessment of wildlife connectivity, analysis of AVC distribution, and interagency cooperation for developing and implementing solutions.

Specifically, we identified four objectives required to meet our goal:

1. Identification and prioritization of road sections with high wildlife connectivity value;
2. Identification and prioritization of road sections with a high risk of AVCs;
3. Identification of where these two conditions intersect, or complementary sets of priority sites if overlap is poor; and
4. Multi-departmental engagement by the Government of Alberta throughout the process, including model design and evaluation.

2.0 Approach

To develop a decision support tool for agencies to improve human and wildlife safety along Alberta's highway network, we worked with agency personal from AT, AEP, and several non-governmental organizations (NGOs). Our approach included three key steps:

1. ***Scoping Workshop 1***: We convened a meeting of stakeholders to provide direction on project scope, including outcomes, modeling approach, species of interest, and study area [Lethbridge AB, April 2016].

2. ***Connectivity modeling and AVC risk analysis:*** We identified high-priority highway sections for improving the safety of wildlife and humans by developing indices for:
   ➢ landscape connectivity among areas of high natural integrity;
   ➢ species-specific functional connectivity; and
   ➢ human safety risk (based on frequency of recorded AVCs).

   These indices were compared and analyzed to identify areas of alignment between wildlife connectivity value and motorist safety concerns, where mitigation could improve connectivity and/or reduce human safety risk.

3. ***Stakeholder Workshop 2***: The connectivity modeling and AVC risk analysis results were presented to staff from AT, AEP, and several conservation NGOs to facilitate a discussion around prioritizing road section. Prioritization tools such as the Analytical Hierarchy Process were used to help guide and formalize decision-making [Calgary AB, December 2018].

AVC and connectivity data and model outputs were displayed visually at the workshop (and made available beforehand) using the online mapping platform Data Basin to enable participants to interactively view geospatial data resulting from analyses. In addition, layer packages of all products have been provided to AT and AEP.

3.0 Scoping Workshop 1

In April 2016, a Scoping Workshop was held in Lethbridge, Alberta, that included AT and AEP staff, project partners, and invited NGOs. The workshop was designed to discuss the following project characteristics:

➢ Desired outcomes (e.g. generic identification of corridors, ranked/ordered, most useful metrics from a planning perspective);
➢ Preferred modeling approaches;
➢ Selection of species for connectivity modeling; and
➢ Availability of AVC data.

The workshop discussion was used to guide the methodology for the next phase of the project. Key insights and decisions resulting from this workshop included:

➢ The project should start with a pilot area of the South Saskatchewan Region, with the understanding that the process be designed to scale up to other planning regions in the future.
➢ There is value in modeling both natural integrity of the landscape and species-specific connectivity.
➢ Species selection for connectivity modeling should be based on the following criteria: (1) species is of management concern (species at risk or species at high risk of collisions resulting in social and economic impacts); (2) empirical baseline data are available or expert knowledge is well established for the species; and (3) species composition is representative of study area. Species meeting these criteria include grizzly bear, mule deer, pronghorn, and rattlesnake.
➢ Where appropriate, models should consider resource patches developed as a result of the SSRP planning process, such as areas of high biological diversity value identified in the Biodiversity Management Framework.
➢ Criteria for prioritizing highway sections could include species of management concern, human safety risk, land security (ownership), highway type (based on classification levels 1-4), mitigation potential, and policy level considerations.
➢ Results should be presented as a decision support tool that includes spatial datasets, reports, and presentation material to support decision making in relation to regional, environmental, and transportation planning, and should inform where highway mitigation is needed.
➢ Project success should be assessed based on successful development of outputs, use of outputs in transportation and environment planning and decision making, and implementation of successful mitigation projects.

Appendix A contains full minutes from the scoping workshop.

4.0 Wildlife Connectivity Modeling

Landscape connectivity is the degree to which the landscape facilitates or impedes animal movement between resource patches that meet an animal's needs to live (e.g., food, water, mates). Maintaining a connected landscape is a key strategy for maintaining biodiversity and a healthy, functioning ecosystem. Because species have different biological requirements and respond to landscape features in different ways, connectivity is an inherently species-specific characteristic of a landscape. Therefore a challenge to identifying connectivity for a landscape such as the South Saskatchewan Region is the need to model for a representative set of species. Ideally, species-specific landscape connectivity modeling is based on empirical data to inform modeling parameters such as location and size of resource patches, travel distance, and response to anthropogenic features within the landscape.

The Scoping Workshop supported the need to represent a broad range of species in our connectivity models – see Appendix A for table of species to be considered. Final species selection was based on partner discussion with AEP staff to determine availability of empirical data, species that are representative of the region, and the role the species plays in helping the project meet the objectives of addressing roads from a species conservation and/or human safety risk (Table 1).

Table 1: Species functional connectivity models.

Species	Spatial coverage	Role
Mule deer	All of study area	Human safety risk: predominant species involved in AVCs
Grizzly bear	Western foothills	Species conservation: threatened in Alberta, prone to road mortality
Pronghorn	Eastern – prairie	Species conservation and human safety risk: sensitive to high-volume roads as barriers to movement, and involved in AVCs
Rattlesnake	Eastern – prairie	Species conservation: sensitive species in Alberta, prone to road mortality (Alberta Environment and Parks, 2016b)

Species-specific empirical data needed to develop connectivity models are often limited in scale and temporal extend and in resolution. Nonetheless, it is imperative that landscape connectivity is considered and planned for even in regions where species data are limited because habitat loss and fragmentation are negatively impacting many species and populations. Structurally connected landscapes are more likely to facilitate abiotic and biotic processes than highly fragmented landscapes, an observation that has led many

recent connectivity studies to use the degree of human modification of the landscape (or, inversely, landscape naturalness or integrity) as an indicator of the landscape's overall resistance to ecological flows, including animal movements (Quinn, Pina Poujol, Tyler, & Chernoff, 2014; Theobald, Reed, Fields, & Soulé, 2012). This approach is particularly applicable to situations in which data are sparse and inferences about connectivity are desired for a large and diverse community of species. The South Saskatchewan Region is a large landscape with a diversity of habitat types and species, and we therefore used this naturalness-based approach to model structural connectivity and provide additional species-agnostic connectivity information that complements the species-specific information provided by models for focal species.

4.1 Wildlife Connectivity Methods

Connectivity models can be useful for identifying locations where important habitat linkages or species dispersal corridors intersect roads, which may be high-priority locations for mitigation measures (Dickson et al., 2018). Recent attention has focused on the use of landscape resistance models, which represent the hypothesized relationship between landscape characteristics and the cost of movement through the landscape, to guide highway mitigation efforts (Landguth et al. 2013). Resistance-based connectivity models can identify broadly important corridors for large, landscape scale processes and movements of many species, or they can use detailed information to model optimal corridors for individual species with distinct needs and behaviors (Cushman, Lewis, & Landguth, 2013; Leonard et al., 2016). Linkage Mapper (McRae, Dickon, Keitt, & Shah, 2008) is a flexible analytical tool for modeling many types of connectivity, and we used this tool, along with existing connectivity model outputs from previous studies, to understand where wildlife connectivity intersects with highway network.

Linkage Mapper requires development of two datasets as inputs: (1) a resistance surface, and (2) a set of focal nodes representing locations among which animal movement is to be modeled. We made use of existing data and models wherever possible when developing landscape resistance surfaces for focal species. Table 2 lists these focal species and key data sources and characteristics of resistance surfaces develop for each. To develop focal nodes used in models for mule deer, rattlesnake, and structural connectivity, the South Saskatchewan Region was subdivided into a 'mesh' by the primary and secondary highways (red lines); meshes greater than 500 km^2 (which approximated the 90th percentile of patch sizes) were selected (yellow polygons) (Figure 1); and source nodes for the connectivity analyses were placed at the centroids of these large polygons (Figure 2). Connectivity model outputs were already available for pronghorn and thus did not require us to develop resistance surfaces or focal nodes. Additional detail on each connectivity model is provided below.
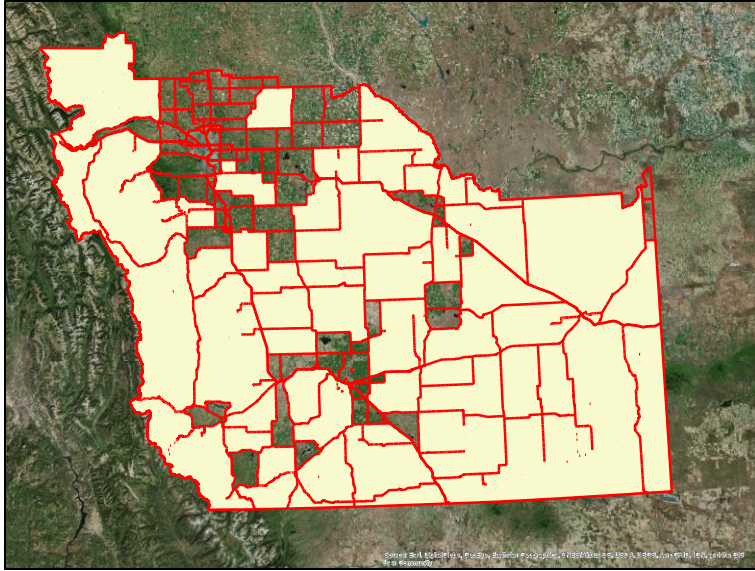
Figure 1: South Saskatchewan Region highway mesh polygons greater than 500 km^2.
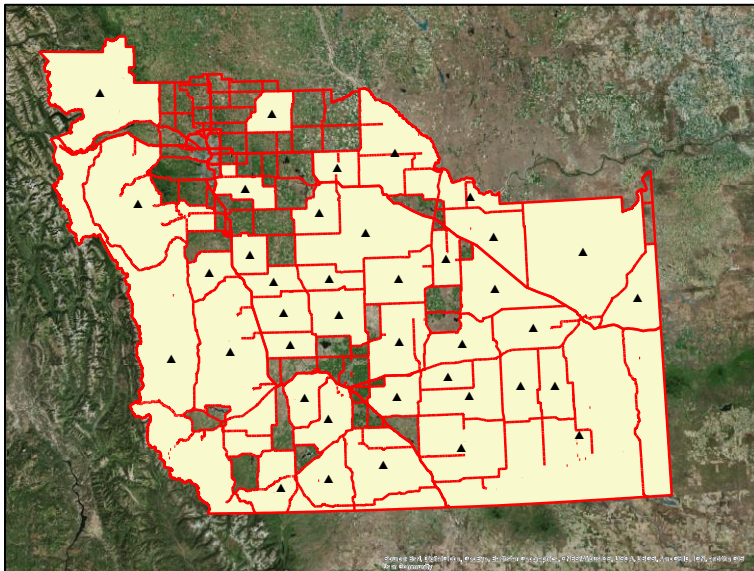
Figure 2: Focal nodes (black triangles) based on mesh centroids.

Table 2: Methods summary for connectivity models.

Taxa	Study area	Resistance layer	Roads[1]	Nodes [2]	Layers
Grizzly bear	Western - foothills	Inverted resource selection function (RSF) from Neilson et al. 2007	Explicit – same coding values as structural layer	Habitat security patches derived from Lee et al. 2017)	The mean of pre-, during-, and post-berry seasons

Pronghorn antelope	Eastern – prairie	Direct from Jakes et al 2015.	Implicit	NA	The mean of spring and fall migration seasons
Mule deer	All	Derived from habitat model[3] based on observed winter survey data	Implicit	Mesh centroids (n =39)	Winter
Prairie rattlesnake	Eastern – prairie	Inverted HSI; scaled to local environment because of regional gradient	Implicit	Mesh centroids (n= 23)	1
Structural	All	Values assigned from Theobald et al. (2012) to the Alberta Biodiversity Monitoring Institute land cover layer	Explicit	Mesh centroids (n = 39)	1

(1) If roads were part of the HIS/RSF, then no further consideration was given to roads per se (i.e., implicit). If roads were not part of the RSF/HSI model, then a 60m buffer was applied to roads and resistance layers (i.e., explicit) according to the size of the road (see Table 3 below).
(2) Nodes represent the source and destination locations among which animal movement is simulated using connectivity algorithms. 'Mesh nodes' refer to the centroids of the largest 'meshes' created by the paved road network. Mesh sizes > 500 km2 were used. The high density of small mesh sizes near Calgary would obscure regional connectivity flows if they were included in the model. See Table 3.
(3) Mule deer habitat model (RSF) is shown below in Table 3.

Grizzly bear modelling methods

We used published grizzly bear resource selection function (RSF) models for three seasons (May 15-June 15, June 16-July 31, and Aug. 1-Oct. 15) developed for Alberta by Dr. Scott Nielson to create a resistance surface to use in connectivity modeling (Nielsen, 2007). RSF values for the three seasons were averaged to generate a single model and then inverted to represent resistance values.

The resulting resistance surface did not include roads, which are known to influence grizzly bear movement and are a key concern for our analysis. We therefore superimposed highways from Alberta base features GIS layer onto the resistance surface with a 60-m buffer, and applied the same resistance values for roads as those used for the structural resistance layer.

Grizzly bear focal nodes were based on grizzly bear security patches greater than 5 km^2 as defined in Lee et al. (2017) based on methodology developed by Gibeau et al. (2001). To develop security areas we used the 2010 AMBI land cover layer (Castilla, Hird, Hall, Schieck,

& McDermid, 2014). All native land cover classes were selected. From the native cover base layer we removed linear features using the 2014 ABMI human footprint layer (Alberta Biodiversity Monitoring Institute, 2012). Linear features that support high human use, defined as >3 human events per day or 100 human events per month, were buffered by 500 m. Natural habitat patches larger than 5 km^2 were identified as focal patches for the linkage mapper analysis.

Pronghorn Modeling Methods

We used a published pronghorn connectivity model developed using Linkage Mapper for both spring and fall by Dr. Andrew Jakes (Jakes, 2015). The connectivity seasonal models were averaged to create one pronghorn connectivity model.

Mule Deer Modeling Methods

We used mule deer winter survey data (n=8121 observed locations) from 1990-2013 provided by AEP to develop a RSF model. Variables selected for testing in the RSF modeling were derived from a previous study conducted northeast of the our study area (Habib, Merrill, Pybus, & Coltman, 2011); however, RSF model coefficients were calculated independently for the current study (Table 3). To select the top model, we used an information-theoretic approach (Akaike information criterion, AICc) and model-average coefficients. All variables from the global model were retained in the top (ΔAICc <4) candidate models. The RSF model was inverted to develop a resistance surface for connectivity modeling.

Table 3: Mule deer resource selection function.

Variable	Coefficient	P-value
Agricultural land	-1.410185	<0.0001
Elevation	0.000851	<0.0001
Distance to road	-0.000020	0.0280
Distance to water	-0.000292	<0.0001
Forest	0.799718	<0.0001
Grass	0.563710	<0.0001
Precipitation	-0.144595	<0.0001
Shrub	1.094981	<0.0001
Terrain Roughness Index	0.005367	<0.0001
Distance to well [oil and gas]	-0.000001	0.5932

Rattlesnake Modeling Methods

We used a rattlesnake habitat suitability model developed by MULTISAR[1] based on hibernacula data from the Government of Alberta Fisheries and Wildlife Management Information System (FWMIS) (Martinson & Wielki, 2012). The resulting habitat suitability index (HSI) was inverted to create a resistance surface for connectivity modeling. Because the HSI is derived for the species range in Alberta, it is represented as a large-scale gradient in snake habitat. These large gradients make it difficult to represent the animal movement process at the fine scales relevant for our study. As such, in rescaling the inversion of the HSI to a resistance layer, we used the maximum and minimum cell values in a 5-km x 5-km moving window to 'localize' variation at a scale more relevant to snake movement than the entire study area. The mesh centroids developed for mule deer that fell within the rattlesnake range were used as focal nodes.

Structural Modelling Methods

To develop a resistance surface for connectivity modeling, we used Alberta Biodiversity Monitoring Institute (ABMI 2010) land cover data and applied resistance scores analogous to values outlined by Theobald et al. (2012) based on the degree of human modification for 13 major land cover groups. The resistance values in Theobald et al. (2012) range from 0 (lowest resistance) to 1 (highest resistance), and Table 4 lists values associated with land cover classes. We cross-walked these values with ABMI land cover data (Table 5) and rescaled values from 0 to 1,000, where 1,000 represents highest resistance.

Table 4: Resistance values in Theobald et al. (2012).

Land cover	Magnitude (1 is high)	Resistance value
Agriculture - cropland	0.68	680
Agriculture - hay	0.56	560
Developed - high intensity	0.85	850
Developed - medium intensity	0.76	760
Developed - low intensity	0.64	640
Developed - open space	0.52	520
Forest	0.07	70
Shrubland	0.05	50
Grassland	0.17	170
Wetlands	0.11	110
Other disturbed	0.24	240
Mine/quarry	0.58	580

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[1] MULTISAR is a multi-species stewardship program for species at risk focusing on the Milk River watershed and portions of the South Saskatchewan drainage.

Sparsely vegetated	0.02	20

Table 5: AMBI land cover resistance values.

ABMI land cover class	Translated to Theobald land cover class	Structural resistance value
Water	NA	200
Snow-ice	Sparsely vegetated	20
Rock rubble	Sparsely vegetated	20
Exposed land	Sparsely vegetated	20
Developed	Developed - high intensity	850
Shrub	Shrubland	50
Grassland	Grassland	170
Agriculture	Average of agricultural cover classes	620
Conifer forest	Forest	70
Broadleaf forest	Forest	70
Mixed forest	Forest	70

4.2 Wildlife Connectivity Results

The outputs of Linkage Mapper are spatial surfaces in which cell values are proportional to the relative probability of movement through each cell. Outputs are often displayed as colored "heat maps" in which warmer colors denote areas that have higher value for connectivity. Below, Linkage Mapper results are displayed for grizzly bear (Figure 3), pronghorn (Figure 4), mule deer (Figure 5), rattlesnake (Figure 6), and structural connectivity (Figure 7).
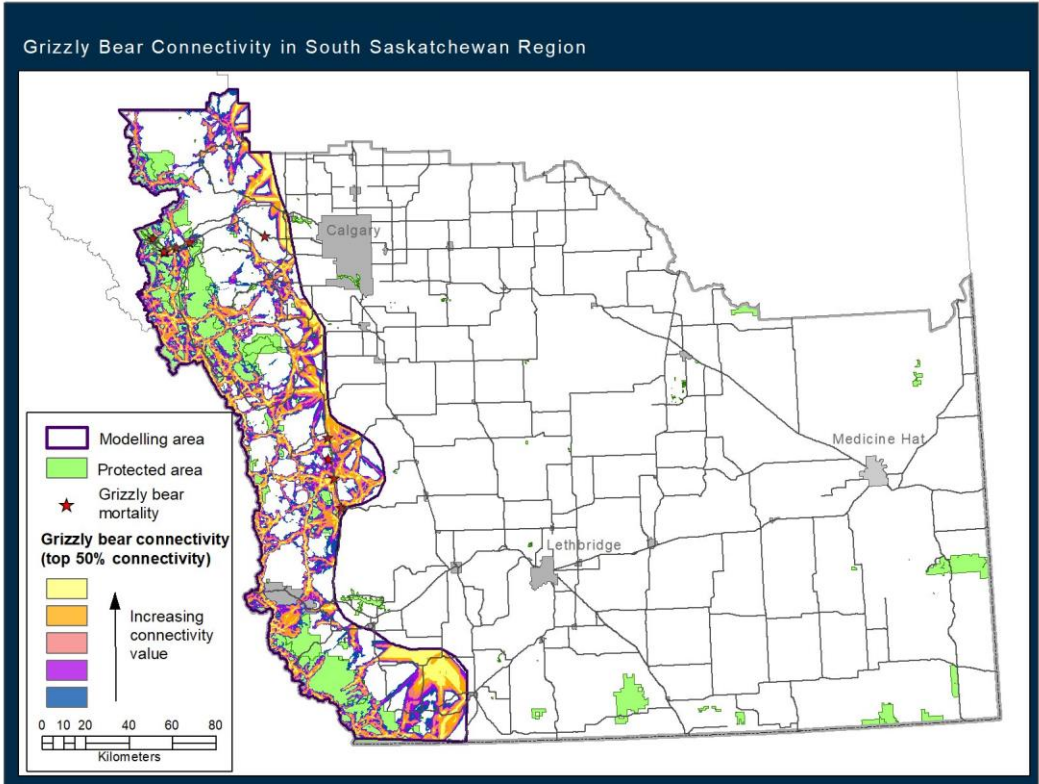
Figure 3: Grizzly bear connectivity model output and recorded road mortalities (from ENFOR)
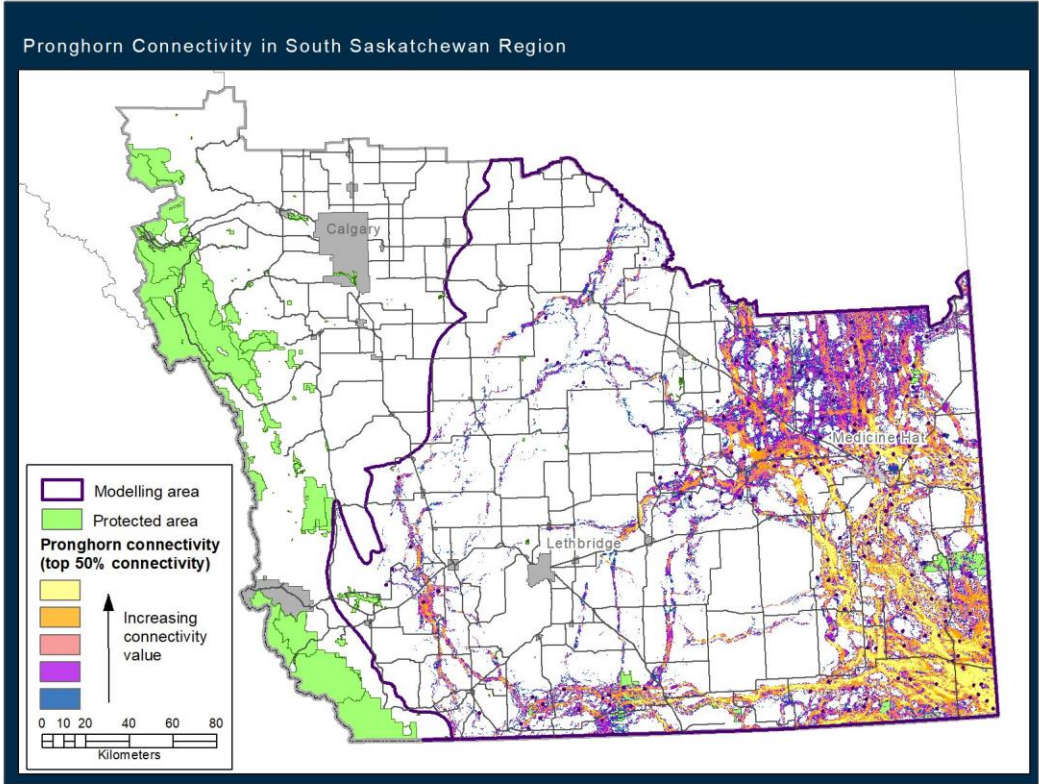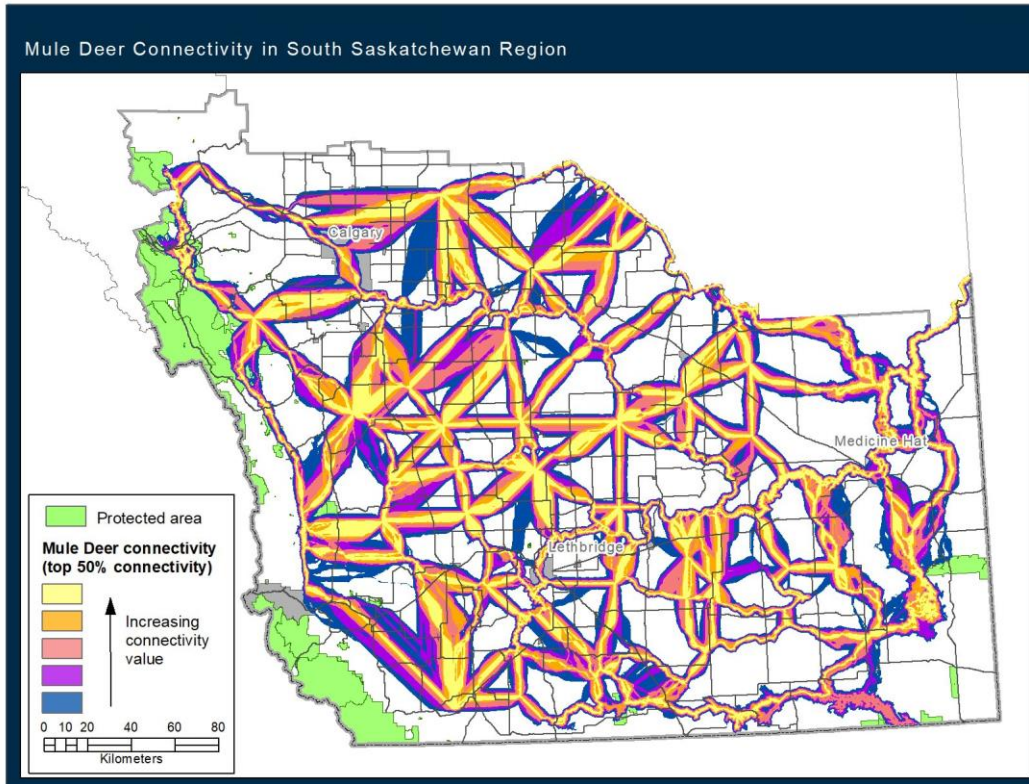

Figure 4: Pronghorn connectivity model output.

Figure 5: Mule deer connectivity model output (modeling area South Saskatchewan Region).
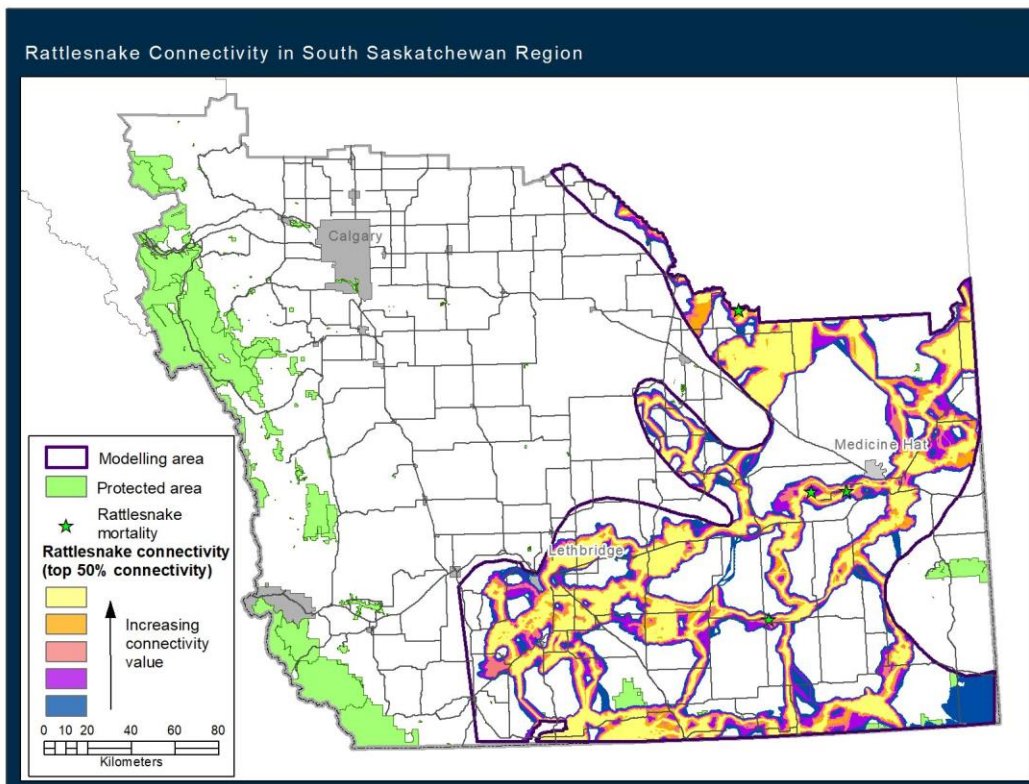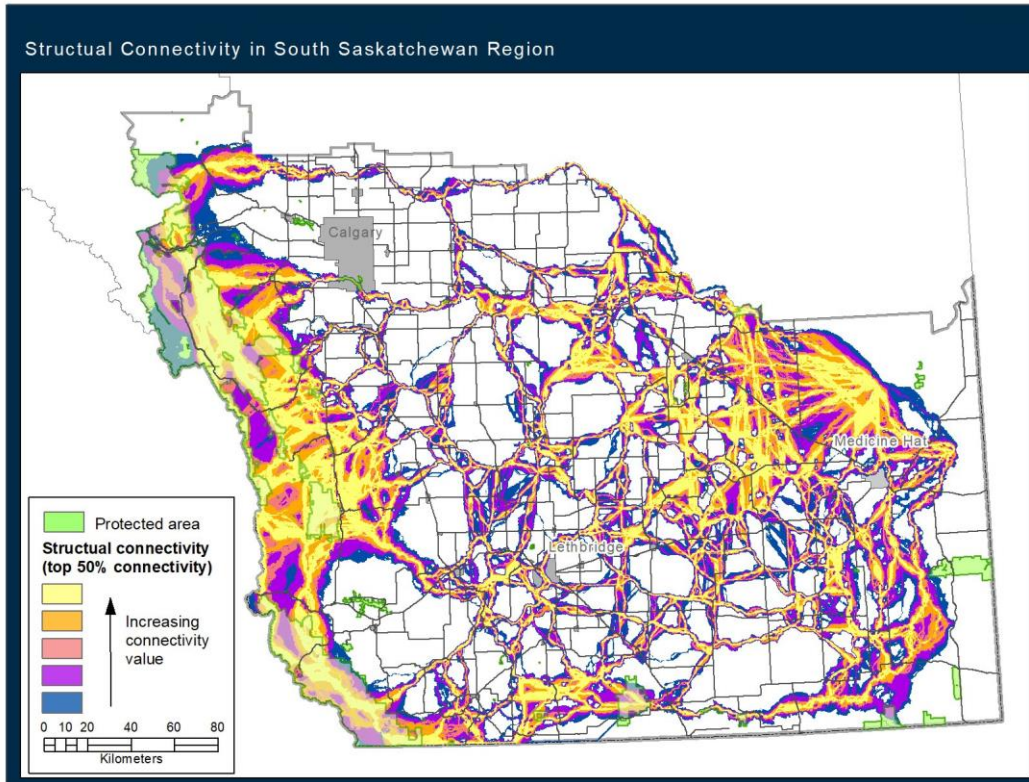

Figure 6: Rattlesnake connectivity model output.

Figure 7: Structural connectivity model (modeling area South Saskatchewan Region).

The connectivity modeling results were used to extract connectivity values associated with highway sections along the highway network. For each connectivity model, we calculated the mean connectivity value of pixels overlapping each highway section as an index of connectivity value for that highway section.

5.0 Animal Vehicle Collision (AVC) Risk Index

Priority locations for implementing mitigation measures are typically identified based on local densities of AVCs determined using animal carcasses data (Teixeira, Kindel, Hartz, Mitchell, & Fahrig, 2017). Traditionally, animal carcass data is acquired from motorist reports to RCMP, which is required for accidents exceeding $2,000 of damage to the vehicle. There are several analytical challenges associated with this type of information; it tends to have poor locational accuracy (typically based on public reporting to RCMP after the incident) and the magnitude of reporting tends to be lower than the actual number of AVCs occurring (Alberta Transportation, 2017). These challenges reduce confidence in the RCMP dataset as a reliable indicator of high-risk AVC highway sections to help determine the best places for mitigation. Although AVCs are under-reported, there is no evidence that reporting is spatially biased in representation, and therefore we used RCMP data to measure relative AVC risk.

Data from sources other than law enforcement records can also provide useful information on patterns of collisions with wildlife, particularly when less abundant species are of interest. Many species of concern are involved in AVCs relatively infrequently and are small-bodied, meaning that they often do not cause enough vehicle damage to warrant reporting to law enforcement. Records kept by natural resource agencies responsible for managing wildlife populations may provide better, or at least complementary, information on AVCs involving such species. Thus, we supplemented our analysis of RCMP records with information on AVCs collected by government conservation officers.

5.1 Animal Vehicle Collision Risk Indices Methods

The AVCs risk metric was developed to determine within the SSRP which highway sections experience the highest volume of AVCs.

We acquired two datasets that had spatial coverage for the study area to represent AVCs:
1. Solicitor General, Enforcement Occurrence Records (ENFOR), reported by Conservation Officers based on a search for "roadkill" observations from April 2014 to July 2017. This dataset had 408 GPS records, including mule deer (n=100), rattlesnakes (n=5), grizzly bear (n=11), and pronghorn (n=6).
2. Royal Canadian Mounted Police (RCMP), AVC dataset, provided by AT, Traffic Safety office for 2010 to 2014. The version of the data set that we used was updated by AT, Environmental Services with species information. This dataset had 309 domestic animal records which were removed from the analysis, and 9,866 animal records which were included in the analysis.

Based on methodology developed by McClure et al. (2014), we created a spatial index of AVC risk by counting the number of records from the RCMP dataset associated with each kilometer segment along highways within the study area. To account for locational uncertainty of AVC records, the value for each section was calculated as the average count within that section and its two neighboring sections (see Appendix B for detailed processing methods). In addition to an index of AVCs with all wildlife species, we also calculated separate indices of AVCs with carnivore species only and with ungulate species only. We also calculated an AVC index that was adjusted for traffic volumes within kilometer segments, as a measure of AVC rate per motorist. Finally, we recalculated the AVC index using the traffic control segment (discussed further in Section 6.2), rather than the kilometer section, as the spatial unit of analysis. All AVC indices were rescaled from zero to one as a relative AVC risk index to allow for comparisons among indices. Due to under-reporting of animal carcasses and unknown locational accuracy, we used these data to explore spatial patterns of AVC risk but did not attempt to make statistical inferences (McClure & Ament, 2014). All AVC indices are described in further detail in Table 6. AVC Risk Index was the index most often used in further analysis unless otherwise stated.

Table 6: Animal Vehicle Collision Risk Indices

Index family	Index name	Acronym	Definition
Animal Vehicle Collision	AVC Risk Index	AVC_A	Animal-vehicle collisions with all wildlife species in RCMP data by kilometer section
	UVC Risk Index	AVC_U	Animal-vehicle collisions with wild ungulate species (antelope, deer, elk, sheep, and moose) in RCMP data by kilometer section
	CVC Risk Index	AVC_C	Animal-vehicle collisions with carnivore species (bear, coyote, cougar, and wolf) in RCMP data by kilometer section
	AVC Risk Index per Traffic Control Section	AVC_A_TCS	Animal-vehicle collisions with all wildlife species in RCMP data by traffic control section
	AVC Risk Index by Traffic Volume	AVC_A_N	Animal-vehicle collisions with all wildlife species in RCMP data by kilometer section, normalized by traffic volume
	ENFOR Risk Index	ENFOR_A	Alberta Government Solicitor General Enforcement database "roadkill" count by kilometer section

5.2 Animal Vehicle Collision Risk Index Results

A total of 9,866 animal carcasses were recorded in the RCMP database over the five-year period in the South Saskatchewan Region, of which 91% represented ungulate species (predominately deer), 6% represented other species (unknown, medium to small mammals, or birds), and 3% represented carnivore species (Figure 8). The AVC Risk Index for all wildlife species (AVC_A, Table 6) was used as a surrogate to represent human safety risk along highway network.
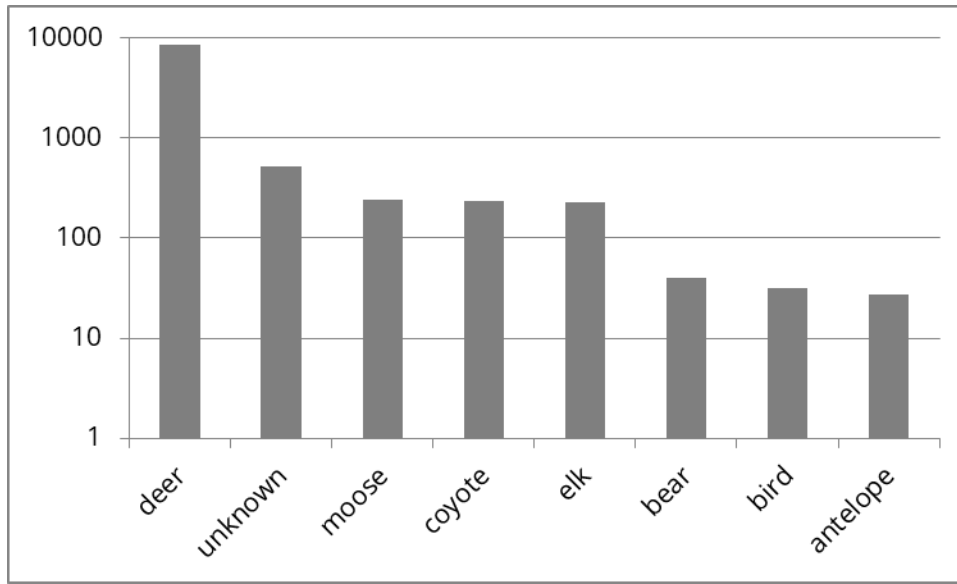
Figure 8: Distribution of animal carcass records (y axis displayed in logarithmic scale) in RCMP database, 2010-2014.

 displays AVC Risk Index (AVC_A) across the highway network of the South Saskatchewan Region based on RMCP carcass records for all wildlife species, with bright red indicating highway sections with AVC risk in the 90th percentile or higher (i.e., top 10% of AVC risk). Highway sections with the highest risk of AVCs are located around large urban centers where traffic volume is highest and deer are abundant. These kilometer sections represent locations with the best potential for improving human safety for the greatest number of people.

Figure 10 displays the wildlife AVC risk index (AVC_A_N) normalized by traffic volume. The brightest red sections (top 10% of risk values) represent areas where animals are most frequently involved in AVCs on a per-vehicle basis, and represent highest risk for local people who frequently drive these highway sections. These kilometer sections might also be important in considering future problem locations for lower volume traffic sections, as increase in traffic volume could lead to higher AVC rates.
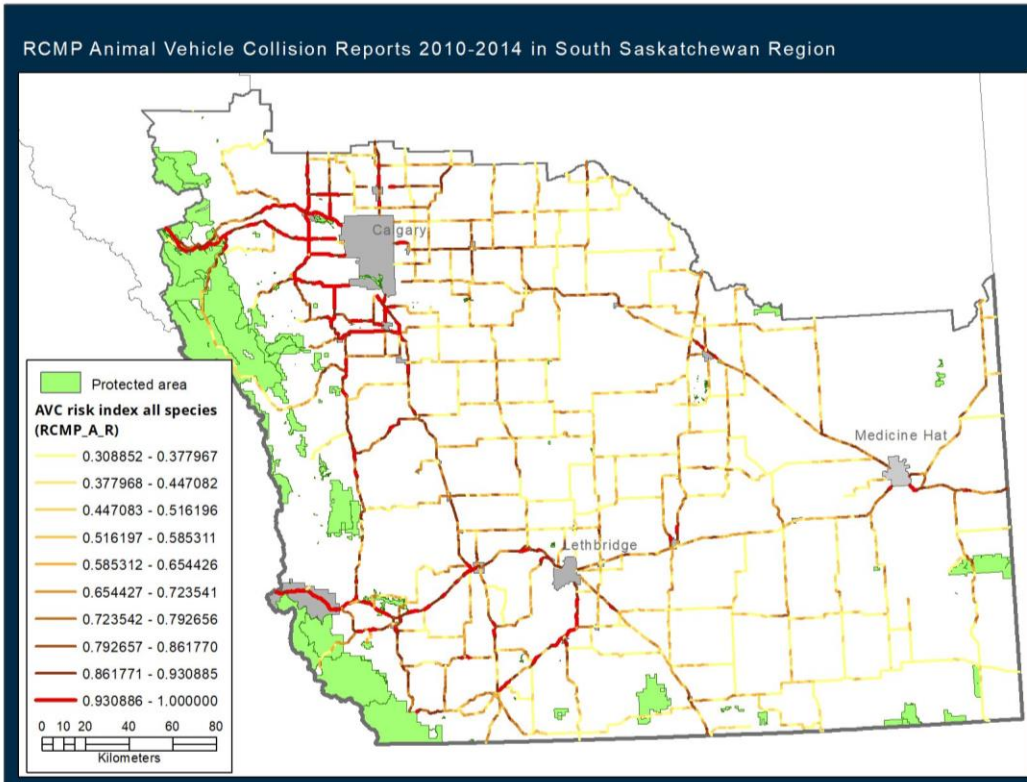
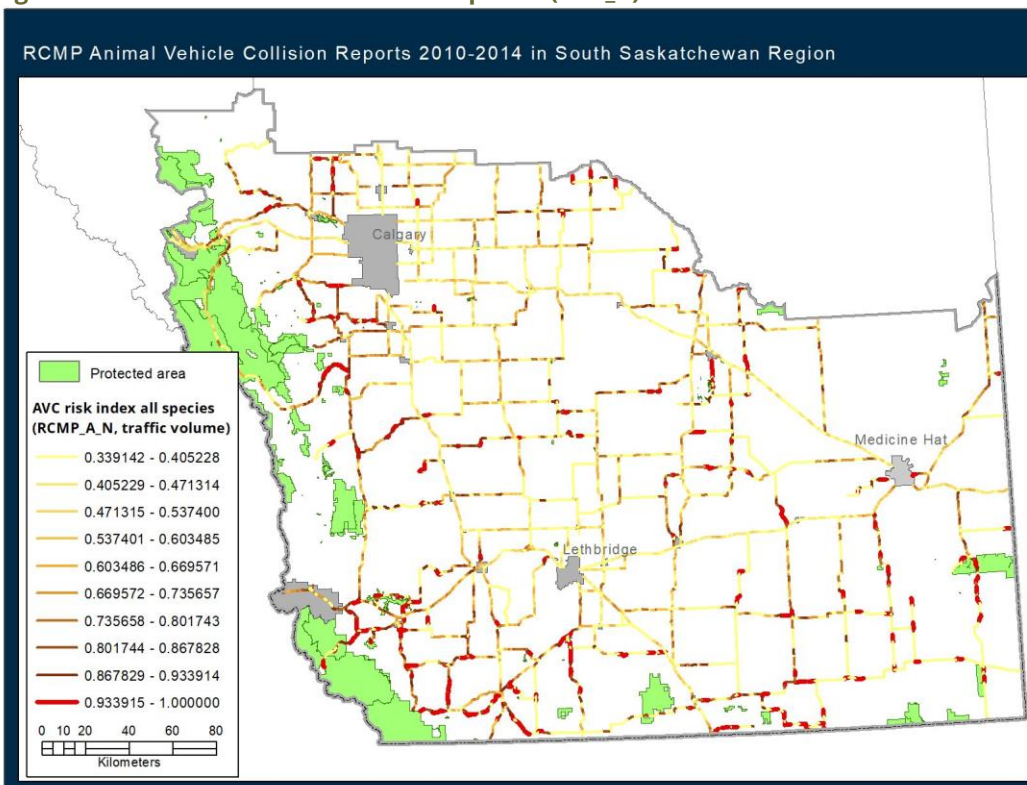**Figure 9: AVC Risk Index for all wildlife species (AVC_A)**

Figure 10: AVC Risk Index for all wildlife species, normalized by traffic volume (AVC_A_N)

6.0 Mitigation Priority Indices

6.1 Kilometer Section Prioritization

We used a weighted averaging approach to determine overall spatial priorities for AVC mitigation efforts that incorporated both conservation value and human safety risk. We used the AVC Risk Index (AVC_A, a score ranging from 0 to 1 for each kilometer section based on the number of collisions with wildlife recorded in that section) as our measure of human safety risk. Because the distribution of values for this index was highly skewed, with the vast majority of road sections having low values and only a handful road sections having very high values (Figure 11), we converted raw index scores to percentiles to better capture the variation within the lower portion of the distribution.
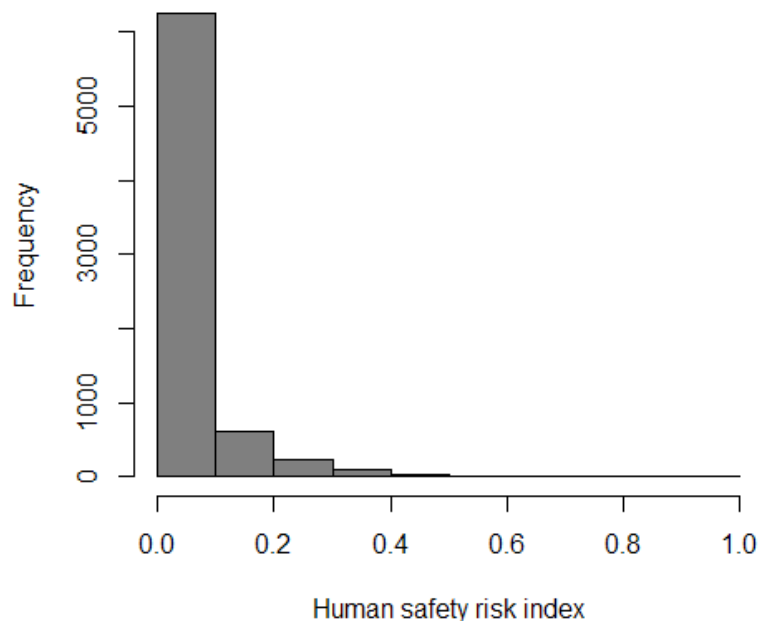
Figure 11: Distribution of AVC Risk Index (Human Safety Risk) values for 1-km road sections within the SSRP.

We derived a Connectivity Value Index for each kilometer section by extracting the grid cell values overlapping that section from the connectivity model outputs for each of four focal species and the structural connectivity model (Table 7). We rescaled values for each species connectivity value index such that values ranged from 0 to 1, with higher values representing greater wildlife connectivity value; this rescaling was necessary because connectivity models produced outputs with different ranges and in some cases opposite interpretations for different species (Figure 12). As with the AVC Risk Index, the distribution of index values was highly skewed for connectivity variables (Figure 13), and we therefore converted index values to percentiles. Figure 14 displays an example of highway kilometer sections of highest value for rattlesnake.

Index family	Index name	Acronym	Calculation/Definition
Wildlife	Grizzly Bear Connectivity Value Index	GB_CVI	Linkage mapper mean of values for grizzly bears per km section
	Rattlesnake Connectivity Value Index	RS_CVI	Linkage mapper mean of values for rattlesnakes per km section
	Pronghorn Connectivity Value Index	PRONG_CVI	Linkage mapper mean of values for pronghorn per km section
	Mule deer Connectivity Value Index	MD_CVI	Linkage mapper mean of values for mule deer per km section
	Structural Connectivity Value Index	STR_CVI	Linkage mapper mean of values for structural connectivity per km section

We considered both the mean and maximum of connectivity value observed along each section, but here we present only results for the mean because these two metrics were highly correlated (Pearson's correlation >0.98 for all species.

Table 7: Wildlife Connectivity Indices

Index family	Index name	Acronym	Calculation/Definition
Wildlife	Grizzly Bear Connectivity Value Index	GB_CVI	Linkage mapper mean of values for grizzly bears per km section
	Rattlesnake Connectivity Value Index	RS_CVI	Linkage mapper mean of values for rattlesnakes per km section
	Pronghorn Connectivity Value Index	PRONG_CVI	Linkage mapper mean of values for pronghorn per km section
	Mule deer Connectivity Value Index	MD_CVI	Linkage mapper mean of values for mule deer per km section
	Structural Connectivity Value Index	STR_CVI	Linkage mapper mean of values for structural connectivity per km section

Figure 12: Relationship between mean connectivity values and maximum connectivity values observed along 1-km road sections within the SSRP for five wildlife species. Pearson's correlation (R) between mean and maximum values is shown in top left of each panel.

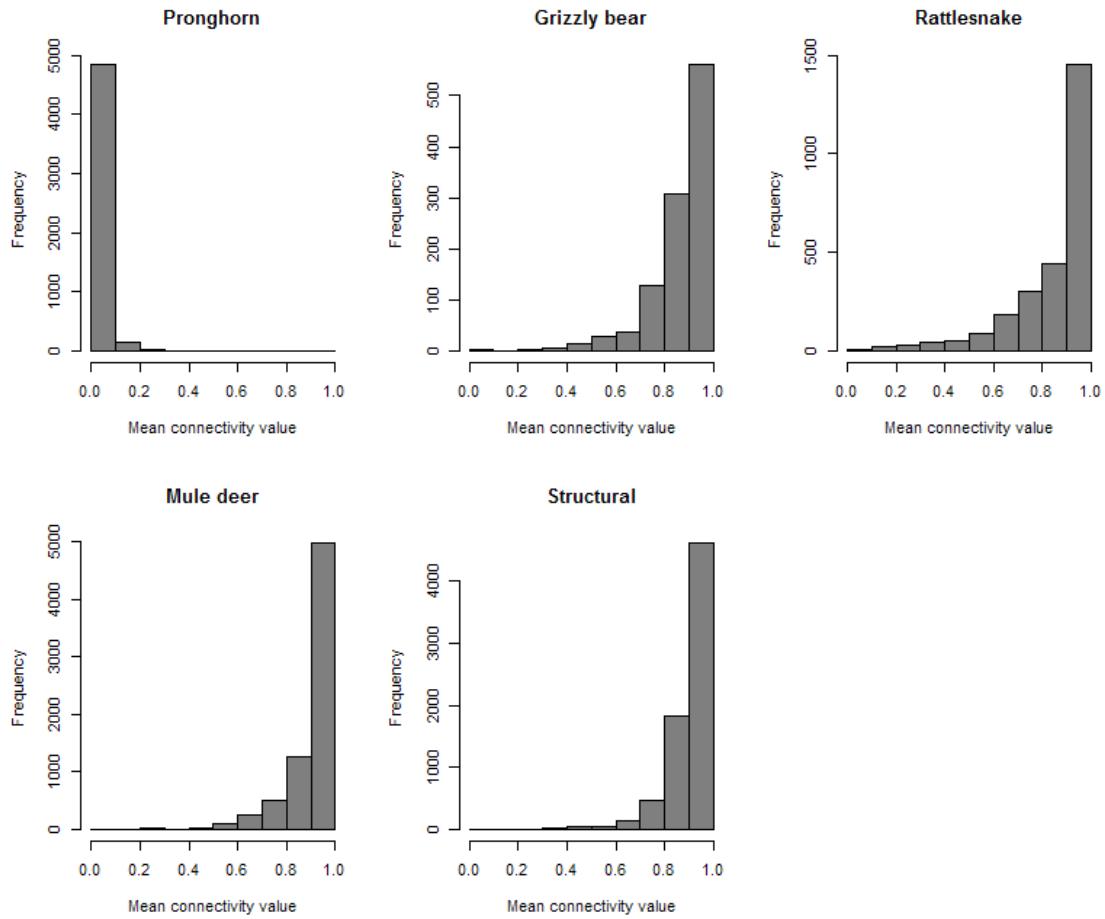**Figure 13: Distribution of connectivity index values for 1-km road sections within the SSRP for four focal species and structural connectivity.**
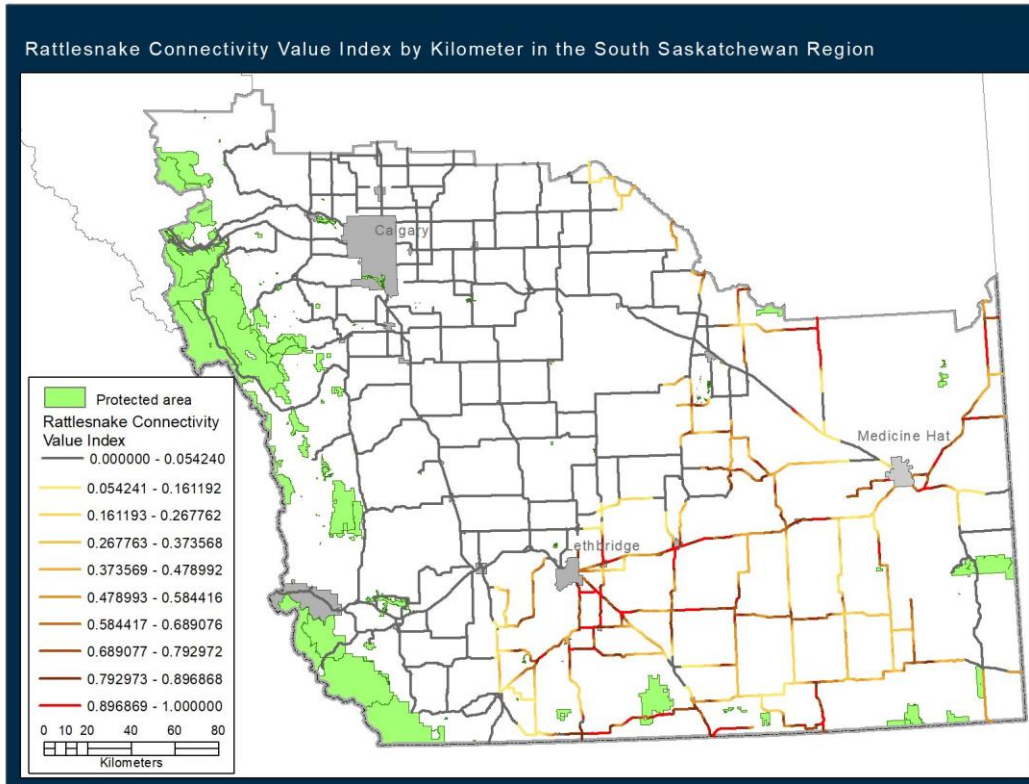
Figure 14: Rattlesnake Connectivity Value Index.

To determine if human safety risk and wildlife connectivity values align, we tested for similarity between indices we felt represented these values using similar methods to McClure and Ament (2014). To represent wildlife connectivity, we used the Structural Connectivity Value Index because it is species-agnostic and is the best available indicator of connectivity for the ecological community as a whole in a highly fragmented South Saskatchewan landscape. For human safety risk, we used the Ungulate Risk Index developed from RCMP data because ungulates are involved in most recorded AVCs and are large-bodied animals that are more likely to cause human injuries and vehicle damage. Results indicate that there is poor overlap between areas with a high Structural Connectivity Value Index and areas with a high Ungulate Risk Index, shown by the lack of points in the top right quadrant of Figure 15 where both would be high priority values. These results highlight the importance of considering both human safety risk and wildlife connectivity value in transportation planning.
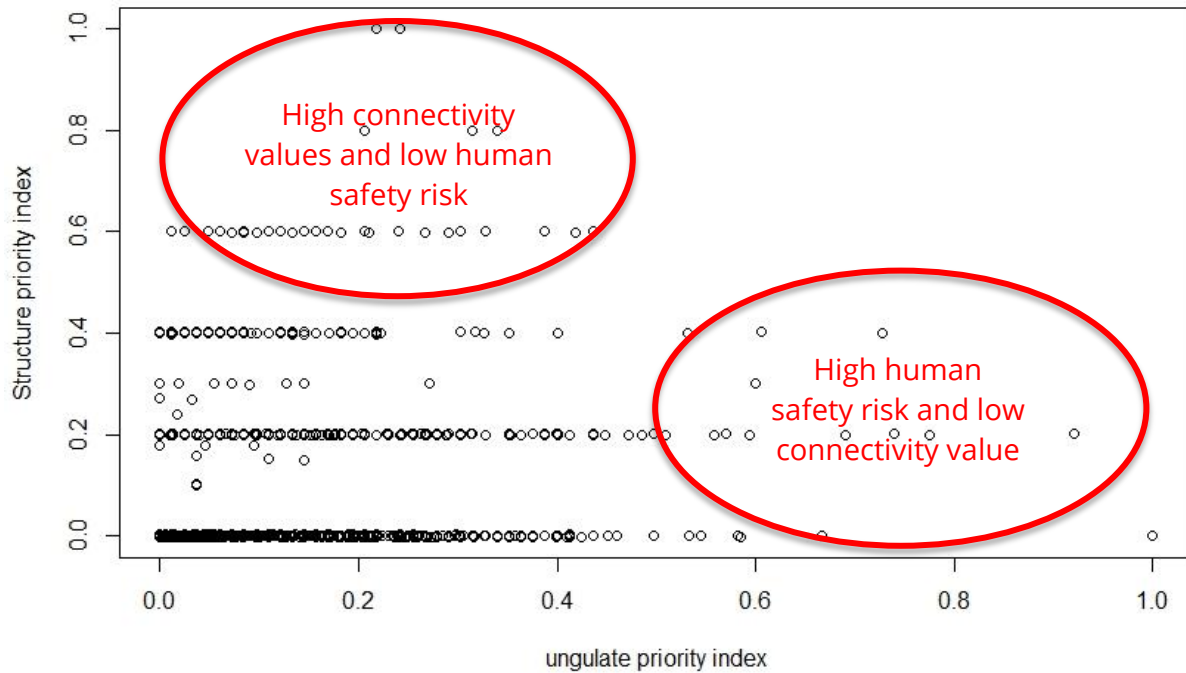
Figure 15: Scatterplot of Structural Connectivity Value Index and Ungulate Risk Index

The project team created a series of scenarios (Table 8) representing a range of plausible options for prioritizing locations of mitigation efforts; these included scenarios favoring human safety, favoring wildlife connectivity, or representing a mixture of the two (Table 9). For each scenario, we assigned a weight to each human safety or connectivity variable such that weights summed to one, and we calculated the weighted mean for each road section as an overall index of mitigation priority. If data were missing for a particular variable in a given highway section (e.g., highway sections outside of a focal species' range), then that variable was assigned a weight of zero for that section and weights for remaining variables were rescaled proportionally to sum to one. Maps showing the spatial distribution of mitigation priorities resulting from these scenarios can be seen in Figure 16, Figure 17, Figure 18, and Figure 19. These results could help transportation planners and wildlife managers to identity important kilometer sections based on specific management objectives.

Table 8: Scenarios and Mitigation Priority indices.

Index family	Index name	Acronym	Calculation/Definition
Mitigation Scenarios	Mitigation Priority Index Wildlife Connectivity	MPI_WC	Average of CV_grizzly_mn, CV_rattlsnk_mn, CV_Pronghrn_mn, CV_mldr_mn, CV_structl_mn by kilometer
	Mitigation Priority Index Human Safety	MPI_HS	AVC Risk Index by kilometer
	Mitigation Priority Index Human safety (50%) and wildlife connectivity (50%)	MPI_HS50_WC50	Weighted average of 50% MPI_HS and 50% MPI_MPI by kilometer
	Mitigation Priority Index Human safety (70%) and wildlife connectivity (30%)	MPI_HS70_WC30	Weighted average of 70% MPI_HS and 30% MPI_WC by kilometer
	Mitigation Priority Index Human safety (30%) and wildlife connectivity (70%)	MPI_HS30_WC70	Weighted average of 30% MPI_HS and 70% MPI_WC by kilometer
	Mitigation Priority Index AHP values	MPI_AHP	See Table 9 for weightings of Indexes by Workshop Stakeholders
	Mitigation Priority Index AHP values by Traffic Control Section	MPI_AHP_TCS	See Table 9 for weightings of indexes by Workshop Stakeholders by Traffic Control Section
	Mitigation Priority Index Human Safety by Traffic Control Section	MPI_HS_TCS	AVC Risk Index by Traffic Control Section
	Mitigation Priority Index Wildlife Connectivity by Traffic Control Section	MPI_WC_TCS	Average of CV_grizzly_mn, CV_rattlsnk_mn, CV_Pronghrn_mn, CV_mldr_mn, CV_structl_mn by Traffic Control Section

Table 9: Priority weighting scenarios and associated indices considered in the analysis.

Scenario	AVC_A	ENFOR_A	PRONG_CVI	GB_CVI	RS_CVI	MD_CVI	STR_CVI
MPI_WC	0.00	0.00	0.20	0.20	0.20	0.20	0.20
MPI_HS	1.00	0.00	0.00	0.00	0.00	0.00	0.00
MPI_HS50_WC50	0.50	0.00	0.10	0.10	0.10	0.10	0.10
MPI_HS70_WC30	0.70	0.00	0.06	0.06	0.06	0.06	0.06
MPI_HS30_WC70	0.60	0.00	0.14	0.14	0.14	0.14	0.14
MPI_AHP	0.70	0.11	0.01	0.02	0.01	0.08	0.07
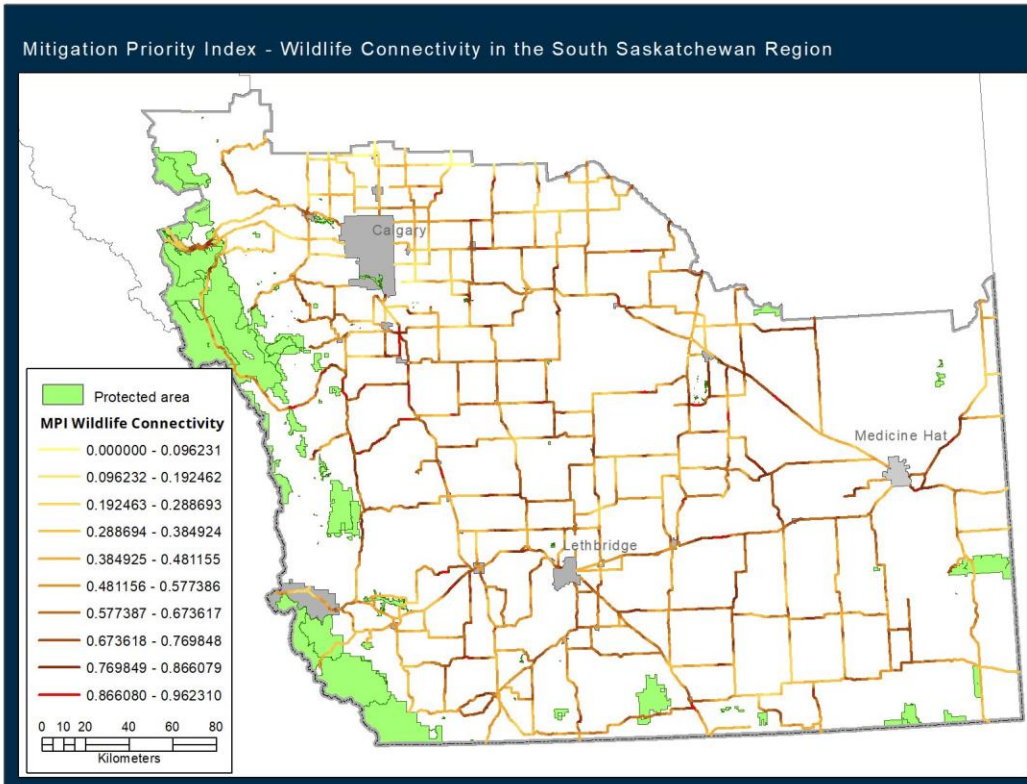
Figure 16: Mitigation Priority Index: Wildlife Connectivity
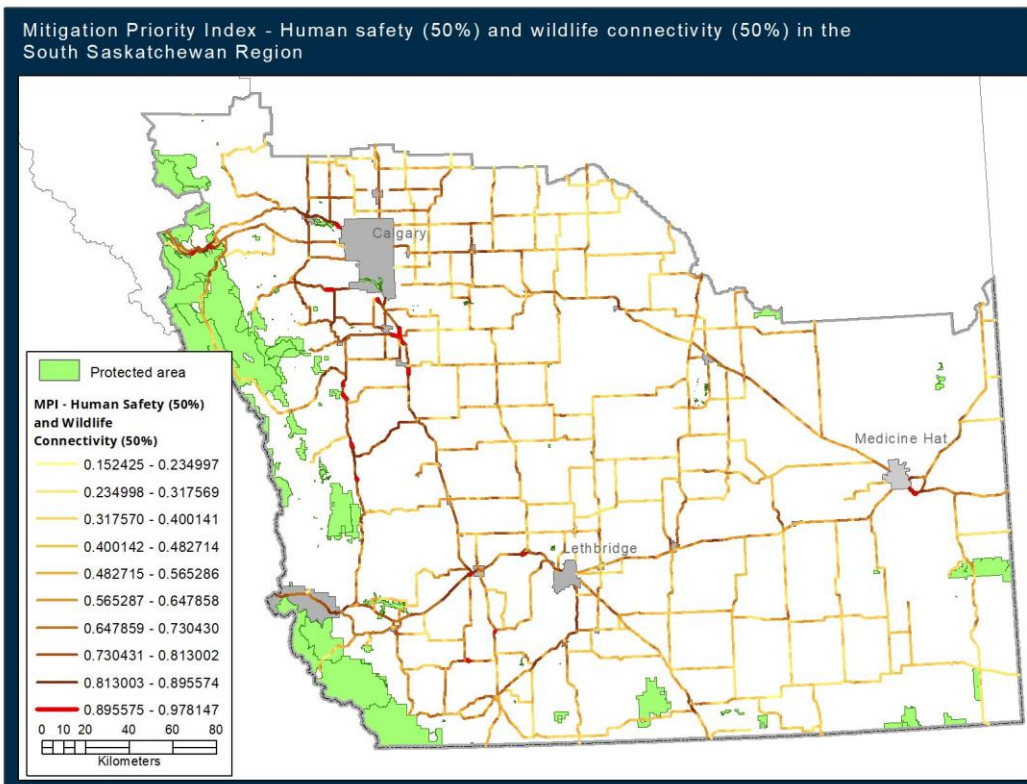
Figure 17: Mitigation Priority Index: 50% Human Safety Risk and 50% Wildlife Connectivity
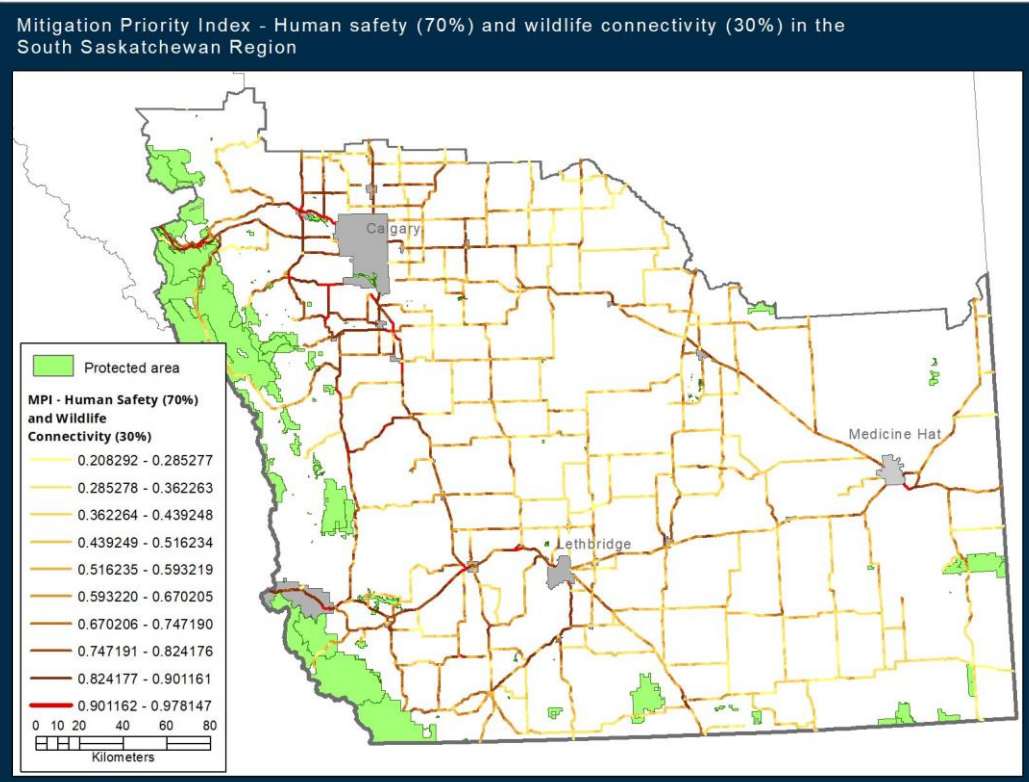
Figure 18: Mitigation Priority Index: 70% Human Safety Risk and 30% Wildlife Connectivity
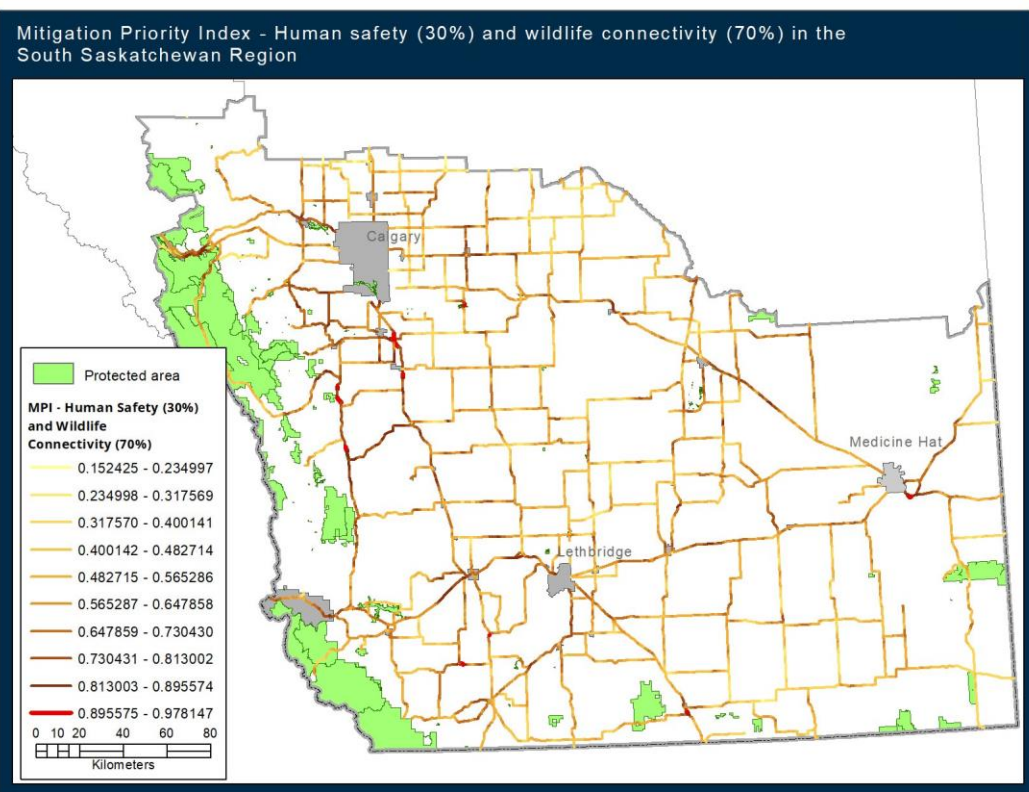
Figure 19: Mitigation Priority Index: 30% Human Safety Risk and 70% Wildlife Connectivity

At a second stakeholder workshop, expert-based weights were generated using an Analytical Hierarchy Process (AHP). The AHP is a mathematical method for analyzing complex decisions using pairwise comparisons ratios. AHP enables experts to use multiple criteria to analyze complex problems. Through pairwise comparisons, it clarifies the advantages and disadvantages of management options under circumstances of risk and uncertainty.

The AHP structure included categories of human safety and ecological concerns and associated spatial layers to represent the categories as presented in Figure 20. Weights used in the AHP (Figure 21) were used to develop a map showing the spatial distribution of mitigation priorities (Figure 22) from expert opinion at the workshop.
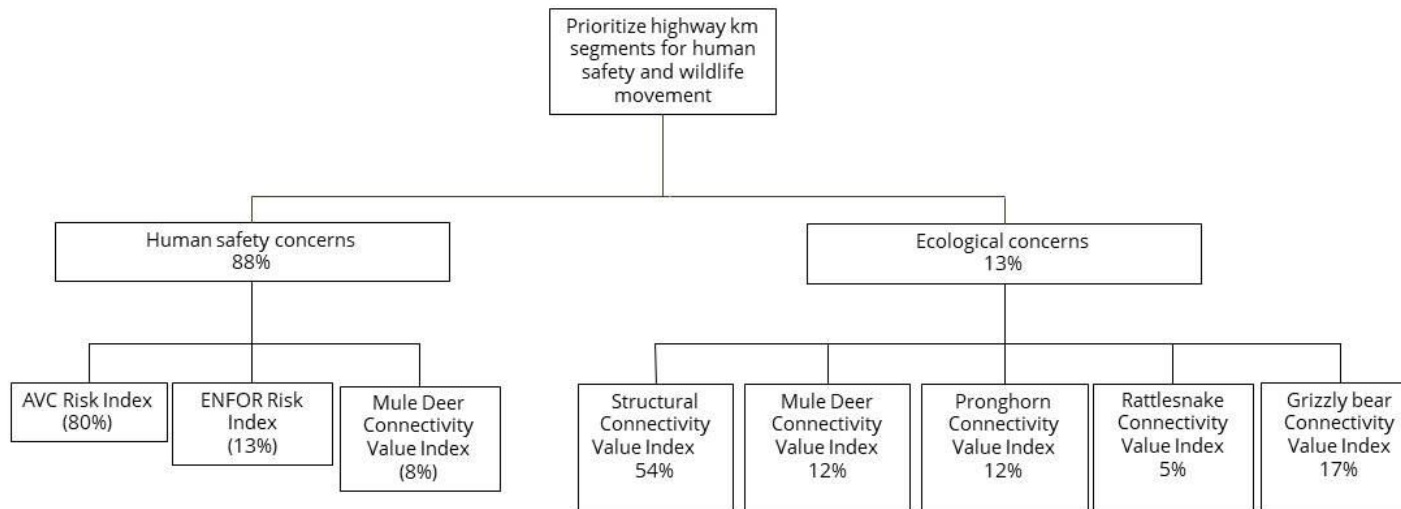
Figure 20: **Basic structure of the Analytical Hierarchy Process used to generate expert-based weights for human safety and wildlife connectivity indices. Resulting weights for indices are shown in the bottom row of boxes and were used to calculate an overall Mitigation Priority Index for each road section.**
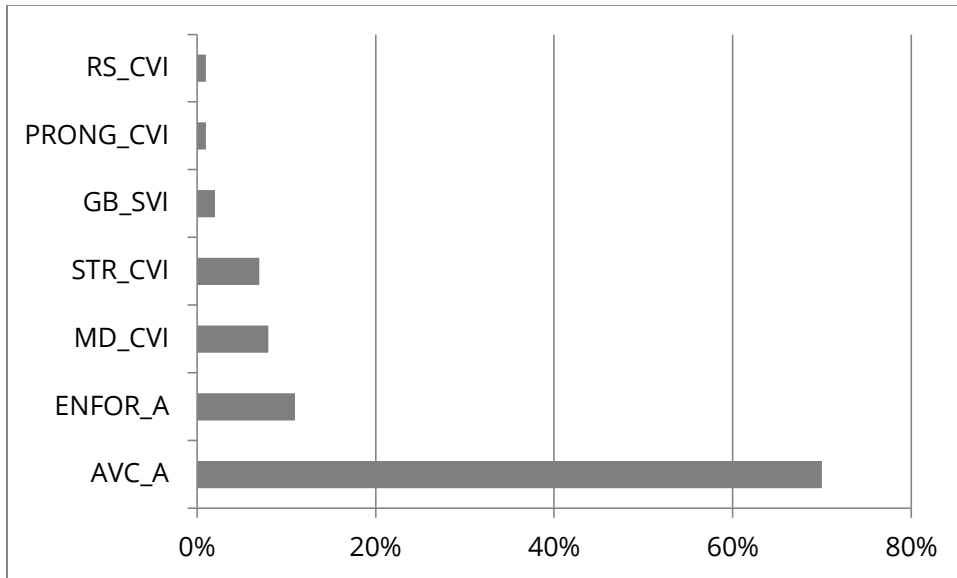
Figure 21: Mitigation Prioritization Index weights generated from expert-based opinion using the Analytical Hierarchy Process.
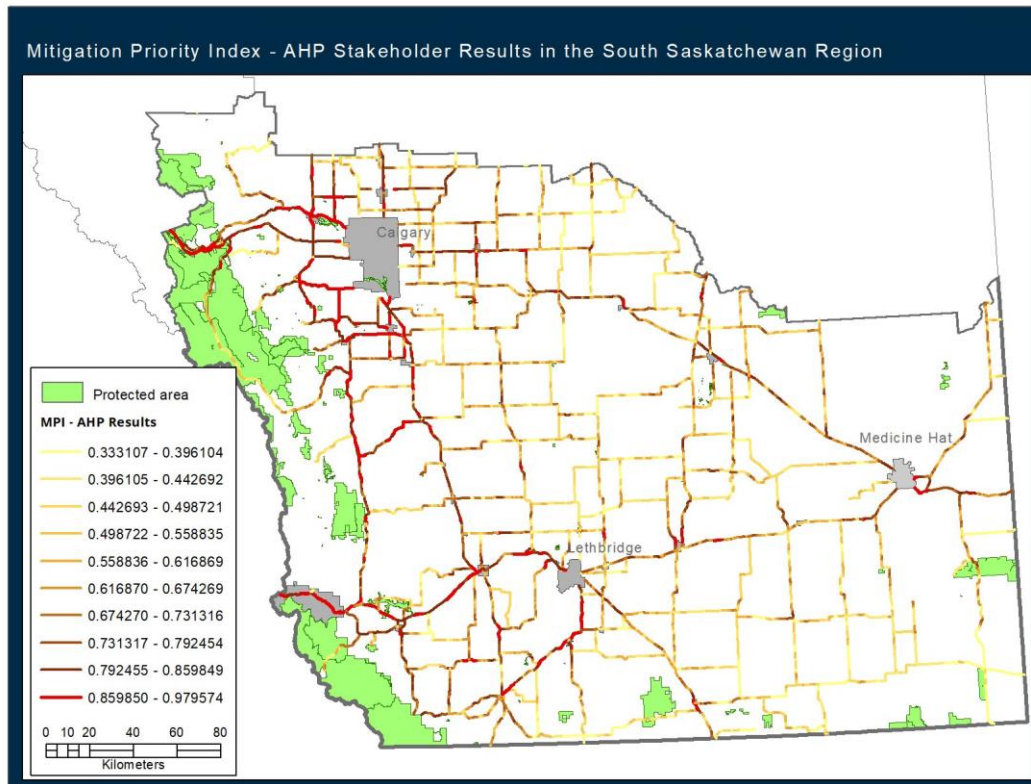
Figure 22: Mitigation Priority Index for kilometer sections based on human safety and wildlife connectivity index weights generated using Analytical Hierarchy Process.

6.2 Traffic Control Section Prioritization

The decision support tool was developed to help identify sections of the highway network where mitigation assessments are most needed, which requires representing the results at a coarser scale than one kilometer. AT has two other levels of highway categorization: traffic control section (TCS) and control section (CS). A TCS is a portion of a CS that has similar traffic characteristics. A CS is a road section defined by Alberta Transportation for management purposes; they are of varying lengths usually between large intersections on the highway network. We calculated a Mitigation Priority Index, using weights from the AHP process, for each TCS to assist transportation planners in selecting high-priority TCSs (based on traffic volume cohorts) for finer-scale mitigation assessments. The resulting Mitigation Priority Index AHP Values by Traffic Control Section identified 129 high-priority traffic sections (defined as TCSs with MPI values in the 80th percentile or higher), representing 12% of the highway network in the South Saskatchewan Region.

Table 10 provides additional details on high-priority TCSs along major highways within the study area.
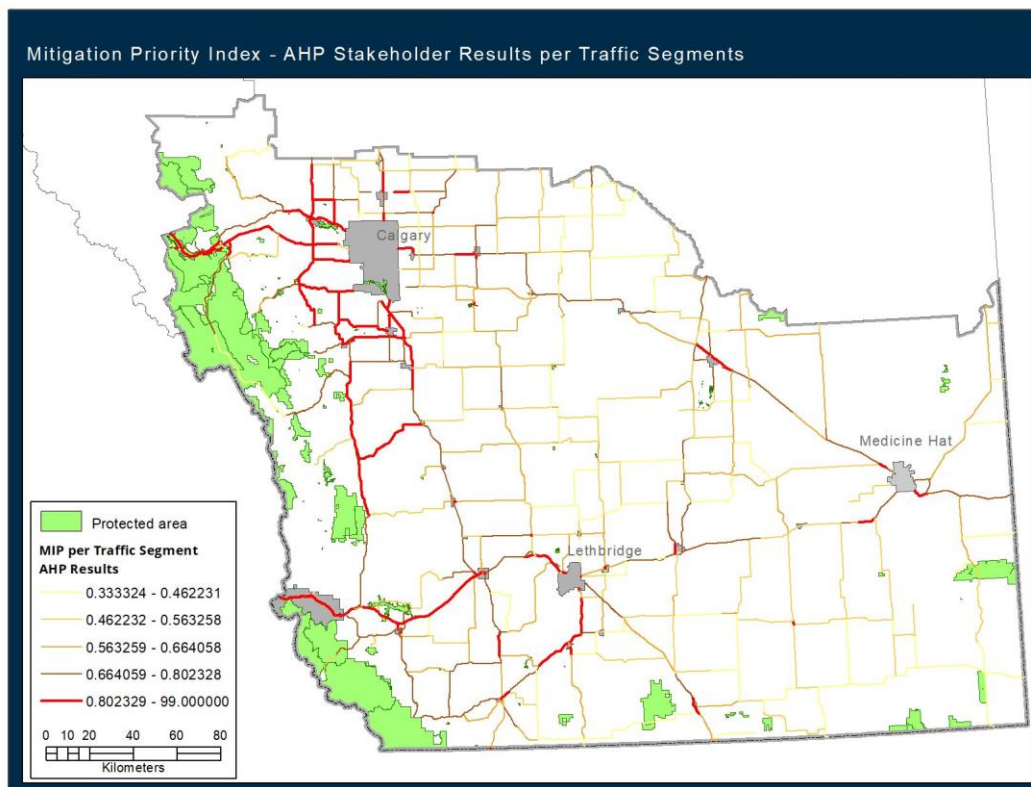
Figure 23: Mitigation Priority Index for Traffic Control Sections, based on weights generated using the Analytical Hierarchy Process.

Table 10: Summary of prioritized Traffic Control Sections.

Highway	Length of TCS in high priority (km)	WAADT* average	# of TCS
1	138.6	17547	16
2	75.3	27043	14
3	136.9	7383	22
4	8.1	2355	2
5	45.5	4437	7
6	2.4	3590	2
7	25.2	8780	2
8	16.5	8950	2
22	180.2	5874	18
24	1.3	2255	2
40	8	1945	2
61	1.5	970	1
62	3.5	610	1
533	37.6	1240	1
549	25.2	1987	3
567	16	3340	2
762	22.2	1130	1
766	11	2380	1
817	1.1	6630	2
864	4	1910	1
1A	39.6	13878	6
22X	6.4	8960	1
2A	11.2	17933	3
Total	**817.3**		**129**

*The Weighted Average Annual Daily Traffic (WAADT) volume is a synthesis of several point AADT volumes into a single volume number called a WAADT for a Traffic Control Section.

7.0 Discussion

The goals of this project were to identify highway sections important to both human and wildlife safety and wildlife movement to inform mitigation priorities. Through a stakeholder-driven process we developed a decision support tool to enable transportation and wildlife management personal to systematically review the highway network. We

identified high-priority kilometer and traffic control sections that warrant further consideration for mitigation planning.

A series of connectivity models were developed using Linkage Mapper software to identify highway sections that intersect with areas of high connectivity value for grizzly bear, pronghorn, rattlesnake, and mule deer, as well as areas of high structural connectivity value across the landscape. Our results highlight the importance of representation of species conservation needs in the South Saskatchewan Region. Individual species modeling results may be helpful for informing species recovery plans where mortality from collisions with vehicles or avoidance behavior associated with roads are a concern, such as for grizzly bear and rattlesnake. For species at risk, modeling results can help to identify areas where further research investment may be important to help validate crossing locations. By identifying kilometer sections and TCSs where mortality risk is highest based on movement needs of these species, AEP and AT can better focus pro-active mitigation efforts on locations that are important to species at risk.

Southern Alberta is heavily influenced by agriculture and industrial development, resulting in a fragmentation and loss of natural habitat. Maintaining connectivity of natural habitat is important for biodiversity and the maintenance of ecological processes. The species-agnostic structural connectivity model identifies the best places for maintaining ecological flows in relation to the highway network. These results can inform the South Saskatchewan Regional Plan, as connecting wildlife habitat across and within land-use planning regions is an important strategy for maintaining and protecting biodiversity (Alberta Government 2014).

To address human safety risk, we used five years of RCMP records to develop an AVC Risk Index based on the number of collisions with wildlife per km. We also derived indices based on collisions specifically with carnivores or ungulates, as well as indices that account for differences in traffic volume among highway sections. Our results highlight that AVCs are more common on the fringes of urban centers where a combination of high traffic volume and abundant deer populations intersect to create a 'perfect storm' of risk to human safety. When AVC rates are normalized by traffic volume, high risk areas are more dispersed across the landscape. These traffic-adjusted results are important to consider because: (1) they represent areas where wildlife are likely crossing (or attempting to cross) roads more frequently, which may be important for maintaining biodiversity; (2) they can help us identify areas that currently have lower traffic volumes but may become a concern in the future as traffic volumes increase; and (3) they represent areas with high per-motorist risk of AVCs, which are often overlooked when traffic volumes are not considered explicitly.

One of the concerns about using RCMP data to develop an AVC Risk Index is the unknown and potentially poor spatial accuracy and magnitude of records. To address this concern, AT recently developed Alberta Wildlife Watch, a new program that engaged GOA staff and

Highway Maintenance Contractors to report sightings of wildlife (dead, alive crossing, or adjacent) along the highway network via a smartphone application. The program is implemented province wide, and will result in a dataset that enables a systematic assessment of statistically significant AVC clusters (Alberta Transportation 2017). In the near future, Alberta Wildlife Watch will enable a more accurate assessment of priority kilometer sections and TCSs that pose a human safety risk. We encourage Alberta Wildlife Watch to also consider AVC data normalized by traffic volume, as well as information on successful crossings and road-adjacent wildlife observations, to garner a better understanding of wildlife needs relating to roads.

Our results are consistent with McClure et al. (2014), who found that highway sections with high AVC risk and high wildlife connectivity value have low spatial overlap. This is an important finding, as transportation departments have often invested in highway mitigation to address motorist safety and not necessarily to maintain wildlife movement. If wildlife safety or movement is considered, it is often as a secondary consideration; for example, in AT's Wildlife Sensitivity Rating System, wildlife connectivity is used to help prioritize already-identified locations with statistically significant AVC sections (Alberta Transportation 2018). This emphasizes the importance of AEP, which has a policy objective of maintaining wildlife connectivity, being actively engaged in and supporting transportation planning where wildlife management issues are impacted by Alberta's highway network.

The decision support tool we developed was designed to help incorporate wildlife issues into future road development and highway upgrade projects, and link transportation planning into Alberta's land use planning process. A series of scenarios were run to accommodate different management objectives, some more focused on human safety and others on wildlife conservation and management. Scenario results can be used by AEP and AT to inform different management objectives relating to human safety, wildlife connectivity, or a combination of the two. For example, the scenario weighted heavily toward wildlife connectivity might be important for AEP to consider in land use planning and biodiversity management in the South Saskatchewan Region.

At our second Stakeholder Workshop, we conducted a prioritization exercise that considered both wildlife conservation concerns and human safety using an Analytical Hierarchy Process. Participants at the workshop heavily weighted human safety over wildlife concerns, resulting in weights of 88% and 13% respectively. Based on participant discussions in the room during the AHP, this weighting appeared to be based on the perception that political, social, and financial support for human safety far outweighs support for wildlife connectivity. Though roads have well-described impacts on biodiversity, the perceptions of participants in this project reflects the importance of public, stakeholder, decision-maker, and policy education regarding investment in conservation strategies relating to roads, species conservation, and land use planning.

We were surprised that workshop participants placed heavier emphasis on structural connectivity (54% of total weight for wildlife connectivity), which represents areas of flow between natural habitat patches remaining on the landscape, than they did on functional connectivity for species of conservation concern, such as grizzly bear (17%), pronghorn (12%) and rattlesnake (5%). Because of this, the functional connectivity models contributed only weakly to the overall Mitigation Priority Index derived from the AHP weights. From a biodiversity perspective, the structural connectivity model is species-agnostic and represents our best available indicator of connectivity for the ecological community as a whole for the South Saskatchewan Region. Workshop participants also mentioned that expanding the structural connectivity model and exploring the impact of changes in model inputs (e.g., changes in mesh size and/or location of focal nodes based on random placement within core native habitat patches) would be desirable from the perspective of AEP and AT. Structural connectivity modeling results are perhaps most useful in areas where fragmentation is high and movement options are limited. In areas with less disturbance (e.g., northern Alberta), species-specific models might be more informative.

The decision support tool we developed can be used to help justify public expenditure of dollars through a systematic assessment of kilometer segments and TCSs that would benefit from a finer scale mitigation assessment. However, understanding the policy context and management issues of concern is an important prerequisite to using the tool to prioritize highway kilometer sections or TCS.

8.0 Conclusion

This project resulted in the development of a decision support tool to help AEP and AT address both human safety and wildlife conservation and management along highway network in the South Saskatchewan Region. Human safety concerns were considered through the development of an AVC Risk Index, while wildlife conservation and management concerns were considered through the development of a series of functional connectivity models for species of interest and a structural connectivity model. Connectivity model values were extracted along the highway network to develop Connectivity Value Indices.

The process resulted in the following recommendations:

➢ Road sections with the highest AVC Risk Index values were most common on the fringes of urban centers, where a combination of high traffic volume and abundant deer populations intersect to create a 'perfect storm' of risk to human safety. It is important to consider additional methods for prioritizing mitigation sections

because these areas may not be important ecologically despite having many recorded AVCs.

➢ The AVC Risk Index, when normalized by traffic volume, identified road sections along the highway network where animals cross most frequently and may be important from an ecological perspective to maintaining biodiversity. In addition these areas represent sections of higher risk of each car being involved in an AVC.

➢ Highway sections with high Ungulate Vehicle Collision Index and those with high Structural Connectivity Value Index exhibited minimal spatial overlap. This is an important consideration because mitigation decisions have traditionally been based on relative AVC risk of highway sections. AT does consider wildlife connectivity, but as a secondary factor once statistically-significant AVC clusters have been identified. This finding emphasizes the importance of AEP, with its policy objective of maintaining wildlife connectivity, being actively engaged in and pro-actively supporting transportation planning where wildlife management issues are impacted by Alberta's highway network.

➢ Workshop participants, through an Analytical Hierarchy Process, assigned much greater weight to human safety than to wildlife connectivity concerns, likely due to the impression that investment in mitigation will be driven primarily by AT's human safety mandate. However, roads may have a significant impact on wildlife via direct mortality or avoidance behavior by species sensitive to road disturbance. Thus, ensuring safe passage of wildlife across roads is an important strategy for maintaining biodiversity and protecting species at risk. Public education and science-policy translation regarding the need for investments in mitigation in support of biodiversity and species-at-risk recovery planning is urgently needed.

➢ Workshop participants identified structural connectivity as the most important connectivity component for wildlife conservation and management concerns, likely because this model is species-agnostic and represents areas important for biodiversity in highly fragmented landscapes. It may also be easier for the public to understand the concept of maintaining natural habitat than the concept of dispersal corridors for individual species. Participants suggested that the structural connectivity model be expanded to the provincial scale and incorporated into Alberta Wildlife Watch mapping products to help inform transportation planning.

➢ Further exploration is needed regarding mitigation investment for species at risk in areas where roads have been identified as a key impact. Products from this assessment may suggest where to focus finer-scale research to better inform transportation planning.

- The decision support tool should be integrated into existing planning processes by AT and AEP and updated as new data become available, new modeling methods are developed, or additional geographic areas are considered.

- Direct engagement among AT and AEP staff and the broader scientific and conservation communities would help to ensure that these goals are realized.

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Appendix A: Scoping Workshop

Scoping Workshop
Friday, April 29 2016
Lethbridge, Alberta
909 3 Ave North on third floor, Coulee Room

Rob Ament, Road Ecology Program Manager, Western Transportation Institute, Montana State University
Dr. Adam Ford, Liber Ero Fellow, University of Guelph
Danah Duke, Executive Director, Miistakis Institute, Mount Royal University
Tracy Lee, Senior Program Manager, Miistakis Institute, Mount Royal University
Dr. Meredith McClure, Spatial Ecologist, Center for Large Landscape of Conservation

Invitees
Alberta Environment and Parks (AEP):
Brett Boukall, Senior Wildlife Biologist, Resource Management Program, Calgary
Brad Jones, Acting Resource Manager, Calgary
Kim Morton, Resource Manager, Resource Management Program, Lethbridge
Rob Simieritsch, Regional Resource Manager, Calgary

Alberta Transportation (AT):
Jerry Lau, Infrastructure Manager, Calgary
Tom Vogelsang, Infrastructure Engineer, Lethbridge
Leslie Wensmann, Environmental Coordinator – Bridges, Lethbridge

Yellowstone to Yukon Conservation Initiative:
Stephen Legault, Program Director

General comments on scope and goals of program
- Scope depends on approach, structural vs species
- Hybrid on scope depending on focal species
- SSRP – is the end goal (suggestion of using Hwy 3 and bow corridor as test sites)
- Model of choice will depend on data GOA has that is available
- Focal species that change along east west gradient in study area, could be rated differently in areas (i.e. elk and elevation)
- Within SSRP – AT does not have regions, AEP does

Project Outcome
- Understanding of where focal species converge
- What would be helpful to AT and AEP for outcomes:

- Only have so much species info, some species we don't know much about
- Tie into SSPR (patches already identified, also check Biodiversity management framework) – make sure not missing anything
- A heat map as an end product would be helpful for planning!
- Policy, strategies that this product will inform
    - SSRP
    - Linear footprint (work with Ryan)
    - Land trust grant program
    - BMF
    - AT Specs (BMPs)

Connectivity Discussion
- Structure vs function – two pronged approach
    - Structure – habitat focused
        - Test it against function, but enable us to impact species not managing for but would benefit.
        - Native – assumption that all native is good – need some truth that potential reflects reality of movement
    - Function – species of concern
- Species of interest:
    - Pronghorn collar data, movement across number 1
    - Grizzly bear, genetic data
    - Big horn sheep
    - Elk - human safety perspective, allocation (hunting), collared
    - Lynx
    - Wolverine
    - Cougar (human wildlife conflict)
    - Snakes in SE (rattlers)
    - Westslope cut-throat trout
    - Bull trout
    - Any species of concern – Fed or Prov. (AT responds to, identified at site level)
    - Concern – spatial gaps geographically
    - We can make habitat models using occurrence data, citizen science data, as well as GPS data
    - Mule deer – safety concern, disease spread,

What models do we already have:
- Elk – Dale Paton
- Pronghorn – Mike Suitor

- Mule deer – patches identified (ask Kim M.)
- Mule deer connectivity – Meril and Northrup
- Elk – Hubblewhite
- Wolves, GB and cougars – Adam
- Northern Sage Brush Step Initiative (sage grouse, pronghorn, mule deer)
- Cougar – Cheryl (Crowsnest, Canmore) Cypress hills (ask Kim M.)
- GB – Stenhouse (habitat model), SHARP HIS models (Carita), Multisar HIS grassland
- Biodiversity values map in SSRP
- Critical habitat – fish species of concern
- Action items – what other models are there
- Create a table species and if they have connectivity, HSI
- FWMIS – no zero values, and only occurrence data

Patches vs. no patch
- Run from study area edge
- Assumptions – where an animal actually moves to and from (make sure don't include areas out of range)
- Current pulls out high potential movement areas (source areas)
- Geography of area instead of biology of species
- Suggestion: SSRP – potential leverage point to get buy in, we should use patches derived from SSRP and BMF to tie in.

Wildlife vehicle collisions/ risk index – species of concern
- GB (conservation)
- Elk (human safety)
- Moose (Human safety)
- Rattle snakes (conservation)
- Deer (Human safety)
- Bighorn sheep
- Mountain goat
- Black bear (human safety)
- Cougar
- Large domestic livestock?
- Bison (future concern)
- Pronghorn (human safety)
- Summary: All ungulates, GB and unique species

Risk index:
- Mile by mile count of WVC data

Data:

- Highway maintenance data: Highway control section (10-12km)
- ENFOR data – spatial accuracy issues and inconsistent (sheep, wolves and cougars for road kill)
- How is this managed in parks – need to consult with parks

Data gaps

- Highway maintenance contractors – hard copy forms that do not get entered, and location information is inconsistent.
- RCMP data – two to three years to get the data, not specific on species
- Range of species identified – no smaller species
- Locational accuracy of the information is not there
- Insurance data – likely same as RCMP data
- Survey effort, monitoring effort unknown on datasets
- Spatial coverage inconsistent
- Species identification a potential concern
- Traffic volume – spatial and temporal data (check AT website – runs 24 hours a day, ask Jerry for hourly data).
- Existing mitigation measures – good to consider as a criteria (ask Jerry)
- Wildlife density information

How are WVC considered in transportation planning?

- They are not considered

Other ideas

- What percent of collisions are due to wildlife?
- Human safety per capita rather than wildlife

Outcomes would enable integration of this project into transportation planning

- Phase 1 – 1st stage – highway control sections identified , second phase 2 – where within high sections do we need to focus
- Highway maintenance contractors control sections length – 30-40km

Action:

- Jerry will look into RCMP data and it we can get it per species

Prioritizing Hwy sections sections – why important?

- Important for AT (bring attention to sections where there are concerns)
- AEP – not a mandate for habitat (influence and inform), private land
- AEP direct input into regulator but has mandate to manage wildlife populations
- AT put in scoping documents for project reviews

- AT feed into future planning studies

Project Outcomes
- Decision support tool - enable scenario planning
- Process – formalized group – AEP/AT working group – suggest a sub-committee

Criteria ideas – set priorities
  - Conservation of species and movement (species of concern)
  - Human safety risk
  - Policy layer – (i.e. bow valley legally defined corridors, SSRP identified areas for connectivity, park, ESA, wildlife corridor sanctuaries)
  - Land security (private (zoning), public)
  - Highway type (traffic density, classification (level 1-4)
  - Mitigation potential
  - Habitat significance of highway section
  - Future scenarios – urban growth, climate change, twinning potential, industrial development, adjacent development

Measures of success
1. Heat map
2. Mitigation
3. Integration – formalization
4. Project identification
5. Decision support tool

This projects needs a logo, acronym
Next steps
- Where we can we use existing infrastructure (bridge, culvert) – think of this as phase 2
- This tool could inform land security around mitigation sites (land trust grant program)

Species	Priority	Primary Focus	Indicator role
grizzly bear	1	conservation	barrier
wolverine	2	conservation	climate
elk	2	human safety	public social value
big horn sheep	2	conservation/human safety	habitat specialist
pronghorn	1	conservation/human safety	public social value
mule deer	1	human safety	public social value
cougar	2	conservation	
lynx	2	conservation	
rattle snakes	2	conservation	habitat specialist
westslope cut-throat trout	2	conservation	
bull trout	2	conservation	
burrowing owl	1	conservation	barrier, climate

*Indicator role: barrier sensitive, habitat specialist, area sensitive, public social value, climate sensitive

Appendix B: Indices and Process Methods

Index family	Index name	Acronym	Calculation/ Definition	lyr file (open in ArcMap)/ Shapefile/ *Field name*
Animal Vehicle Collision	AVC Risk Index	AVC_A	Includes animal vehicle collisions for all species (domestic removed) in RCMP data by kilometer section	**AVC Risk Index.lyr** weighted_output_RCMP_all.shp *wghtl*
	UVC Risk Index	AVC_U	Includes ungulate vehicle collisions in RCMP data by kilometer section.	Not included in package
	CVC Risk Index	AVC_C	Includes carnivore vehicle collisions in RCMP data by kilometer section	Not included on package
	AVC Risk Index by Traffic Volume	AVC_A_N	AVCs counts by kilometer section, normalized by traffic volume	**AVC Risk Index by Traffic Volume.lyr** weighted_output_RCMP_all_norm.shp *wghtl*
	ENFOR Risk Index	ENFOR_A	Alberta Government Solicitor General Enforcement database "roadkill" count by km section.	Not included in package
Wildlife Connectivity	Grizzly Bear Connectivity Value Index	GB_CVI	Linkage mapper mean of values for grizzly bears per km section	**Grizzly Bear Connectivity Value Index.lyr** priority_index_using_AHP_weights_v2.shp *grzzly_mn*
	Rattlesnake Connectivity Value Index	RS_CVI	Linkage mapper mean of values for rattlesnakes per km section	**Rattlesnake Connectivity Value Index.lyr** priority_index_using_AHP_weights_v2.shp *rttlsnk_mn*

	Pronghorn Connectivity Value Index	PRONG_CVI	Linkage mapper mean of values for pronghorn per km section	**Pronghorn Connectivity Value Index.lyr** priority_index_using_AHP_weights_v2.shp *prnghrn_mn*
	Mule deer Connectivity Value Index	MD_CVI	Linkage mapper mean of values for mule deer per km section	**Mule Deer Connectivity Value Index.lyr** priority_index_using_AHP_weights_v2.shp *mldr_mn*
	Structural Connectivity Value Index	STR_CVI	Linkage mapper mean of values for structural connectivity per km section	**Structural Connectivity Value Index.lyr** priority_index_using_AHP_weights_v2.shp *strctrl_mn*
Mitigation Scenarios	Mitigation Priority Index Wildlife Connectivity	MPI_WC	Average of GB_CVI, RS_CVI, PRONG_CVI, MD_CVI, STR_CVI by kilometer	**Mitigation Priority Index Wildlife Connectivity.lyr** weighted_output_all_connectivity.shp *wghtl*
	Mitigation Priority Index Human Safety	MPI_HS	AVC Risk Index by kilometer	**AVC Risk Index.lyr** weighted_output_RCMP_all.shp *wghtl*
	Mitigation Priority Index Human safety (50%) and wildlife connectivity (50%)	MPI_HS50_WC50	Weighted average of 50% MPI_HS and 50% MPI_MPI by kilometer	**Human safety (50%) and wildlife connectivity (50%).lyr** weighted_output_WVC50_connectivity50.shp *wghtl*
	Mitigation Priority Index Human safety (70%) and wildlife connectivity (30%)	MPI_HS70_WC30	Weighted average of 70% MPI_HS and 30% MPI_V by kilometer	**Human safety (70%) and wildlife connectivity (30%).lyr** weighted_output_WVC70_connectivity30.shp *wghtl*
	Mitigation Priority Index Human safety (30%) and wildlife connectivity (70%)	MPI_HS30_WC70	Weighted average of 30% MPI_HS and 70% MPI_WC by kilometer	**Human safety (30%) and wildlife connectivity (70%).lyr** weighted_output_WVC30_connectivity70.shp *wghtl*
	Mitigation Priority Index AHP values	MPI_AHP	See Table 8 for weightings of Indexes by Workshop Stakeholders	**Mitigation Priority Index AHP Values.lyr** priority_index_using_AHP_weights_v2.shp *wghtl*

	Mitigation Priority Index AHP values by Traffic Control Section	MPI_TCS	See Table 8 for weightings of indexes by Workshop Stakeholders by Traffic Control Section	**Priority Index AHP values by Traffic Control Section.lyr** SSRP_traffic_clean_real.shp *AHP_MN*
	Mitigation Priority Index Human Safety by Traffic Control Section	MPI_HS_TCS	AVC Risk Index by Traffic Control Section	**Mitigation Priority Index Human Safety by Traffic Control Section.lyr** SSRP_traffic_clean_real.shp *SAFE_MN*
	Mitigation Priority Index Wildlife Connectivity by Traffic Control Section	MPI_WC_TCS	Average of GB_CVI, RS_CVI, PRONG_CVI, MD_CVI, STR_CVI by kilometer by Traffic Control Section	**Mitigation Priority Index Wildlife Connectivity by Traffic Control Section.lyr** SSRP_traffic_clean_real.shp *CON_MN*

AVC Risk Indices Development

All processing in ARCMAP unless otherwise stated.

- ➢ Reduce double lane highways to single lane by selecting only L1 and C1 roads from highway network layer.
- ➢ Split single lane highway network on provincial km marker point data, creating network of 1km or less segments.
- ➢ Spatially position, project and clean the RCMP AVC data of any unwanted species. Add count column with a value of 1 for all records. Split data into datasets for ungulates and carnivores.
- ➢ Generate Near Table using 100m search radius, maximum number of matches to be 1 between point layers and 1km road segment layer.
- ➢ Join point layer to their corresponding Near table and delete records that have no matches then dissolve on NEAR_ID.
- ➢ Join dissolved tables to the 1km segment layer. Calculate length of each segment.
- ➢ Create length ratio using count and length.
- ➢ Generate near table of the 1km road segments to itself and join the hwy segments to the near table on IN_FID, calculate the road name to new field. Remove join and repeat using NEAR_FID. Compare the road names and create a new table for all segments that have matching road names. This eliminates near records that are not part of the same road as its source.

- On newly created table do summary statistics on data columns while summarizing on IN_FID, this sums all the attaching segments, not including the source segment.
- Join this table back to the highway segments layer and add the sum of attaching segments to the current source segment and divided by number of segments to give an average for a 3 segment window.
- Erased cities of Lethbridge, Medicine Hat and Calgary and saved as new file.
- Using traffic volume linear features, pull out L1 and C1 roads, erase Lethbridge, Medicine Hat and Calgary and normalize traffic for 1000 vehicles per day per section.
- Spatial join traffic volume to1km highway segments and calculate traffic volumes to the 1km segments.
- Generate 0-1 ratios for each of the data fields by dividing the values by its highest value.
- Create correction based on traffic volume data then create a 0-1 ratio for each of the data fields by dividing by its highest value.

Connectivity Modeling

- All connectivity modeling used Linkage Mapper, requiring the development of resistance surface and focal nodes for each model
- To develop a resistance surface for **structural** connectivity modeling, we used Alberta Biodiversity Monitoring Institute (ABMI 2010) land cover data and applied resistance scores analogous to values outlined by Theobald et al. (2012) based on the degree of human modification for 13 major land cover groups. To develop focal nodes the South Saskatchewan Region was subdivided into a 'mesh' by the primary and secondary highways; meshes greater than 500 km^2 (which approximated the 90th percentile of patch sizes) were selected; and source nodes for the connectivity analyses were placed at the centroids of these large polygons. The resulting connectivity model was displayed using five quantiles. See structural_connectivity_rescale_SSRP.tif
- We used published **grizzly bear** resource selection function (RSF) models for three seasons (May 15-June 15, June 16-July 31, and Aug. 1-Oct. 15) developed for Alberta by Dr. Scott Nielson to create a resistance surface to use in connectivity modeling (Nielsen, 2007). RSF values for the three seasons were averaged to generate a single model and then inverted to represent resistance values. Highways were superimposed from Alberta base features GIS layer onto the resistance surface with a 60-m buffer, and applied the same resistance values for roads as those used for the structural resistance layer. Focal nodes were developed based on process to identify 5 km^2 secured habitat using ABMI land cover data (2010) and ABMI human footprint data following Gibeau et al. (2001). The resulting connectivity model was displayed using five quantiles. See grizzlybear_connectivity_rescale_SSRP.tif

- We used a published **pronghorn** connectivity model developed using Linkage Mapper for both spring and fall by Dr. Andrew Jakes (Jakes, 2015). The two models were averaged to generate a single model. Not shared please contact Dr. Andrew Jakes for access.
- For **mule deer** we used winter survey data (n=8121 observed locations) from 1990-2013 provided by AEP to develop a RSF model. The RSF model was inverted to develop a resistance surface for connectivity modeling. To develop focal nodes the South Saskatchewan Region was subdivided into a 'mesh' by the primary and secondary highways; meshes greater than 500 km^2 (which approximated the 90th percentile of patch sizes) were selected; and source nodes for the connectivity analyses were placed at the centroids of these large polygons. The resulting connectivity model was displayed using five quantiles. See muledeer_connectivity_rescale_SSRP.tif
- We used a **rattlesnake** habitat suitability model developed by MULTISAR based on hibernacula data from the Government of Alberta Fisheries and Wildlife Management Information System (FWMIS). The resulting habitat suitability index (HSI) was inverted to create a resistance surface for connectivity modeling. Because the HSI is derived for the species range in Alberta, it is represented as a large-scale gradient in snake habitat. In rescaling the inversion of the HSI to a resistance layer, we used the maximum and minimum cell values in a 5-km x 5-km moving window to 'localize' variation at a scale more relevant to snake movement than the entire study area. The mesh centroids developed for mule deer that fell within the rattlesnake range were used as focal nodes. Not shared please contact MULTSARS for access.

Wildlife Connectivity Value Indices

- Created focal statistics table for each of the 5 connectivity models, using hwy 1 km segments as focal region and summarized by mean for the length of each segments. Tables were joined and values calculated back to hwy 1km segment layer.

Mitigation Priority Index Scenarios

- Rescaled all AVC risk and wildlife connectivity indices from raw values (i.e., AVC rates per km section or connectivity model outputs) to 0-1 range
- For grizzly bear, rattlesnake, mule deer, and structural connectivity indices, inverted values such that higher values represent greater connectivity
- Converted rescaled index values to percentiles
- Imported weights for each index from AHP results or pre-established scenarios

➢ Calculated weighted average of index values for each kilometer section; for sections with NA values for one or more indices (e.g., road sections outside of species range), rescaled weights for remaining indices to sum to one prior to weighted averaging

Traffic Control Sections

➢ Generated near table between 1km segment layer and traffic control section layer
➢ Joined near table to 1km segments and transferred the traffic control section ID to the 1km segment layer.
➢ Dissolved 1km segments on the traffic control section, averaging the values of its corresponding segments.