

WHERE PEOPLE AND WILDLIFE INTERSECT



Prioritizing mitigation of road impacts on wildlife connectivity

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EXECUTIVE SUMMARY

Roads present a growing threat to the wildlife of the U.S. Northern Rocky Mountains, a region spanning the Greater Yellowstone, Salmon-Selway, and Crown of the Continent Ecosystems that is unique in continuing to support a full suite of native ungulates and carnivores. The continued viability of wildlife populations are dependent on their continued ability to move, including daily movements among local resources, migrations between seasonal ranges, long-range dispersal supporting gene flow, and species range shifts over time in response to changing conditions.

As wildlife movements across landscapes intersect with human movements via roads, both human safety and the health of wildlife populations are impacted. Several mitigation measures aimed at reducing wildlife-vehicle collisions and other road impacts on wildlife connectivity have been proven as effective means of both protecting human safety and preventing wildlife mortality. In this study, we seek to provide decision support in answering the crucial question of *where* to mitigate roads to yield the greatest positive impact for wildlife and people.

We create an index of road risk to wildlife based on roadside carcass data, then overlay corridors modeled by the Western Governors' Association Wildlife Corridors and Crucial Habitat Initiative to understand how risk and connectivity values align. We show that high risk road segments tend to have low connectivity value, though carnivores tend to be killed closer to road intersections with corridors than other species. Based on these findings we identify four alternative sets of potential priority sites for mitigating road impacts on wildlife that together capture the unique perspectives of diverse stakeholder groups, including departments of transportation, land and wildlife managers, citizen groups, and conservation practitioners.

We also detail specific roles that diverse stakeholders can play in the mitigation process, and highlight opportunities for each to engage in that process by working in partnership with transportation agencies. Examples of these roles and opportunities are described through case studies that together illustrate the four alternative perspectives on mitigation priorities that we identify.

This report is accompanied by fully documented downloadable data products and a web-based decision support tool that allow practitioners to both explore patterns in risk and connectivity values across the study area, and to examine risk values, connectivity values, and risk factors present at a particular site of interest. We hope that this report and its associated decision support tools will aid practitioners working in the U.S. Northern Rockies to engage in mitigation of road impacts on wildlife connectivity and to do so where it matters most in the context of each practitioner's unique perspective and goals.

INTRODUCTION

Background

The U.S. Northern Rockies, spanning the Greater Yellowstone, Salmon-Selway, and Crown of the Continent Ecosystems (Figure 1), is one of the last best places supporting iconic wildlife populations and their movement. In the Rocky Mountain ecotype, elk and pronghorn continue to migrate tens to hundreds of kilometers between seasonal ranges, and grizzly bears, wolverine, and lynx roam vast home ranges, their young dispersing over great distances. The U.S. Northern Rockies region is the only place left in the conterminous United States that continues to support its full suite of native ungulates and carnivores. However, natural amenities-driven residential development has rapidly expanded across the U.S. Northern Rockies in recent decades¹, bringing with it a burgeoning road network. This has led to increasingly fragmented landscapes, posing a growing threat to the wildlife and their movements that make this region unique and that are crucial to its ecological function and resilience.

Landscape connectivity is an essential component of intact, healthy landscapes that support wildlife movement as well as ecological processes. Connectivity is most often defined as “the degree to which the landscape facilitates or impedes movement”². Corridors have been defined in a variety of ways, but are generally agreed to constitute distinct components of the landscape that provide connectivity. Wildlife crossings are more narrowly defined as structures that allow animals to safely cross barriers such as roads and can be an important component of wildlife corridors.

The continued viability of wildlife populations in the Northern Rockies is dependent upon movement spanning multiple temporal and spatial scales, including daily movements among local resources, migrations between seasonal ranges, long-range dispersal in search of new territories, and species range shifts over time in response to changing conditions. These movements ensure access to resources and mates, demographic rescue effects following local extirpation events, sustainable levels of genetic diversity, and the capacity to adapt to a changing climate and other disturbances. More broadly, landscape connectivity supports the adaptive capacity for communities to recover from acute disturbances (e.g., fire) or to shift in response to chronic disturbances. Connected landscapes are also crucial to the functional integrity of ecological processes such as water, energy, and nutrient flows.

Fragmentation due to human land use is understood to disrupt and impede wildlife movement and other ecological processes, and roads have been named the single most destructive driver of habitat fragmentation³. While less than 1% of the land area of the United States is covered by roads, roads’ zone of influence, which factors in roadside clearing of vegetation and the distribution of road-related pollutants, occupies an estimated 20% of U.S. land area⁴. Approximately 80% of all lands in the conterminous U.S. fall within 1 km of a road, and only 3% lie more than 5 km away from a road⁵.

As wildlife movements across landscapes intersect with human movements via roads, the impacts on both humans and wildlife are clear. Approximately 1-2 million wildlife-vehicle collisions (WVCs) occur annually in the United States, and this number has been on the rise over the past decade⁶. Each year, WVCs cause hundreds of human deaths, over 29,000 human injuries, and induce estimated costs of over \$8 billion.

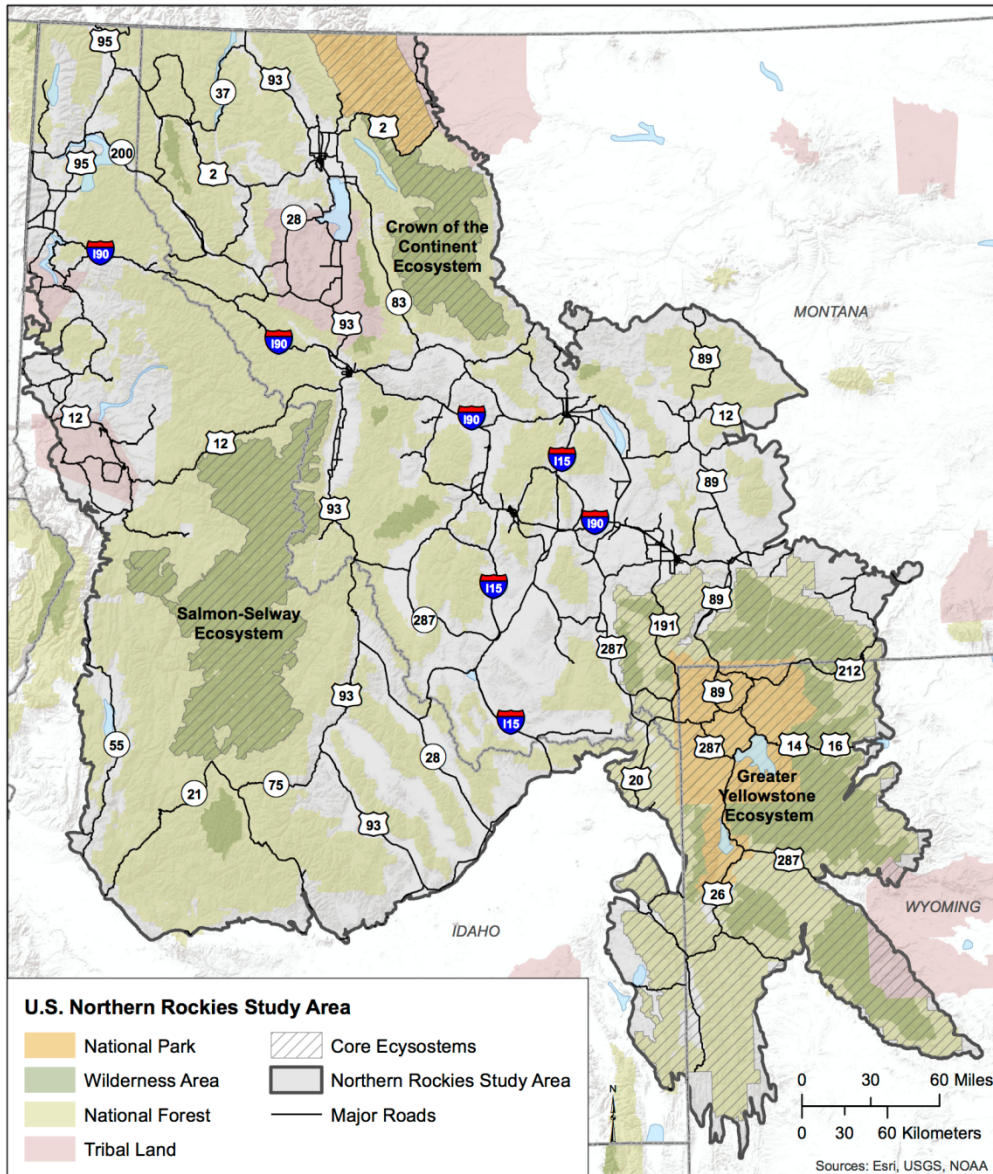


Figure 1. The U.S. Northern Rockies study area, focusing on connectivity among the Greater Yellowstone, Salmon-Selway, and Crown of the Continent Ecosystems

Wildlife-vehicle collisions are, of course, highly detrimental to wildlife as well. Many species occurring in the Northern Rockies have known sensitivities to the presence of highways and vehicle traffic⁷, which may negatively impact populations through direct mortality⁸, road avoidance behavior⁹, and habitat loss or degradation¹⁰. Road mortality has been identified as a major threat to species survival for 21 species listed as threatened or endangered, including Canada lynx¹¹. Loss of connectivity due to highways may also threaten the long-term persistence of some wildlife populations by disrupting demographic and genetic connectivity¹². As traffic volume or speed increases, eventually animals may be deterred from the road completely and choose not to cross¹³.

Huijser and colleagues¹⁴ synthesized studies of the effectiveness of mitigation measures aimed at reducing WVCs and other road impacts on wildlife connectivity. These studies demonstrate 86-100%

reductions in WVCs by long-term mitigation measures, such as wildlife under- and overpass structures and automatic detection systems (ADS) that alert drivers to the presence of wildlife on or approaching the road (Table 1). These structures not only enable wildlife to cross roads safely¹⁵, thereby improving landscape permeability for wildlife, but can also yield safety and monetary benefits for people when installed at WVC hotspots¹⁶.

National transportation policy now supports implementation of such mitigation measures to reduce WVCs and other adverse impacts on wildlife. The most recent transportation act, *Moving Ahead for Progress in the 21st Century* (MAP-21)¹⁷, includes provisions supporting the installation of roadway infrastructure to reduce or eliminate wildlife-vehicle collisions, as well as programs to assess the impacts of transportation projects on wildlife habitat and connectivity¹⁸.

These advances have set the stage for action. For the first time, practitioners in the transportation, land management, and conservation sectors now have both a clear means and ample opportunity to address the impacts of roads on wildlife. Here we seek to provide decision support in answering the crucial question of *where* to mitigate roads to yield the greatest positive impact for wildlife and people.

Table 1. Estimated effectiveness, present value costs (in 2007 US\$, 3% discount rate), and costs per percent reduction of mitigation measures aimed at reducing collisions with large ungulates over a 75 year time period (Huijser et al. 2009; see sources therein).

Mitigation measure	Effective-ness	Crossing opportunity?	Source	Present value costs (US\$)	Costs per percent reduction (US\$)
Seasonal wildlife warning sign	26%	Yes	Sullivan et al. (2004): 51%; Rogers (2004): 0%	\$3,728	\$143
Vegetation removal	38%	Yes	Jaren et al. (1991): 56%; Lavsund & Sandegren (1991): 20%	\$16,272	\$428
Fence, gap, crosswalk	40%	Yes	Lehnert & Bissonette (1997): 42%, 37%	\$300,468	\$7,512
Population culling	50%	Yes	Review in Huijser et al. (2007a)	\$94,809	\$1,896
Relocation	50%	Yes	Review in Huijser et al. (2007a)	\$391,870	\$7,837
Anti-fertility treatment	50%	Yes	Review in Huijser et al. (2007a)	\$2,183,207	\$43,664
Fence (incl. dig barrier)	86%	No	Reed et al. (1982): 79%; Ward (1982): 90%; Woods (1990): 94%-97%; Clevenger et al. (2001): 80%; Dodd et al. (2007): 87%	\$187,246	\$2,177
Fence, underpass, jump-out	86%	Yes	Reed et al. (1982): 79%; Ward (1982): 90%; Woods (1990): 94%-97%; Clevenger et al. (2001): 80%; Dodd et al. (2007): 87%	\$538,273	\$6,259
Fence, under- and overpass, jump-out	86%	Yes	Reed et al. (1982): 79%; Ward (1982): 90%; Woods (1990): 94%-97%; Clevenger et al. (2001): 80%; Dodd et al. (2007): 87%	\$719,667	\$8,368
Animal detection system (ADS)	87%	Yes	Mosler-Berger & Romer (2003): 82%; Dodd & Gagnon (2008): 91%	\$1,099,370	\$12,636
Fence, gap, ADS	87%	Yes	Mosler-Berger & Romer (2003): 82%; Dodd & Gagnon (2008): 91%	\$836,113	\$9,610
Elevated roadway	100%	Yes	Review in Huijser et al. (2007a)	\$92,355,498	\$923,555
Road tunnel	100%	Yes	Review in Huijser et al. (2007a)	\$147,954,696	\$1,479,547

Purpose

Our primary objective is to provide decision support for prioritizing conservation action to mitigate the impacts of roads in the U.S. Northern Rockies on wildlife connectivity. We seek to help practitioners focus engagement in road mitigation efforts where these efforts are most critical for reducing risk to motorists and wildlife, preventing loss of connectivity where high-value wildlife corridors are crossed by roads, or both.

To accomplish this objective, we:

- identify road segments that intersect corridors of high predicted connectivity value,
- produce an index of risk to wildlife presented by roads based on roadkill data,
- evaluate the congruence of risk and connectivity values across the road network to identify potential priority sites for mitigation of road impacts on wildlife,
- identify opportunities for diverse stakeholder participation in the mitigation process, and
- develop data products and decision support tools to aid informed prioritization of mitigation sites and stakeholder engagement.

Mitigation of road impacts on wildlife most often focuses on wildlife-vehicle collision (WVC) “hotspots”, or road segments at which WVCs most frequently occur. This focus is most often driven by the human safety-focused missions governing most federal and state transportation agencies¹⁹ and their traditional use of safety funding for WVC mitigation. It is generally assumed that implementing mitigation that reduces WVCs also provides the added benefit of improving wildlife connectivity. However, this assumption has been largely unexamined and untested.

If road segments presenting high risk to wildlife, as indicated either by high WVC rates or high numbers of reported wildlife carcasses, also have high predicted wildlife connectivity value, we seek to identify these segments as priorities for mitigation that would provide the greatest benefits to both human safety and wildlife connectivity. If, instead, segments with high risk to wildlife and high predicted connectivity value exhibit little congruence, we seek to identify multiple priority segments that together meet both safety and connectivity objectives.

In either case, we seek to highlight opportunities for diverse stakeholders, including transportation agencies, state and federal land managers, private land trusts, and citizen groups and conservation organizations with a range of specific conservation targets, to actively participate in the process of planning, funding, and implementing measures to mitigate the impacts of roads on wildlife. To do so we seek to provide publicly available data products and decision support enabling diverse stakeholders to engage in meaningful ways.

METHODS

U.S. Northern Rockies Study Area

This project's study area was defined so as to span the Crown of the Continent, Salmon-Selway, and Greater Yellowstone Ecosystems, a region often referred to as the High Divide. Connectivity among these ecosystems is expected to be crucial for the long-term persistence of wildlife in this region, particularly wide-ranging species with low population density like grizzly bears and wolverines, in order to maintain access to resources, gene flow, and the capacity to adapt in response to climate change.

The study area boundary was delineated based on Ecoregions defined by the Environmental Protection Agency (EPA)²⁰, which are intended to encapsulate areas within which ecosystems (as well as the type, quality, and quantity of environmental resources) are generally similar. First, EPA Level III Ecoregions spanning the ecosystems of interest were merged. This initial boundary was further expanded based on the finer-scale EPA Level IV Ecoregion boundaries where these additional areas were needed to capture all potential linkage areas (designated National Forests and Wilderness Areas) between ecosystems.

Defining the Major Road Network

We focused on the network of major roads in the study area because these roads were generally expected to have greater impacts on wildlife connectivity than minor roads and because collection of wildlife carcass data was expected to be more consistent on these roads.

In Montana, the major road network was defined by Montana Department of Transportation (MDT) current On-System Routes. On-System Routes include National Highway System (NHS) Interstate, NHS Non-Interstate, Primary, Secondary, and Urban routes. In Idaho, major roads were defined by current active State Highway System (SHS) Routes. SHS Routes include main routes, state highway connectors, business loops, and business spurs. Wyoming roads were not included in our analysis because our focus was on connectivity *between* rather than *within* the three major ecosystems framing our study area and in order to minimize inconsistency issues with data availability and quality.

Montana On-System Routes and Idaho SHS Routes provide an equivalent level of detail across the study area and align at the Montana-Idaho state boundary. Together, these routes constitute 6,946 miles of road across the U.S. Northern Rockies study area. Mile markers along these routes serve as the unit of analysis in our study, as described below.

Wildlife Connectivity Value

This study aimed to assess potential road impacts on broad-scale, multi-species connectivity throughout the U.S. Northern Rockies. To do so, we relied on the landscape integrity-based west-wide connectivity model developed by the Western Governors' Association (WGA) Wildlife Corridors and Crucial Habitat Initiative (Figure 2). This model was produced as part of an effort by the 16 Western states to provide the public and practitioners in a variety of sectors (i.e., energy, housing development, transportation) with potential impacts on wildlife habitat with a high-level overview of "crucial habitat" across the West. It represents one component of the WGA's web-based Crucial Habitat Assessment Tool (CHAT)²¹, which is intended to help users in the pre-planning stage of energy or other large-scale corridor projects by establishing a common starting point across the West for the intersection of development and high wildlife conservation values. The model is non-species specific and is intended to provide a coarse-filter, "20,000 foot" view of areas expected to be important for connectivity, supporting movement of a wide

range of species as well as the continuity of ecological processes. It is currently the only connectivity model available for this purpose that covers the entire U.S. Northern Rockies study area, which spans the Idaho-Montana state border. While connectivity flowlines generated by the model are not species-specific, they are biome-specific in that each flowline connects blocks of habitat consisting primarily of one of four major biomes, including forest, Great Plains grassland, alpine grassland, and cool desert.

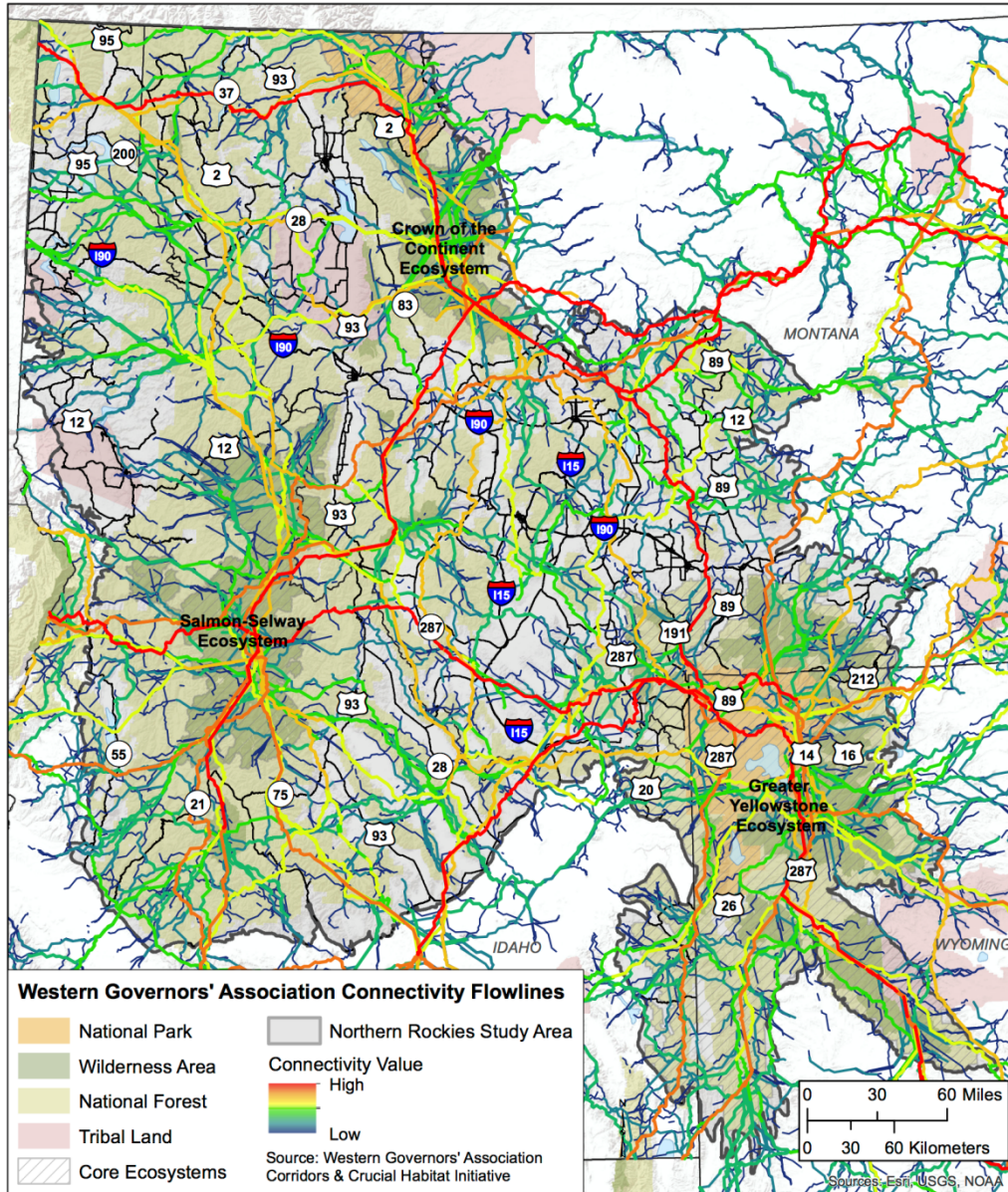


Figure 2. Landscape integrity-based multi-species connectivity model developed by the Western Governors' Association Wildlife Corridors and Crucial Habitat Initiative.

The WGA connectivity model is based on a least cost path approach, which calculates the cost-weighted distance between a source location and destination location and identifies the path that minimizes the tradeoff between travel distance and difficulty of travel, or resistance to movement²². The least cost path is predicted to be the optimal route between the source and destination, presenting the least total resistance to movement.

In the WGA connectivity model, resistance to movement is defined by the NatureServe Landscape Condition Assessment, which is a remote sensing-based measure of land cover impacted by human activities²³. The model provides an index of ecological condition by integrating 19 data themes representing land cover modification, urban and industrial development, and transportation infrastructure impacts to the landscape. It assigns higher resistance to movement to locations with high human modification of the landscape for one or more of these land uses (Table 2).

Table 2. Summary of data inputs used for the NatureServe Landscape Condition Model (see Comer & Hak 2012 for full details).

Theme	Data Source	Presumed Relative Stress
<i>Transportation</i>		
Dirt roads, 4-wheel drive	ESRI StreetMap 2010	Low
Local and connecting roads	ESRI StreetMap 2010	Medium
Secondary and connecting roads	ESRI StreetMap 2010	High
Primary highways with limited access	ESRI StreetMap 2010	Very High
Primary highways w/out limited access	ESRI StreetMap 2010	Very High
<i>Urban and Industrial Development</i>		
Low density development	NLCD 2006	Medium
Medium density development	NLCD 2006	Medium
Powerline/transmission lines	Platts (obtained under WGA agreement)	Medium
Oil/gas wells	USGS/TNC	Medium
High density development	NLCD 2006	Very High
Mines	USGS/MRDS	Very High
<i>Managed and Modified Land Cover</i>		
Ruderal forest & upland	SW ReGAP, NW ReGAP, LANDFIRE EVT	Very Low
Native veg. with introduced species	SW ReGAP, NW ReGAP, LANDFIRE EVT	Very Low
Recently logged	SW ReGAP, NW ReGAP, LANDFIRE EVT	Very Low
Managed tree plantations	SW ReGAP, NW ReGAP, LANDFIRE EVT	Low
Introduced tree & shrub	SW ReGAP, NW ReGAP, LANDFIRE EVT	Medium
Introduced upland grass & forb	SW ReGAP, NW ReGAP, LANDFIRE EVT	Medium
Introduced wetland	SW ReGAP, NW ReGAP, LANDFIRE EVT	High
Cultivated agriculture	SW ReGAP, NW ReGAP, LANDFIRE EVT	High

The WGA connectivity model implements a novel multi-scale least cost path approach, in which many cost-distance surfaces generated between source-destination pairs defined to capture multiple spatial scales of movement were overlaid. Paths frequently identified as low-cost in many of these cost-distance surfaces are considered important for connectivity. This approach is analogous to a hydrologic flow model of water accumulation into drainages across a landscape: where many least cost paths converge, major flowlines (“rivers”) with high connectivity value are produced, which are fed by minor flowlines (“tributaries”) with lower connectivity value.

Connectivity flowlines are attributed with centrality scores, which quantify their relative contribution to connectivity of the landscape-wide network as a whole. Flowlines with high centrality (maximum score of 13) are those most crucial to maintaining connectivity across the West as a whole. Flowlines with lower centrality values (minimum score of 6) serve as collectors that feed into flowlines with higher scores. Paths with scores less than 6 were considered minimally important for connectivity and were not included. For the purposes of this study, we created a simple connectivity value index by rescaling centrality scores (6-13) to range from zero to one.

Least cost path methods represent just one of many approaches to modeling connectivity, and they are accompanied by important assumptions. This approach assumes that least cost paths offer the best opportunity for movement between a given source and destination; it does not necessarily assume that these paths are most likely to be traveled or exhibit the highest frequency of use. Limited knowledge of the landscape as a whole, as well as other factors that may influence individual wildlife movements (e.g., inter- and intraspecific interactions, conditions at the time of travel) may result in selection of other routes. Least cost path methods may be more appropriate for modeling migration movements of ungulates, which are expected to have some knowledge of the landscape and select the same or similar migration paths year after year and from generation to generation, than for modeling dispersal movements of carnivores that are likely to take them through novel landscapes²⁴. However, the regional scale at which this connectivity analysis was conducted may best represent genetic and demographic connectivity via long-distance dispersal over multiple generations while overlooking local movements, including ungulate migration between winter and summer ranges. In sum, the WGA connectivity model and the least cost path methodology on which it is based is expected to provide a valuable first look at paths expected to offer the best chance for maintaining long-term connectivity for multiple species on a regional scale, but its assumptions should be taken into account and additional fine-scale information should be considered when interpreting the model at the project level.

In order to assess potential road impacts on this connectivity network in the U.S. Northern Rockies, we intersected connectivity flowlines with the major road networks of Montana and Idaho, then attributed rescaled (0-1) flowline centrality values to the nearest mile marker along these roads (Figure 3). The WGA Corridors and Crucial Habitat Technical Team recommends a 1-mile buffer on each side of connectivity flowlines to represent uncertainty in their precise location, which we take into account in site-level assessments of mitigation opportunities.

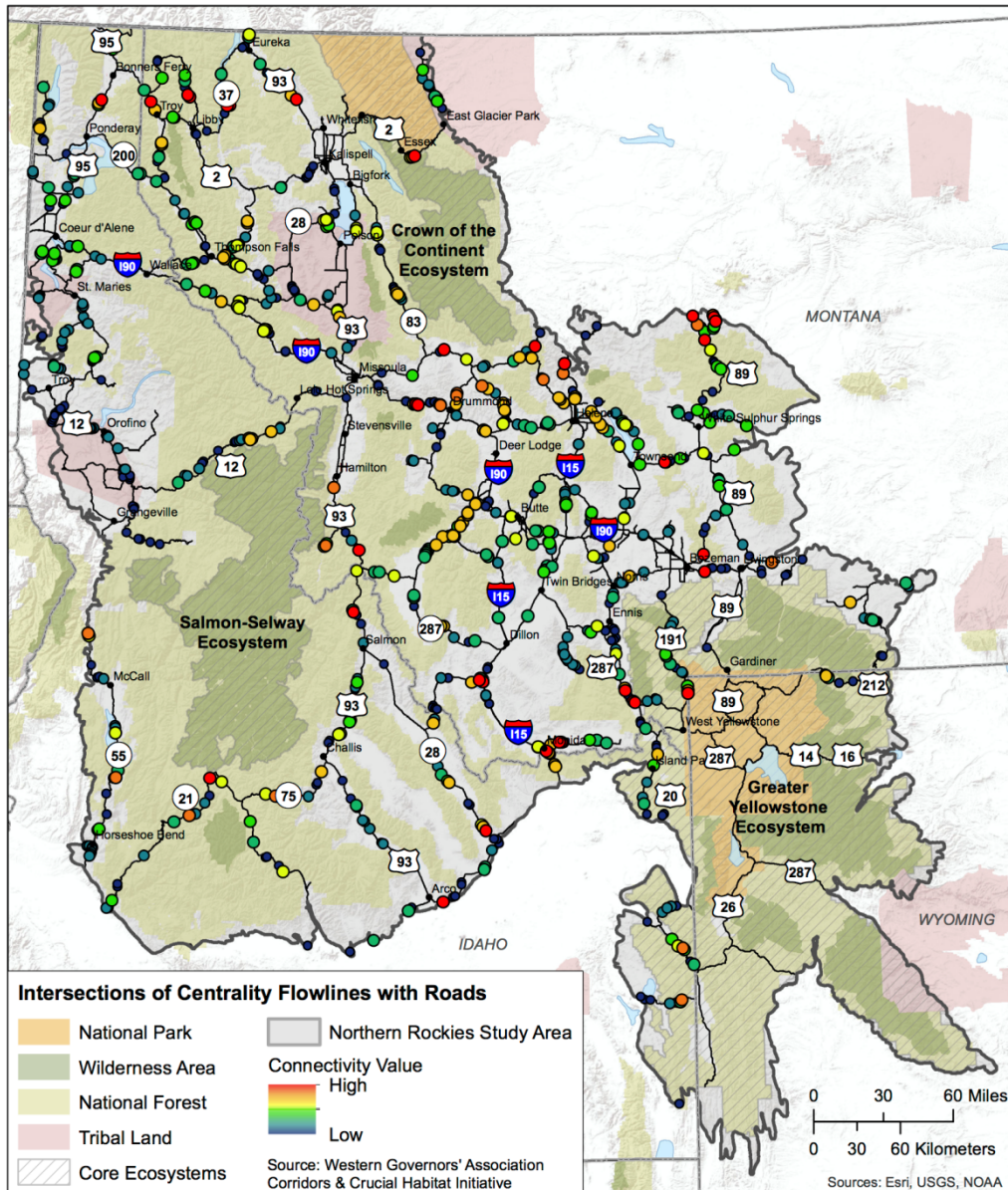


Figure 3. Intersection of WGA connectivity flowlines with the major road network. Colored dots indicate the connectivity value of the flowline and where it intersects with a road.

Road Risk Index

To estimate an index of risk presented to wildlife by roads, we obtained 5 years (2008-2012) of wildlife carcass data from MDT, Idaho Department of Fish & Game (IDFG), and the U.S. Fish & Wildlife Service. Montana carcass data were collected and recorded by MDT road maintenance crews. Idaho carcass data were collected and recorded by IDFG and ITD personnel, with additional citizen reporting of carcasses through IDFG's online database²⁵ starting in 2012. Additional USFWS grizzly bear (*Ursus arctos*) carcass data that were not included in state databases were collected and recorded by the USFWS Grizzly Bear Recovery Team (provided by C. Servheen, Grizzly Bear Recovery Coordinator). Note that while lynx, wolverine, and fisher are known to be killed on roads (J. Williams, MT FWP, personal communication), no spatial data for these events could be located among our agency partners.

While carcass data were available for years prior to 2008, we restricted analysis to a five year period in order to minimize inconsistencies in data collection and reporting and to minimize the influence of any significant changes to the road network over time (e.g., road upgrades or installation of mitigation measures) on observed patterns in roadkill frequency. The frequency and consistency of carcass collection and reporting are known to vary among maintenance sections and among routes within states (D. Wambach, MDT, personal communication). Idaho carcass data are also thought to be significantly underreported compared to Montana (G. Vecellio, IDFG, personal communication). Detection, identification, and collection of wildlife carcasses varies by season, with winter carcasses often not located until spring, at which time there is often little left to identify, as well as by topography, with animals struck adjacent to steep slopes rarely being recovered. Because of these issues, MDT issues the following disclaimer concerning use of wildlife carcass data:

“The MDT carcass database contains information on carcasses collected by MDT maintenance personnel; however not all carcass collection is reported consistently or on a regular schedule. This makes the information provided by the carcass database useful for pattern identification, but not statistically valid.”

Due to these data limitations, we developed a simple index of road risk to wildlife rather than fitting a statistical model based on potential risk factors; focused on qualitative assessment of the extent to which this risk index aligns with predicted connectivity value; and limited interpretation to coarse patterns in highly aggregated carcass counts.

Prior to analysis, several data screening steps were performed. First, records for which species was marked “Unknown”, species that did not present a concern from a human safety or wildlife conservation perspective (e.g., domestic animals, insects), or obvious erroneous entries (e.g., harbor porpoise) were excluded. Next, records for which only a mile marker, intersection, or other specific spatial reference was given were assigned the coordinates of this reference point. Records with no specific spatial reference or only referenced to a road were excluded from analysis. Road segments on which carcasses were likely to have occurred but were not reported were then excluded from analysis by identifying roads on which carcass reports ended abruptly at a maintenance section boundary. While other reporting inconsistencies between maintenance sections are likely to have occurred, complete lack of reporting was deemed to be the most problematic error and was the only error that could be objectively identified and omitted. Lastly, the three sources of carcass data were merged, clipped to the study area boundary, and clipped to within 100 meters of the major road network to exclude animals that were killed on minor roads or animals that were not likely to have been road-killed.

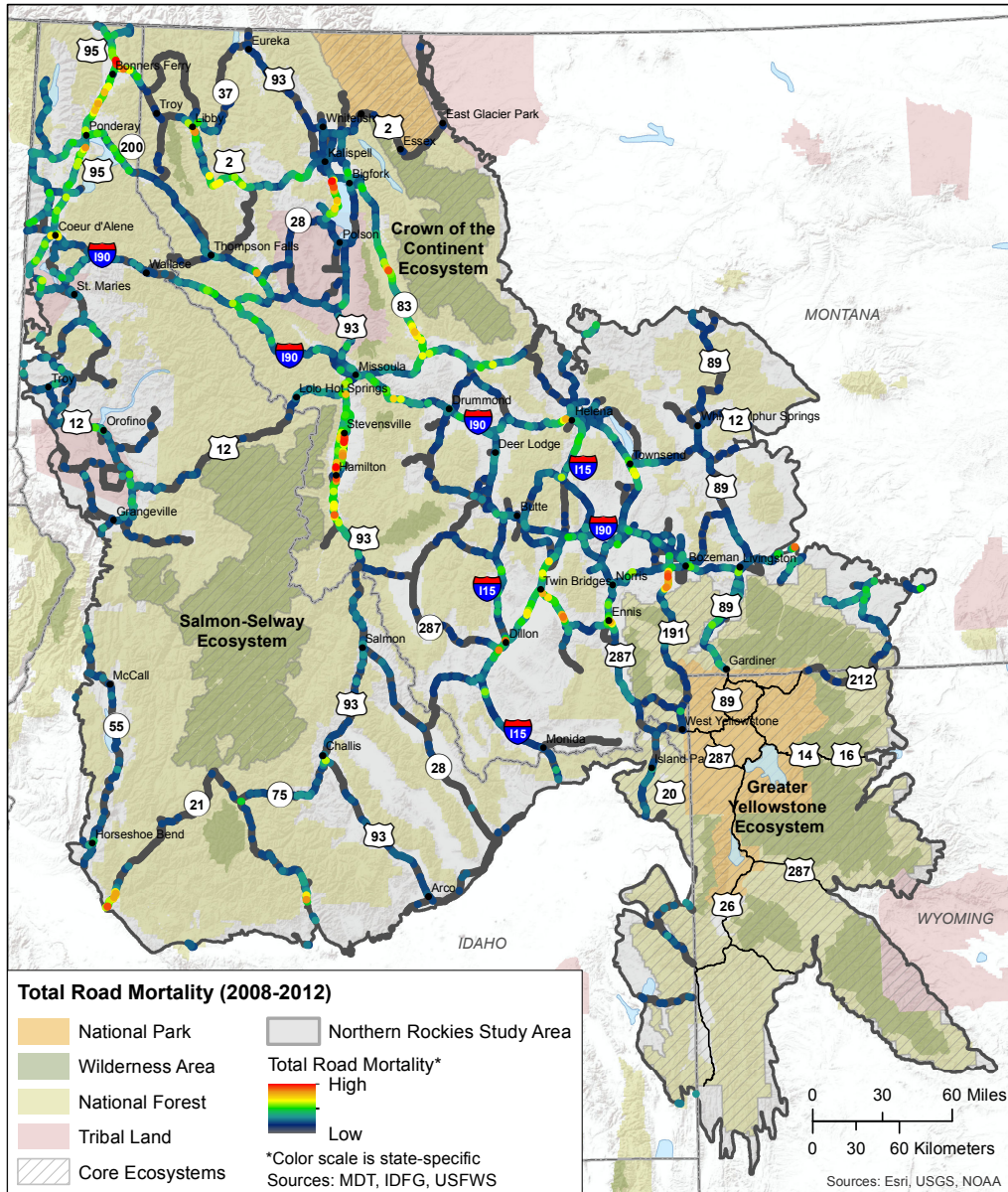


Figure 4. Count index of road risk to wildlife derived by aggregating carcass counts to the nearest mile marker.

We created a simple index of road risk to wildlife by aggregating recorded carcasses to the nearest mile marker, which allowed us to then attribute each mile marker with a 5-year total count of all wildlife found closest to that mile marker (Figure 4). We then rescaled counts from zero to one within each state to focus discussion on *relative* risk because inconsistent collection of carcass data renders absolute counts not particularly meaningful. We also created an indicator of road risk to carnivores by isolating carnivore carcass records and aggregating them to mile markers as above (Figure 5) because the carcass dataset is heavily dominated by deer (90.2%) and carnivores of conservation concern are poorly represented (0.7%; Figure 6),

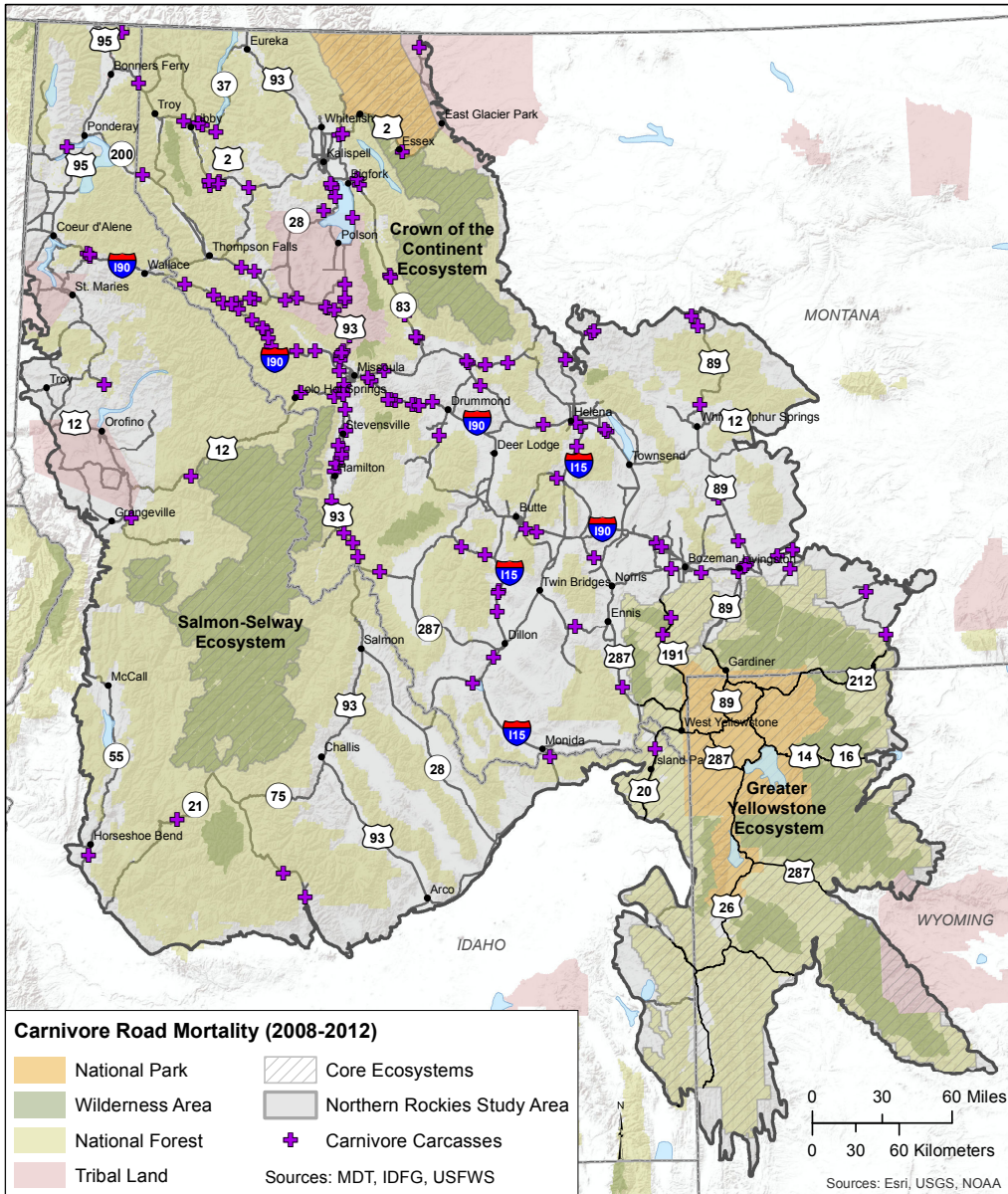


Figure 5. Presence of road-killed carnivore carcasses, aggregated to mile markers.

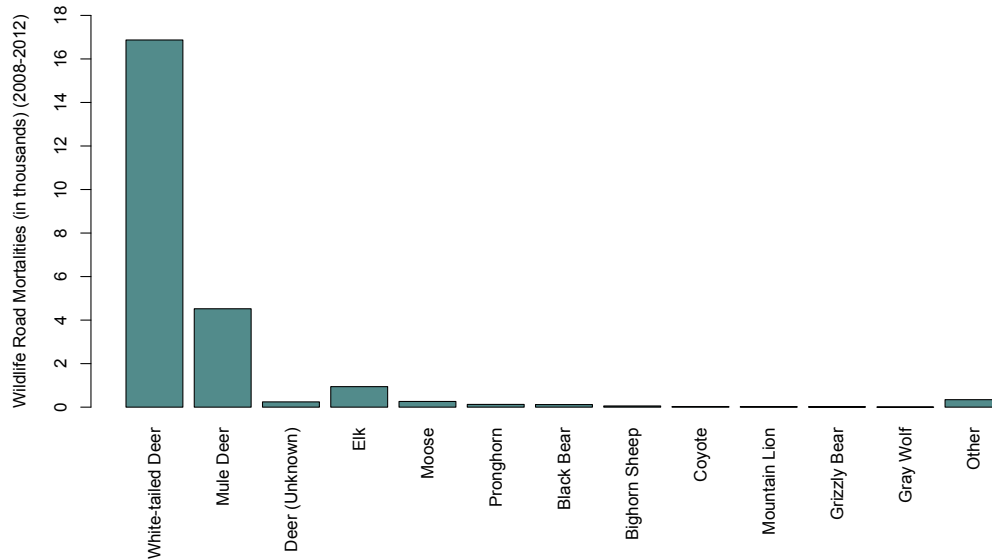


Figure 6. Distribution of carcass records across species. Deer (white-tailed and mule deer) account for 91.8% of the dataset, while key carnivore species (black bear, grizzly bear, mountain lion, and gray wolf) account for 0.7%.

Identifying Priority Sites

To identify potential priority sites for mitigation of road impacts on wildlife that balance a human and wildlife safety perspective with a wildlife connectivity perspective, we created a simple overlay of connectivity value and road risk value attributed to each mile marker. We then assessed the congruence between connectivity values and road risk values based on a scatterplot of the values attributed to mile markers for each factor. Points falling in the upper-right quadrant of this plot would indicate both high connectivity value and high risk value, and thus good alignment of mitigation priorities from safety and connectivity perspectives (Figure 7). Points falling in the upper-left or lower-right quadrants would indicate either high connectivity and low risk, or high risk and low connectivity, respectively. In this case, alignment of mitigation priorities from safety and connectivity perspectives would be poor, indicating that mitigation measures to ensure human and wildlife safety and mitigation measures to ensure broad-scale connectivity may need to be implemented at different sites, employ different strategies, and engage different stakeholder groups.

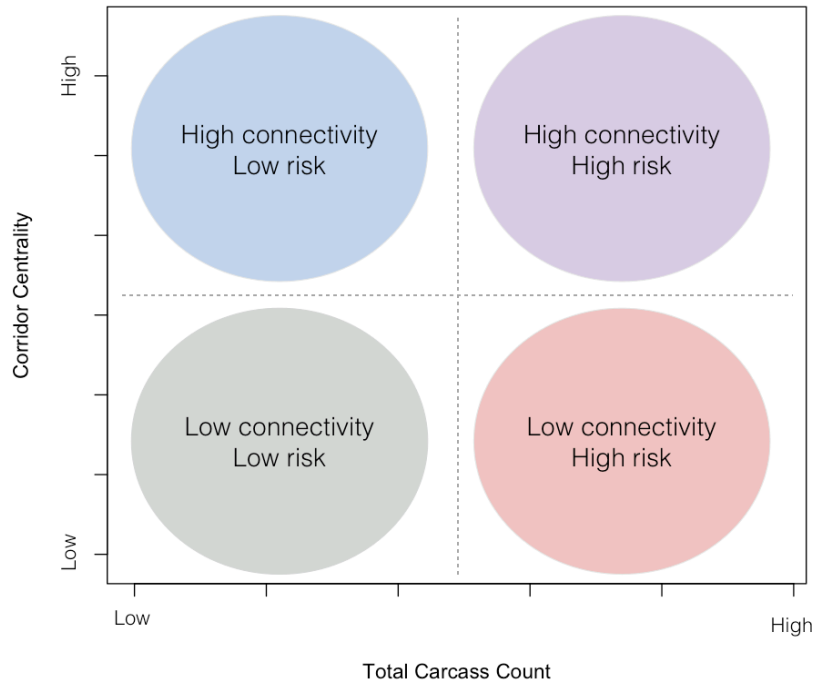


Figure 7. Schematic of connectivity value versus road risk value scatterplot for identifying potential mitigation priorities.

Spatially Assessing Connectivity Versus Risk

In addition to identifying broad categories of priority sites based on congruence of risk and connectivity values, we also wished to understand spatial relationships between risk and connectivity. We sought to determine:

- whether carcasses tended to be found closer to sites at which roads crossed connectivity flowlines than expected by chance, and
- whether carcasses of carnivores, whose movements are expected to be most dependent on intact tracts of habitat, tended to be found closer to flowlines than carcasses of ungulates, which are expected to be more tolerant of lower landscape integrity and perhaps to exhibit local migratory movements that do not necessarily align with predicted broad-scale paths of wildlife connectivity.

For each wildlife carcass and for an equal number of random points generated along the road network, we assessed the distance to the closest point at which a road intersected a connectivity flowline. We then made general comparisons based on median distances because the data do not support further statistical analysis and the distance values were not normally distributed. We conducted a similar comparison of carnivore and ungulate carcass distances to connectivity flowlines.

Assessing Risk Factors

In order to identify potential factors associated with high road risk to wildlife, we reviewed peer-reviewed published literature as well as relevant reports and other “grey” literature prepared by or for departments of transportation or other transportation-focused research entities. These factors fell into three categories:

- Road Attributes: attributes associated with the road’s function or surface
- Topographic Attributes: topography of the landscape adjacent to roads that may affect rates of wildlife movement and/or driver visibility
- Habitat Attributes: attributes capturing habitat quality adjacent to roads, which may affect rates of wildlife movement across the road

All potential risk factors were sampled at each mile marker throughout the study area.

Road Attributes

We consulted with Montana and Idaho departments of transportation (DOTs) to determine which of the road attributes we identified as potential risk factors had spatial data available from both states. The following road attributes were included as potential risk factors in our assessment: number of lanes, road surface width, road functional class (e.g., major route, minor arterial), and average annual daily traffic (AADT). Speed limit was also identified as a potentially important risk factor, but these data were not available because posted speed limits are determined locally and are not incorporated into databases maintained by state departments of transportation. Furthermore, posted speed limits were not thought by DOT staff to be a reliable measure of actual vehicle speeds on a given road segment.

Topographic Attributes

The following attributes representing topography adjacent to the road surface were considered potential risk factors because they may affect rates of wildlife movement and/or driver visibility: topographic ruggedness and topographic position index (TPI). Ruggedness was calculated as the standard deviation of slope values within a half-mile radius of each mile marker. TPI was calculated as the observed elevation at each mile marker minus the mean elevation within a half-mile radius of the marker. High TPI values are generally associated with ridgelines or edges of high plateaus, while low TPI values are typically associated with canyon bottoms. Moderate values may be associated with slopes or with broad flat areas.

Wildlife Habitat Attributes

Because our analysis was not species-specific, we included an index of habitat suitability adjacent to roads that is expected to be relevant for the probability of occurrence and movement of multiple wildlife species as a risk factor. We selected the NatureServe Landscape Condition Assessment, a remote sensing-based measure of land cover impacted by human activities described in detail above (Table 2). This landscape condition index also served as the basis for modeling connectivity flowlines as described above²⁶. Each mile marker was attributed with the mean of landscape condition values within a half-mile radius.

Risk Assessment

As described above, the carcass data used in this study were not collected consistently, making them useful for exploring patterns but not suitable for statistical inference. We therefore chose not to conduct multiple regression analysis of carcass counts on the above risk factors. Instead, we created coarse categories of values for each risk factor, grouped road segments within these categories, and made simple comparisons of carcass frequencies per mile among categories²⁷.

Risk factor values were divided into “high” and “low” categories based on obvious breaks between values (e.g., 2 lane roads vs. 3-4 lane roads) or were divided at the median of the range of observed values. Total carcass counts across all road segments within each category were then summed and divided by the total mileage within the category, then divided by the number of years sampled (2008-2012) to obtain the frequency of wildlife carcasses per year per mile in each category. We treated these

frequencies as proportions, and calculated 95% confidence intervals (CIs) on each using the uncorrected score method²⁸, which produces asymmetrical CIs to account for boundary issues (proportions and their lower CIs cannot fall below zero) and unequal sample sizes. We then restrict analysis to general comparisons of frequencies across “high” and “low” categories of each risk factor. We compared proportions of all wildlife carcasses as well as frequencies of carnivore carcasses alone.

RESULTS

Alternative Priority Sets for Mitigation

Our assessment of wildlife carcass counts (risk value) versus connectivity value for each mile of major roads in the U.S. Northern Rockies study area indicated that no sites exhibit both high risk value and high connectivity value (Figure 8, Figure 9). Instead, sites tend to have high risk but low connectivity, high connectivity but low risk, or low connectivity and low risk. Therefore, rather than highlighting sites that simultaneously met both risk-based priorities and connectivity-based priorities for mitigation of road impacts on wildlife, we instead identified four alternative priority sets expected to provide opportunities for a variety of practitioners with diverse missions to engage in mitigation for wildlife.

Note that these ‘priority sets’ are not distinctly defined here according to minimum connectivity or risk values. Instead, they are intended to serve as guides for practitioners wishing to identify sites at which to potentially focus mitigation efforts as they consider both connectivity and risk factors. The minimum connectivity value or risk value of a given site that will qualify for consideration of mitigation options will vary depending on practitioners’ perspectives and goals.

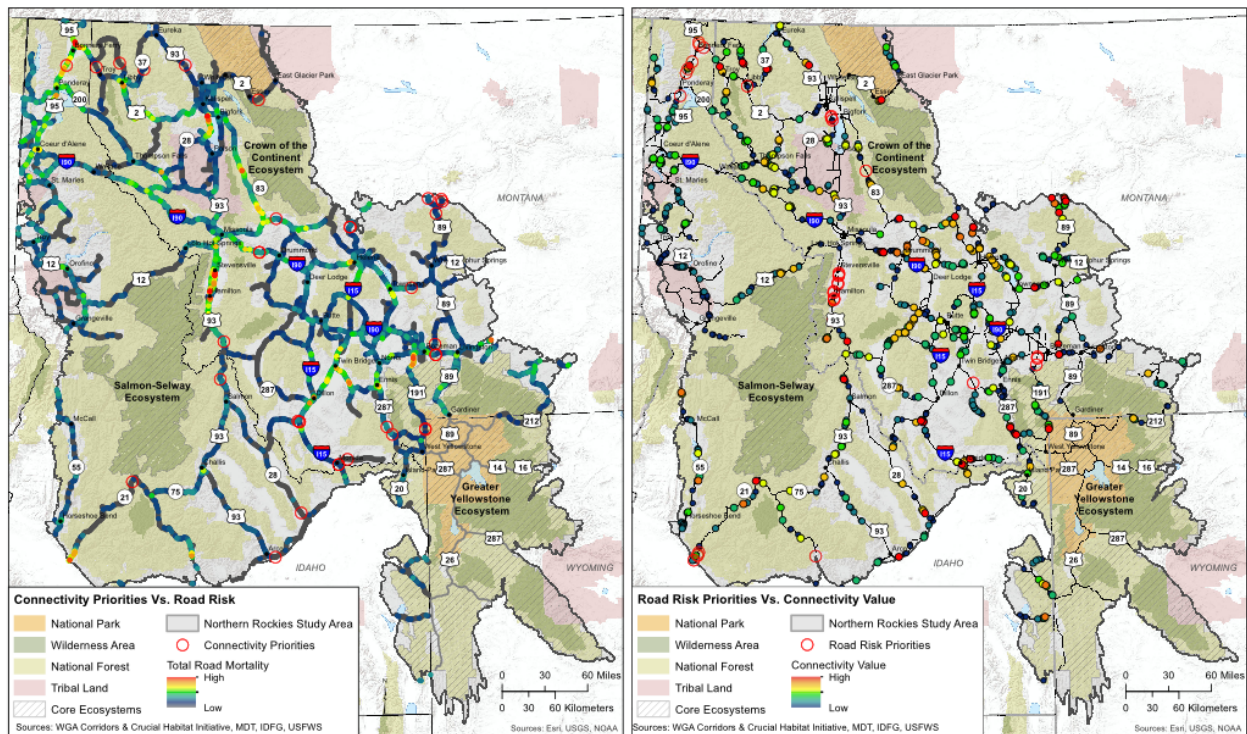


Figure 8. Misalignment of connectivity value and risk, shown as a) sites with highest connectivity value overlaid on road risk and b) sites with highest road risk overlaid on connectivity values.

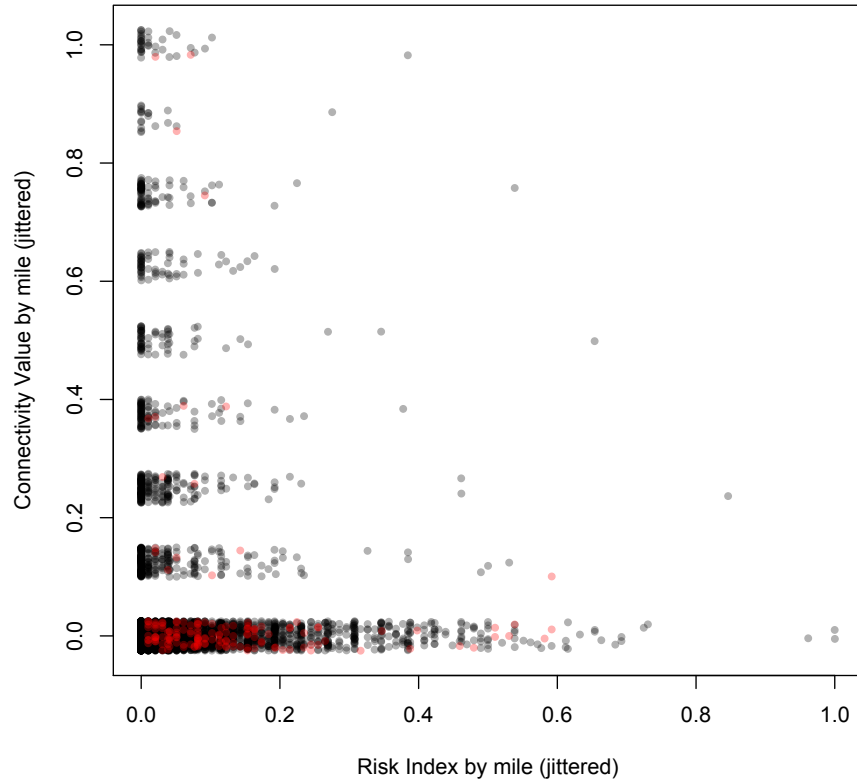


Figure 9. Scatterplot of connectivity value versus road risk value at each mile marker in the U.S. Northern Rockies indicating poor alignment of risk-based and connectivity-based mitigation priorities. Sites with carnivore carcasses are highlighted in red.

Set 1: Low connectivity, high risk

First, we highlight sites that have low predicted connectivity value, but that have high wildlife carcass counts, indicating high risk to wildlife. These sites are generally most likely to be mitigated under DOTs' standard mitigation practices because they are most compatible with balancing DOTs' human safety priority with commitments to mitigating environmental impacts. High carcass counts are expected to correspond to high rates of wildlife-vehicle collisions (WVCs), which present a risk to wildlife as well as human life, limb, and property. High ungulate carcass counts at these sites may also indicate local connectivity value for ungulate migration or daily movement among resources, two movement processes that are not captured in the broad-scale focus of the WGA's connectivity flowlines analysis.

Set 2: High connectivity, low risk

Next, we highlight sites with high connectivity value, but low carcass counts, suggesting little risk to wildlife. It is possible that at some of these sites, the carcass counts are low because animals are avoiding the road and not attempting to cross. However, given that most of these sites are far from major human population centers and have low average annual daily traffic (AADT), it is more likely that these sites are conducive to wildlife movement. Mitigation of these sites is unlikely to be prioritized by DOTs as these road segments do not appear to currently present a human safety or wildlife mortality risk, which are generally higher priorities for mitigation than maintaining connectivity. Instead, these sites are expected to be of interest for federal, state, and potentially county land managers, as well as private land trusts and landscape-scale conservation organizations, aiming to ensure long-term management or protection of adjacent lands to support continued wildlife movement. This is also expected to help ensure that mitigation of the road is possible in the future if necessary.

Set 3: High connectivity, moderate risk

Some sites offer connectivity value as well as presenting some risk to wildlife. While these sites are not among the top hotspots for road-killed wildlife, and thus are less likely than sites in Set 1 to be included as DOT mitigation priorities, mitigation at these sites is expected to offer human and wildlife safety benefits as well as wildlife connectivity benefits. They therefore represent potential common ground opportunities between DOT safety priorities and conservation-focused missions, and are good opportunities for DOTs to fulfill the environmental sensitivity components of their missions in ways that both prevent wildlife mortality and support wildlife connectivity.

Set 4: High connectivity, risk to carnivores

Lastly, because carnivores are often a key management and conservation focus in the Northern Rockies, particularly those listed as threatened or endangered, we highlight potential priorities for mitigating road impacts on carnivores. This set includes sites that offer high predicted connectivity value at which carnivores of management and conservation concern have been killed, including grizzly bears, black bears, mountain lions, and wolves. (Lynx, wolverines, and fishers would also be included in this list, but were not represented in the available carnivore carcass data.)

Spatial Relationship between Connectivity and Risk

Wildlife carcasses tended in general to be found further from road intersections with connectivity flowlines than were random points throughout the study area's major road network. Random points were found a median distance of 5.48 miles from connectivity flowline intersections, while wildlife carcasses were found a median distance of 7.06 miles from flowline intersections. This pattern is likely strongly driven by ungulates, which constitute the vast majority of the carcass dataset. Common ungulate carcasses, including white-tailed deer, mule deer, and elk, were found a median distance of 7.11 miles from flowline intersections. In contrast, carnivore carcasses, including black bears, grizzly bears, mountain lions, and wolves, were found a median distance of 5.78 miles from flowline intersections, a distance that does not differ markedly from that expected by chance (Figure 10). In short, carnivore carcasses tended to be found approximately as far away from road intersections with connectivity flowlines as expected by chance, while ungulate carcasses tended to be found further away from flowlines than expected by chance.

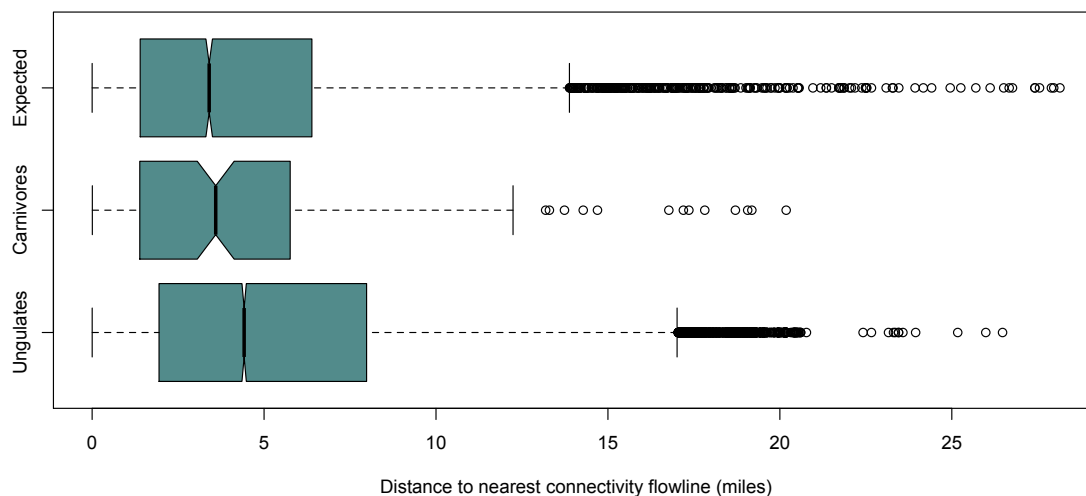


Figure 10. Distribution of ungulate and carnivore carcass distances from nearest connectivity flowlines, as well as distances of random points to illustrate the pattern expected by chance.

Risk Factors

We compared frequencies of wildlife carcasses per year per half-mile of road between “high” and “low” categories of each risk factor for all species and for carnivore carcasses only (Table 3). Calculation of frequencies per half-mile was necessary because in some cases, frequencies per mile were greater than one and therefore could not be treated as proportions for calculation of appropriate confidence intervals.

The frequency of wildlife carcasses per year per half-mile of road was higher among road segments with high annual average daily traffic (AADT) than among segments with few vehicles per day. Carcass frequencies were higher among 3-4 lane road segments than among 2 lane segments, and higher among wide roads than narrow roads. Roads classified as “interstate” or “principal arterial” exhibited higher frequencies of wildlife carcasses per mile than roads classified as “minor arterial” or “major collector”, as did road segments surrounded by high levels of human modification compared to those surrounded by low levels of modification. Carcass frequencies were higher along road segments passing through landscapes with low ruggedness than landscapes with high ruggedness, and were higher among high topographic position than low topographic positions.

Frequencies of carnivore carcasses per year per half-mile of road were higher among high traffic roads than low traffic roads, among 3-4 lane roads than 1-2 lane roads, and among wider roads than narrower roads. Carnivore carcasses were also more frequent along roads classified as “interstate” or “principal arterial” than those classified as “minor arterial” or “major collector” and roads passing through landscapes with high human modification than those surrounded by low modification. In contrast to overall patterns in wildlife carcasses, carnivore carcasses were more frequent in landscapes with high ruggedness than in those with low ruggedness, as well as in low topographic positions compared to high topographic positions.

Table 3. Comparison of carcass frequencies between "high" and "low" risk factor categories for a) all species, and b) carnivores only.

a) All carcasses

Risk Factor	Median Cutoff Value	Low		High	
		Frequency	95% CI	Frequency	95% CI
Traffic Volume	1520 AADT	0.195	0.1905-0.1990	0.492	0.4869 - 0.4975
Surface Width	28 feet	0.212	0.2080 - 0.2165	0.493	0.4877 - 0.4986
Number of Lanes	N/A*	0.324	0.3207 - 0.3280	0.657	0.6426 - 0.6719
Functional Class	N/A**	0.271	0.2659 - 0.2754	0.451	0.4456 - 0.4569
Landscape Modification	0.523 (0-1 scale)	0.276	0.2717 - 0.2812	0.412	0.4069 - 0.4173
Ruggedness	0.172 (0-1 scale)	0.374	0.3692 - 0.3795	0.314	0.3093 - 0.3192
Topographic Position	0.404	0.306	0.3007 - 0.3105	0.383	0.3778 - 0.3881

b) Carnivore carcasses

Risk Factor	Median Cutoff Value	Low		High	
		Frequency	95% CI	Frequency	95% CI
Traffic Volume	1520 AADT	0.0014	0.00101 – 0.00184	0.0035	0.00287 – 0.00414
Surface Width	28 feet	0.0011	0.00076 – 0.00147	0.0039	0.00329 – 0.00470
Number of Lanes	N/A*	0.0023	0.00195 – 0.00270	0.0044	0.00260 – 0.00693
Functional Class	N/A**	0.0015	0.00110 – 0.00195	0.0036	0.00293 – 0.00430
Landscape Modification	0.523 (0-1 scale)	0.0018	0.00142 – 0.00236	0.003	0.00246 – 0.00365
Ruggedness	0.172 (0-1 scale)	0.0014	0.00103 – 0.00186	0.0034	0.00286 – 0.00413
Topographic Position	0.404	0.0033	0.00270 – 0.00394	0.0016	0.00119 – 0.00206

*"Low" includes 2 lane roads, "High" includes 3-4 lane roads

**"Low" includes "Minor arterials" and "Major collectors", "High" includes "Interstates" and "Major arterials"

DISCUSSION

Tradeoffs in prioritizing mitigation opportunities

A leading objective of this study was to identify sites for potential mitigation that would both address human safety concerns and enhance wildlife connectivity where it is expected to matter most. We found no sites that were identified as priorities for both mitigating risk and enhancing connectivity. Instead, sites with high predicted connectivity value tended to be far from populated areas with their associated high traffic volumes, wide roads, and highly modified surrounding landscapes, factors associated with the highest risk to wildlife. This pattern results in generally very different sets of priority sites from the perspectives of mitigating risk versus enhancing connectivity. It also results in a wider variety of opportunities for practitioners and other stakeholders with diverse interests and goals to engage in mitigation for wildlife due to the fact that while few sites are characterized by both high risk and high connectivity value, many sites exhibit some risk and/or some connectivity value. We highlight four distinct sets of potential priority sites, each reflecting unique and complementary stakeholder perspectives.

Spatial Patterns of Risk Versus Connectivity and Risk Factors

Wildlife carcasses tended to be found further from road intersections with connectivity flowlines than expected by chance. While the statistical significance of this difference cannot be assessed given the quality of the data, this pattern agrees with the pattern of poor alignment of risk and connectivity value observed in the above maps (Figure 8) and scatterplot (Figure 9). Assessment of risk factors suggests that wildlife are at greater risk when crossing higher functional class roads (interstate highways and principal arterials) that are wider, have more lanes, and carry higher traffic volumes. These roads may be particularly risky where they pass through highly modified landscapes that experience higher levels of human use.

Roads passing through less rugged landscapes also appear to have greater risk; this is likely the result of higher crossing frequencies in landscapes that are easier for wildlife to travel through, particularly ungulates. Higher risk associated with higher topographic positions in the landscape (ridgelines or edges of high plateaus) is the result of the “high” topographic position category actually being composed of moderate topographic positions due to the skewed distribution of TPI values (Figure 11). Most roads in the study area run through open, flat areas like valley bottoms. At the relatively fine spatial scale at which TPI was calculated (half-mile radius), these areas tend to be assigned moderate topographic positions. Other roads tend to be at low topographic positions (narrower valley or canyon bottoms) rather than at high positions (ridgelines). Therefore, the “low” TPI category consists of truly low values, while the “high” category consists of moderate values associated with broader, flat areas.

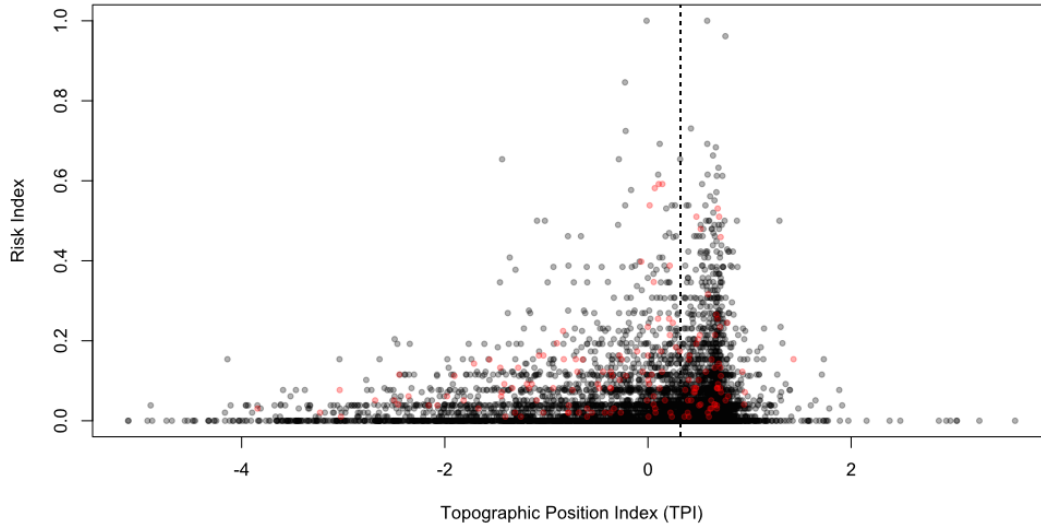


Figure 11. High risk with "high" TPI is actually associated with moderate topographic positions due to the skewed distribution of TPI values; the median (dashed line) marks the cutoff between "high" and "low" categories.

Carnivores are generally understood to be more dependent on intact habitat with low human impacts than are ungulates. It is therefore not surprising that carnivore carcasses tended to be found closer to connectivity flowlines that connect high quality habitat while avoiding human land use footprints than were ungulate carcasses. This pattern is unlikely to be driven by higher risk to carnivores at these sites compared to areas further from flowlines. Instead, we suggest that it is driven by higher rates of carnivore movement and attempted road crossings in the intact areas that flowlines connect compared to areas subject to greater human impacts.

In general, the same patterns in risk factors associated with carcass frequencies for all species were apparent for carnivore carcasses specifically. Carnivore carcasses were more frequently associated with wide, high volume highways in areas experiencing greater human modification. However, carnivore carcass frequencies were higher where roads passed through rugged landscapes at low topographic positions. This is likely the result of carnivores' preference for remote, low human-impact areas that often tend to be more rugged. In these rugged areas, the narrower valleys and canyons that roads pass through may tend to result in lower topographic position values relative to the surrounding landscape.

Opportunities for Stakeholder Engagement

The goal of this analysis is not only to identify potential sites offering worthwhile opportunities for mitigating the impacts of roads on wildlife, but also to highlight ways in which practitioners and stakeholders working in a variety of roles and from a variety of perspectives can engage in the mitigation process. While DOTs will ultimately implement mitigation measures for the roads under their jurisdiction, there are limits to the number and location of mitigation projects that they can take the lead on given their human safety-focused missions and limited funding in the context of competition with other priorities. At the same time, there are a host of ways identified by DOT personnel and other entities working in transportation planning in which partner organizations can contribute to mitigation. We highlight some of those key opportunities here.

Leadership Roles

While many practitioner and stakeholder groups have opportunities to engage in mitigation for wildlife, these measures are ultimately under the purview of, and fall to the discretion and expertise of, those

charged with managing roads. Most high speed, high traffic volume roads in the study area are managed and maintained by state departments of transportation, county road departments, and the Federal Highway Administration. In addition, federal land management agencies such as the U.S. Forest Service, U.S. Fish and Wildlife Service, and Bureau of Land Management are charged with managing the roads on the lands under their jurisdiction. Combined these federal, state and local entities are the ultimate decision makers concerning where, when, and how to mitigate road impacts on wildlife.

Understanding these entities' planning processes, mission-driven priorities, budgetary limitations, and organizational structure can be crucial for outside organizations wishing to engage in the process and contribute expertise, resources, or information in appropriate ways. As public agencies, these agencies are generally open to meeting with and developing working relationships with other practitioners wishing to support wildlife mitigation projects, particularly in ways that fill gaps in the lead agency's capacity (e.g., provision of funding, additional data, advocacy).

Adjacent Land Security Roles

DOTs and other agencies in leadership roles with ultimate responsibility for planning and implementing mitigation measures are unlikely to invest time and resources in a mitigation project, particularly involving construction of a major wildlife crossing structure, if the lands adjacent to the mitigation site are at risk of potential development that would thwart wildlife access to, or use of, the crossing site.

Where a potential mitigation site bisects public land, partnership with agencies responsible for managing those lands (e.g., U.S. Forest Service, Bureau of Land Management, state departments of fish and wildlife) can be crucial for ensuring that adjacent lands are managed to support the long-term connectivity value of a prospective mitigation measure. Adjacent lands might be specifically identified in long range planning documents, such as 20-year federal land management plans or state wildlife action plans, as targets for continued management action that minimizes barriers to wildlife movement to and from the potential crossing site.

Where a potential mitigation site bisects private land, DOTs will rarely invest in mitigation unless the lands are under long-term conservation easement and the owners are amenable to minimizing barriers to wildlife movement through their lands, e.g., via removal of fencing or placement of wildlife-friendly fencing. Therefore, private land trusts and organizations that purchase lands for private conservation efforts or for donation to public land management agencies can play a crucial role in securing high value mitigation sites to allow installation of wildlife mitigation measures on highways.

Advocacy Roles

DOTs and other agencies responsible for road management decisions are responsible for engaging the communities affected by their projects and decisions, as they seek to meet their missions and mandates. Many individuals, and communities at large, may be unaware of the costs and benefits of wildlife mitigation measures. This means that there may be instances of local resistance to the installation of mitigation measures, e.g., crossing structures and associated fencing. Organizations with missions that allow them to engage in advocacy for wildlife may be able to fill an important role in these settings by engaging with local communities, providing information on the benefits of mitigation, and addressing concerns about how mitigation will impact citizens and their properties. Likewise, situations may arise in which mitigation for wildlife is not deemed a priority by agencies managing roads due to the cost of mitigation or competition with other projects for time and resources, yet there is strong public support for mitigation. Advocacy groups may play an important role in these situations as well by organizing citizen advocates, providing a unified voice, and communicating this perspective to lead entities for consideration in mitigation project decisions.

Fundraising Roles

A recent survey of the transportation sector in the Western United States indicated that the leading impediment to implementing highway mitigation for wildlife is lack of sufficient funding, in the context of competition for available funding from other priorities²⁹. DOTs have limited budgets that are likely to be allocated to other types of projects, particularly when the prospective mitigation site does not present a risk to human safety. However, when external funding sources can be secured, DOTs may often be willing and able to work with partners to implement mitigation measures outside of their internally funded project schedule.

Conservation and research grants may be available to nonprofit organizations for which DOTs and other public agencies are not eligible. While some foundations and other funders avoid supporting projects that fall within the purview of public agencies and could be funded by state or federal government budgets, others are more flexible. Some may offer grant opportunities for specific portions of the cost of mitigation, such as securing easements on adjacent lands or monitoring efforts before and after installation of a mitigation measure. A variety of potential sources may be approached depending on whether the prospective mitigation site is on public or private land, whether it is important from a risk perspective or a connectivity perspective, which species are expected to benefit from mitigation, and the region or landscape in which the site is located.

The current transportation act, Moving Ahead for Progress in the 21st Century (or MAP-21)³⁰, was signed into law by President Obama in 2012. Funding surface transportation programs at over \$105 billion for fiscal years (FY) 2013 and 2014, it is the first national transportation law to specifically authorize state, federal, and tribal managers to explicitly allow the use of federal transportation funding to for reduction of wildlife-vehicle collisions and the improvement of wildlife connectivity among habitats disrupted by roads³¹. Although MAP-21 *authorizes* spending on wildlife mitigation, it does not provide additional funding specifically for these projects. Therefore, while the Act succeeds in providing DOTs and other entities with legal justification for directing funds to this purpose, the availability of external funding is still likely to be a key factor in whether mitigation projects beyond those that are most urgent for protection of human safety, or that can be completed as an inexpensive component of an already planned larger project, are pursued.

Research Roles

Often DOTs, wildlife and police agencies are required to collect and manage wildlife-vehicle collision and wildlife carcass data and generally have access to wildlife and habitat data from other agencies. However, time and resources for analysis of these and other data, particularly in pre-planning stages for the purposes of identifying potential mitigation opportunities early, are limited and may tend to be allocated to other research needs of greater priority. Partner agencies or organizations with capacity to collect data or develop models pertaining to wildlife habitat values or road risk to wildlife, or to obtain such resources, can serve a valuable role in providing planning-relevant wildlife information to DOTs.

This information can be provided to DOTs during public comment periods for their plans or projects. State DOTs constantly update their State Transportation Improvement Program (STIP), which identifies locations of upcoming road construction and improvement projects throughout each state. These generally include maps identifying any planned project exceeding a baseline minimum cost estimate and detail the type of work planned as well as the timeframe for its implementation. Draft highway corridor planning studies focusing on a particular section of road are developed on an as-needed basis. These studies identify issues that may require action along the transportation corridor, document existing conditions, conduct an environmental analysis, forecast traffic volumes, develop goals and a statement of needs, and list potential improvements to meet the goals and needs. In both cases, STIPs or Highway

Corridor Plans, external wildlife data or analysis can contribute to identifying potential wildlife impacts of a planned project and identifying potential solutions early so that mitigation can be incorporated into the implementing projects' work plan, timeline and budget.

Both Montana and Idaho DOTs also solicit contract research projects through their Research Programs. Research projects are conducted in partnership with DOT staff and are funded by federal State Planning and Research dollars. These programs provide an excellent opportunity to identify DOT information needs pertaining to mitigation for wildlife and address them in collaboration with DOT staff within the framework of the department's planning process.

Additional Considerations

Some additional specific considerations when engaging in the wildlife mitigation process apply to multiple roles described above. These considerations are listed here, and examples are discussed further in the context of the case study sites detailed below.

- Consider wildlife early in the planning and project processes to identify potential wildlife mitigation sites before project design and development. Keep in mind that DOTs typically work within a 5-10 year advance planning window. Look for draft planning documents for opportunities to file comments and develop collaborative working relationships with DOTs early.
- Build public-private partnerships to identify and accelerate wildlife mitigation opportunities. Meet with DOTs and other potential partnering agency staff to learn about upcoming project timelines, identify wildlife-related information or public outreach needs, flag potential wildlife issues or mitigation opportunities, and begin developing long-term working relationships.
- Look for retrofit opportunities (e.g., widening existing culverts or stream crossings) as potential cost-effective ways of implementing mitigation measures, as well as opportunities to incorporate wildlife mitigation into already planned construction projects. Mitigation is much more likely to be implemented when it can be accomplished affordably given competing priorities and limited funding.
- Identify opportunities for innovative, next-generation crossings that will reduce costs in the longer term without compromising effectiveness (e.g., ARC Solutions³²). Provide funding and incentives for continued development and application of novel, low-cost crossing structure building materials and techniques (i.e., the FHWA's accelerated bridge construction program).
- Maximize coordination of wildlife-vehicle collision, wildlife carcass, wildlife habitat, and other pertinent data collection, analysis, and planning among partner agencies, i.e., transportation, land, and wildlife management agencies. If possible, maintain a dedicated staff position responsible for inter-agency coordination.

MITIGATION OPPORTUNITY CASE STUDIES

We illustrate potential opportunities for mitigation and partner engagement for each of the above priority sets through a series of case studies. These case study sites are *not* necessarily recommended as the top priorities for mitigation road impacts on wildlife in the U.S. Northern Rockies. Rather, they are intended to serve as examples of how the information provided in this report might be used for priority selection and for planning purposes, how some of the opportunities described above might be

applied on the ground, and the impacts of a variety of other considerations that come into play in selecting sites for possible mitigation and designing mitigation solutions for those sites. For each priority set, one site in Montana and one site in Idaho are described (Figure 12).

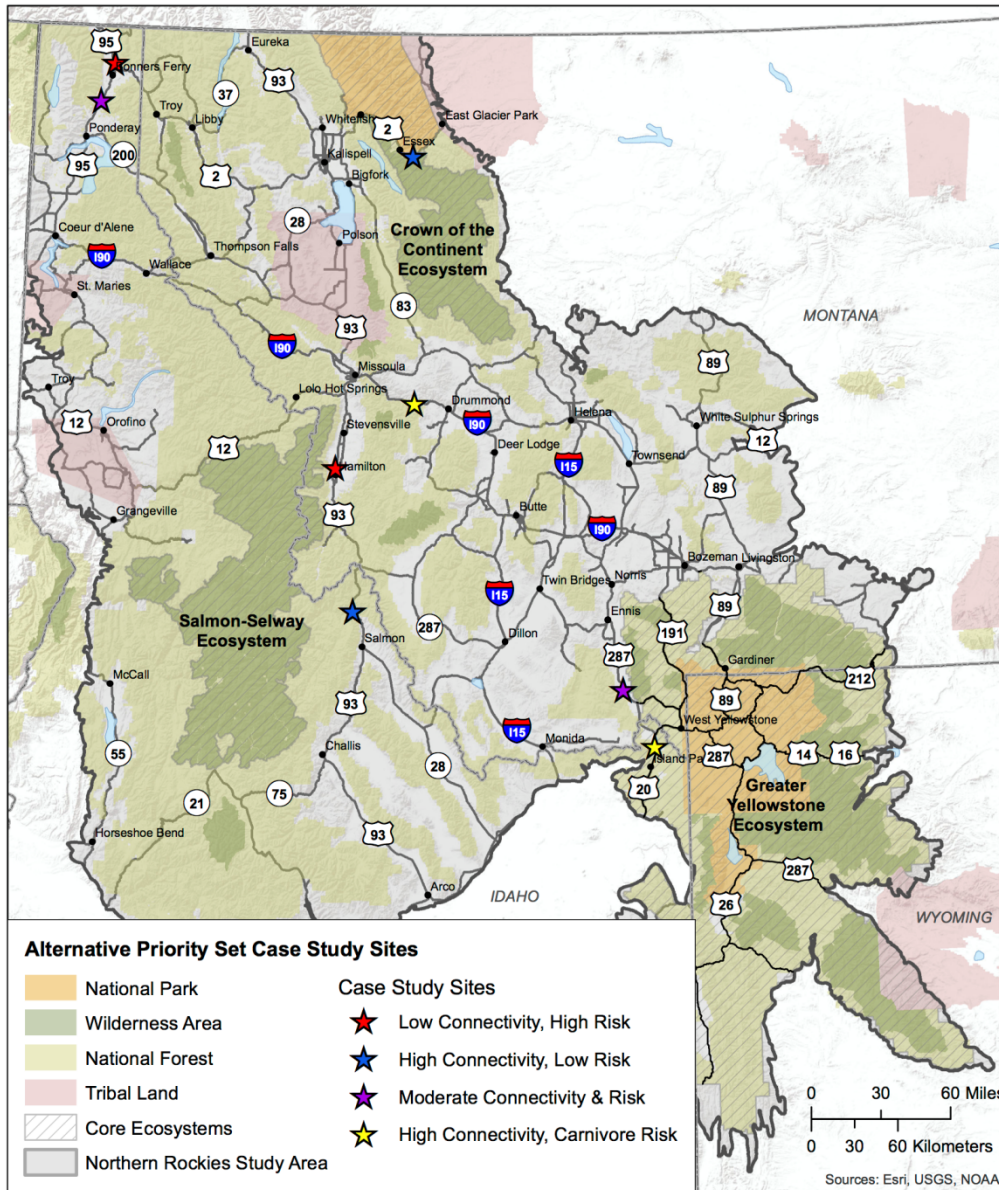


Figure 12. Overview map of case study sites illustrating potential mitigation opportunities from alternative priority sets. These sites are not intended to represent top mitigation priorities, only to provide an illustrative sample.

Set 1: Low Connectivity, High Risk

Site 1a: US-93 milepost 51, between Stevensville and Hamilton, MT (Ravalli County).

This site lies in the Bitterroot Valley south of Missoula, MT, which separates the Sapphire Mountains to the East from the Selway-Bitterroot Wilderness to the West (Figure 13). This road segment is a two-lane, undivided highway with an average daily traffic volume of 9,750 - 16,040 vehicles. Mile marker 51 is attributed with what is by far the highest wildlife carcass count in the entire U.S. Northern Rockies

study area (scaled risk value of 1), with a total of 98 carcasses reported between 2008 and 2012, all of which were white-tailed deer. Much of the stretch of US-93 between Stevensville and Hamilton, along with the adjacent Eastside Highway that parallels US-93 between these towns, exhibits high carcass counts compared to the rest of the study area. No regional connectivity value is predicted for mile marker 51 or any portion of this stretch of highway by the WGA connectivity flowlines model. Instead, flowlines are predicted to circumvent this highly modified, high-traffic portion of the Bitterroot Valley. High rates of attempted deer crossings of this highway may, however, indicate some value of this area for local ungulate movement between the Sapphire and Bitterroot Mountains.

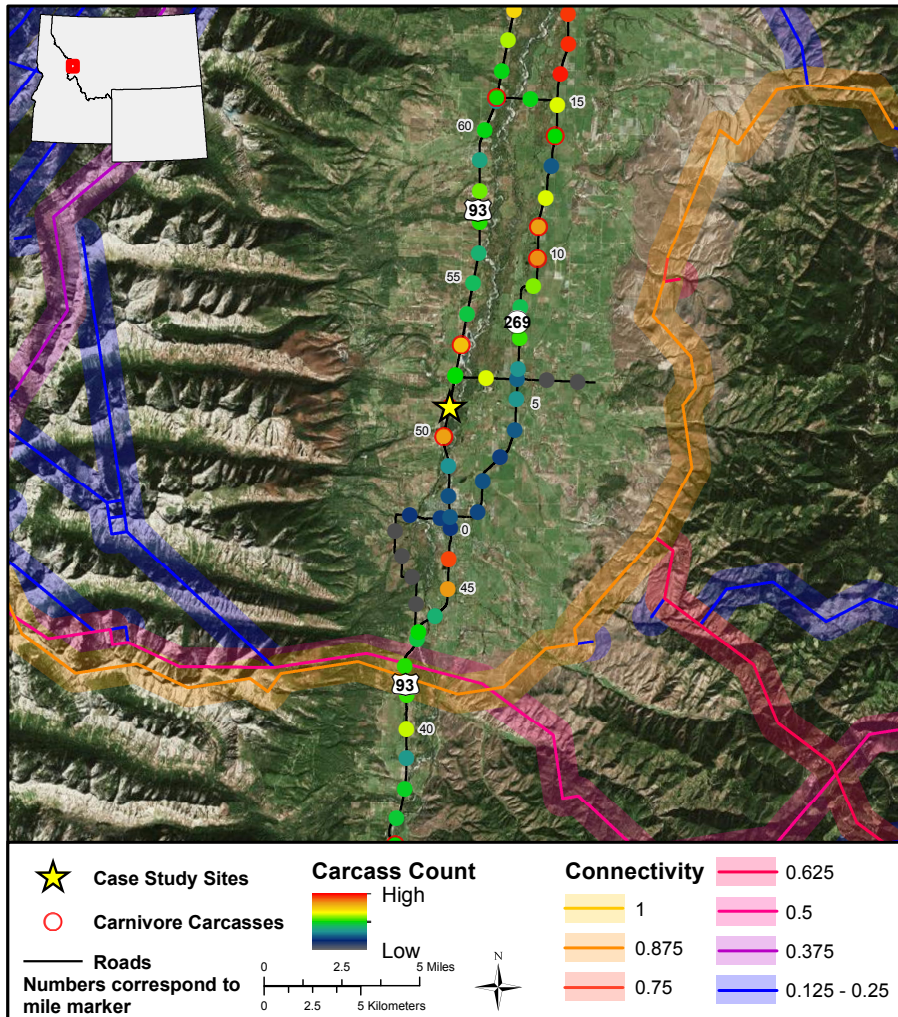


Figure 13. Site 1a, US-93 milepost 51 between Stevensville and Hamilton, MT.

Nineteen wildlife crossings were installed along US-93 between Florence and Hamilton between 2005 and 2012. These consist of bridges, round corrugated steel culverts, and concrete box culverts offering wildlife passage under the highway at stream crossings³³. While monitoring of changes in animal-vehicle collisions between pre-construction and post-construction of crossing structures is ongoing (2008-2015), preliminary kernel density analysis of carcass data distribution over space and time thus far appears inconclusive regarding a reduction in wildlife roadkill following installation of crossing structures (Figure 14). Crossing structures are present at miles 50 and 55, but not at mile 51.

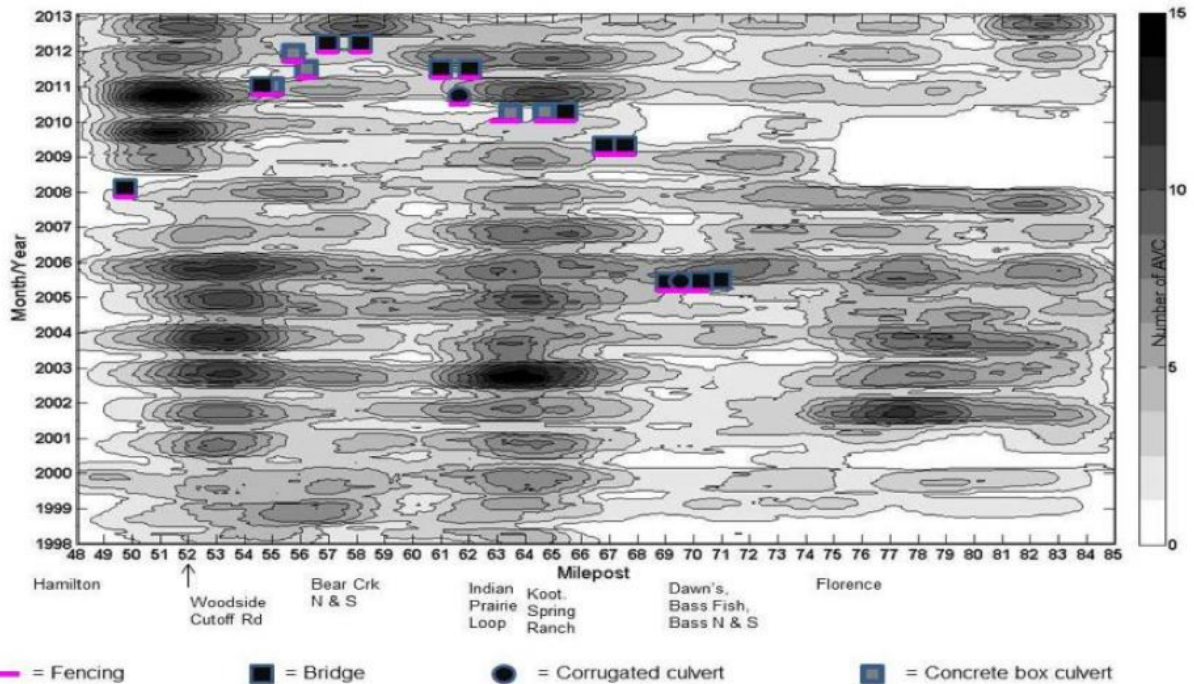


Figure 14. Preliminary kernel density analysis of wildlife carcass data for US-93 S, mileposts 48-85 (1998-2013). Darker spots reflect higher carcass counts. Time and location of wildlife crossing structures are indicated (Cramer & Hamlin 2013).

Field inspection of crossing structures (M. McClure & M. Huijser, June 2013) showed that wing fencing (Figure 15), which serves to guide animals into crossing structures and prevent them from crossing the road surface between structures, is either not present or extends only a short distance on either side of many crossing structures, allowing animals to enter the roadway between structures. Continuous fencing between structures may therefore be a highly effective option for reducing wildlife-vehicle collisions and roadkill at this site and other high-risk sites along this stretch of highway that adds value to existing cross structures at relatively low cost. However, this endeavor is complicated by the presence of many driveways and side roads connecting to the highway. These access points would require additional infrastructure to allow passage of traffic while preventing passage of wildlife (cattle guards with perpendicular fencing; Figure 15), which increase fencing costs and may be met with resistance from residents and business owners who do not wish to see high wildlife fences or cross cattle guards on their properties.

Thus, while the safety risk presented by high rates of wildlife-vehicle collisions (presumably indicated by high wildlife carcass counts) at this site is expected to make it a good candidate for mitigation under the Montana Department of Transportation's (MDT) priorities, and installation of fencing and cattle guards comprises a relatively inexpensive mitigation measure, implementation of these measures may be unlikely to occur without the support of the local community. Other stakeholders may therefore be able to support MDT mitigation efforts by advocating for installation of wing fencing to support safe wildlife passage with local residents and business owners or by working to securing adjacent lands on which fencing is most critical.



Figure 15. Wing fencing and cattle guards with adjacent perpendicular fencing are designed to keep animals from entering the roadway between crossing structures. Photo taken June 2, 2014 by M. McClure at US-93 and St. Mary's Road, Stevensville, MT.

Site 1b: US-95 milepost 514, North of Bonners Ferry, ID (Boundary County).

This site lies in the Idaho panhandle, between large blocks of the Idaho Panhandle National Forest (Figure 16). The road is a paved, two-lane highway with average annual daily traffic volume of 3,000 - 3,500 vehicles. It exhibits the highest wildlife carcass counts in Idaho (scaled risk value of 1), with 26 recorded carcasses between 2008 and 2012, all of which were white-tailed deer. In the past five years, 75% of collisions reported at this site were wildlife-vehicle collisions³⁴. Between Bonners Ferry and McArthur Lake to the south, which provides winter range for deer and elk, more than 320 wildlife-vehicle collisions were reported between 2000 and 2010, which caused two deaths, 36 injuries, and damages estimated at \$4.9 million. This stretch of highway is not predicted to hold any broad-scale connectivity value; all WGA connectivity flowlines skirt the junction of US-95 and US-2 just to the south of this site by 9 miles or more. High rates of attempted deer crossings of this highway may, however, indicate some value of this area for local ungulate movement between adjacent National Forest units.

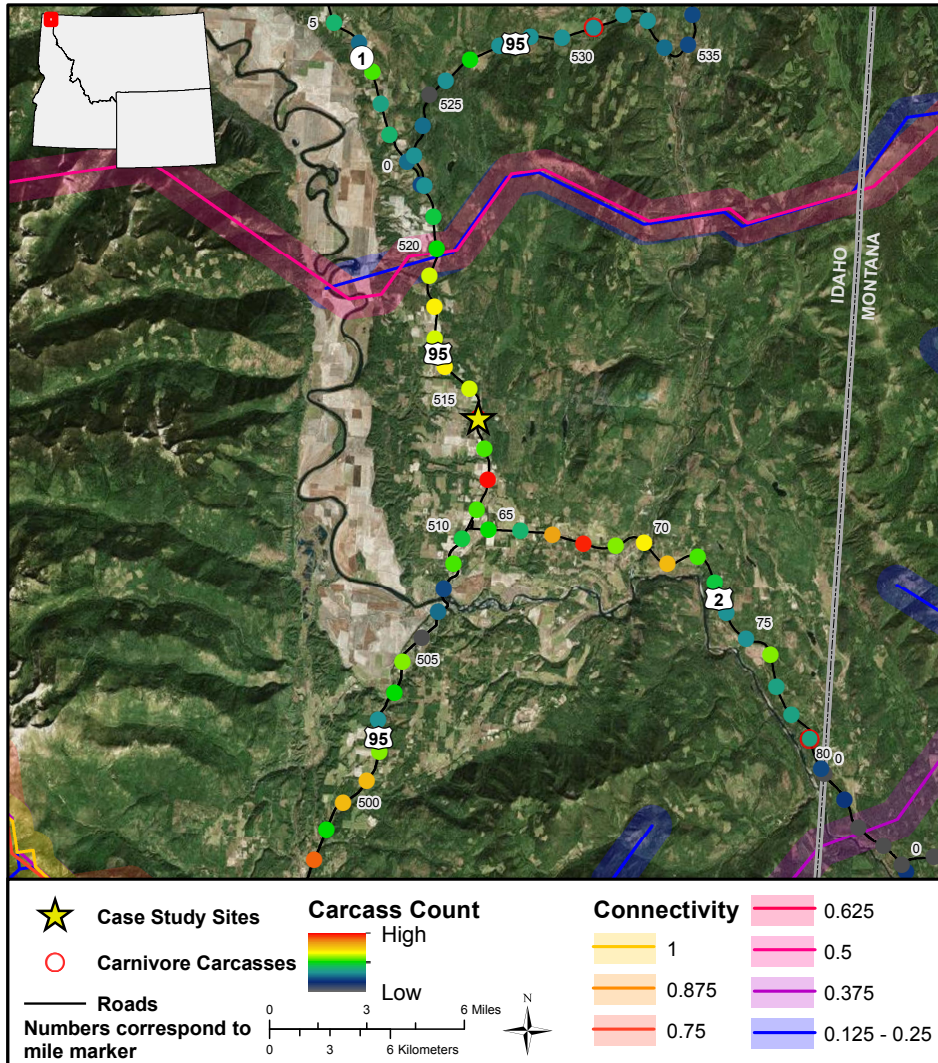


Figure 16. Site 1b, US-95 milepost 514, North of Bonners Ferry, ID.

An animal detection system (ADS), which alerts drivers to the presence of wildlife on or approaching the road (Figure 17), was tested on a nearby segment of US-95 south of Naples from December 2013 to March 2014. In other pilot projects, ADS have been shown to reduce wildlife-vehicle collisions by 85%³⁵, and during the US-95 trial, no animals were struck by vehicles in the detection zone while the ADS was in operation³⁶. The system is now being tested at the case study site North of Bonners Ferry, as well. An ADS is considered advantageous at this site compared to a system of wildlife under- or overpasses accompanied by fencing because the upfront costs are typically lower, the system can be moved or turned off during non-migratory seasons, and fencing miles of road between crossing structures is not considered realistic or appropriate for maintaining wildlife movement in this area.



Figure 17. An animal detection system (ADS), which alerts drivers to the presence of wildlife on or approaching the road (Photo courtesy of Marcel Huijser).

This case study demonstrates the potential for and value of partnerships among stakeholders with diverse perspectives, as well as opportunities for support of mitigation from non-DOT funding sources. There is a 15-year history of cooperative efforts to reduce collisions in Boundary County. This particular ADS monitoring effort represents a partnership between the Idaho Transportation Department, the Nature Conservancy, the Kootenai Valley Resource Initiative, and a private company, Sloan Security Technologies, which developed the ADS. It is funded by a \$100,000 grant from the National Fish and Wildlife Foundation (NFWF) and local funding matches.

Set 2: High Connectivity, Low Risk

Site 2a: US-2 milepost 189, East of Essex, MT (Flathead County).

This site lies on US-2 where it bisects the Crown of the Continent Ecosystem, running narrowly between Glacier National Park to the North and the Bob Marshall Wilderness to the South (Figure 18). The road segment is a paved, two-lane, undivided highway with average annual daily traffic volume of 1,030 - 1,740 vehicles. Two connectivity flowlines intersect the highway closest to this mile marker, with scaled values of 1 and 0.75. Two more flowlines, with scaled values of 0.75 and 0.625, intersect the highway just 1.5 miles to the West. No wildlife carcasses were recorded in this mile or within 6-8 miles in either direction between 2008 and 2012.

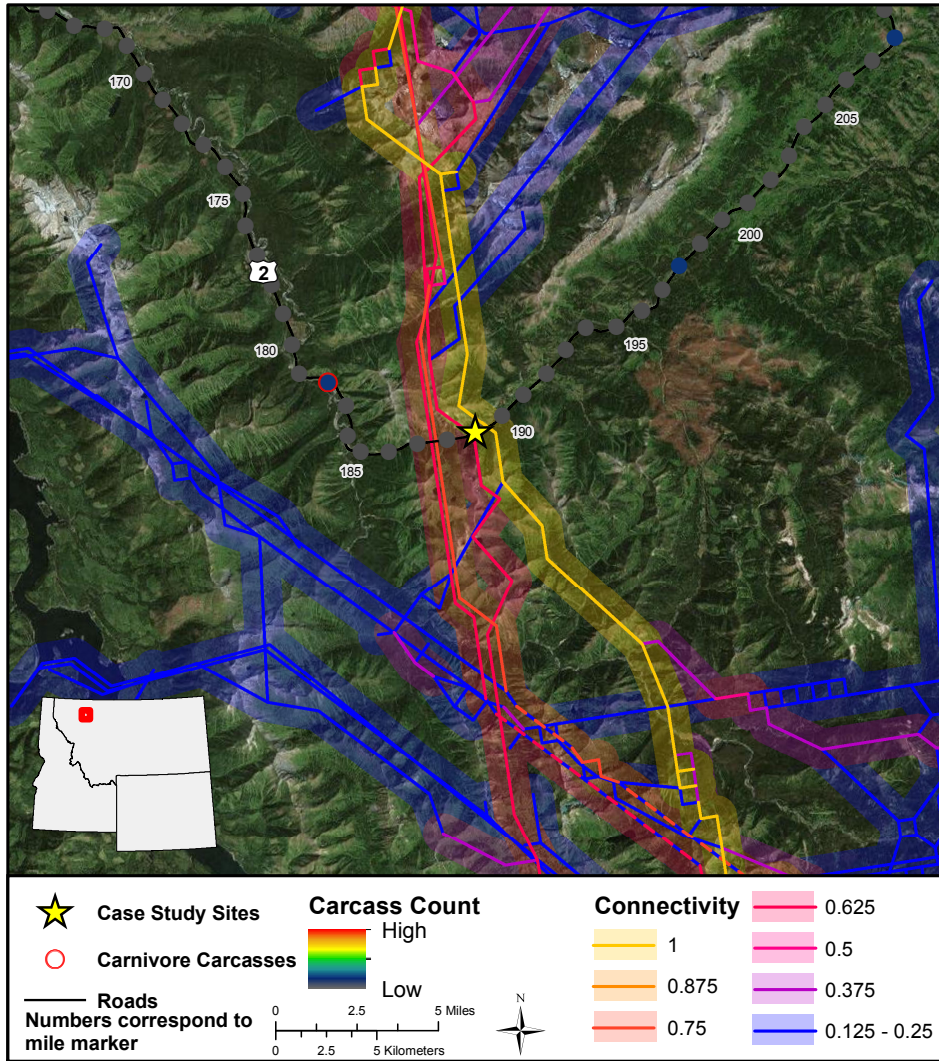


Figure 18. Site 2a, US-2 milepost 189, East of Essex, MT.

A recent study examining potential future traffic impacts on wildlife connectivity in Northwest Montana (Lincoln and Flathead Counties) also highlighted this site as having high potential connectivity value for connectivity of large carnivores and other forest species³⁷. The study overlaid predicted corridors from connectivity models for wolverine, lynx, black bears, and forest generalists with WGA forest biome connectivity flowlines to identify sites predicted by multiple models to be important for connectivity. This case study site was identified as important for wolverine and forest generalist connectivity in addition to forest biome connectivity. A local field study of the presence of wildlife trails crossing the highway between mile markers 153 and 193 further indicated a moderate density of wildlife trails passing within a mile of this site³⁸.

Multiple data sources point to the importance of this site for connectivity between two important large blocks of public land, and this road segment appears to present very little risk to wildlife as measured by carcass counts. Furthermore, lands adjacent to this segment are owned and managed by the National Park Service to the North and the U.S. Forest Service to the South. This site is therefore expected to be of interest to managers of these lands (Glacier National Park and Bob Marshall Wilderness) in developing long-term management plans that maintain the connectivity value of adjacent lands.

Permeability of the road segment bisecting these public lands is, as a whole, expected to be crucial to safe passage of grizzly bear, lynx, and wolverine, which are listed or proposed to be listed as threatened species. Federal funding through the Endangered Species Act may therefore be available for future mitigation of the impacts of US-2 on these species. With projected future increases in traffic volume on this road³⁹, these impacts may include increased road mortality as well as loss of demographic and genetic connectivity⁴⁰. A study of 25 radio- and GPS-collared grizzly bears indicated that bears were most likely to cross Highway 2 in this area at night when traffic levels are low, and hypothesized that traffic volumes greater than 100 vehicles/hour may present a barrier to grizzly movement⁴¹. Traffic projections for this road segment indicate that daytime traffic is likely to exceed this level⁴², warranting early attention to this site in order to take advantage of any opportunities for mitigating future traffic impacts.

Site 2b: US-93 milepost 326, North Fork, ID (Lemhi County).

This site is found in the High Divide, within the unincorporated community of North Fork along US-93 where it bisects the Salmon-Challis National Forest (Figure 19). The road is a paved, two-lane, undivided highway with an average annual daily traffic volume of 900 - 1,100 vehicles. One connectivity flowline with the maximum scaled value of 1 passes through this site, and a second flowline with a scaled value of 0.375 crosses the highway 1.5 miles to the North. Only one mule deer and one white-tailed deer have been killed between milepost 325 and 328 from 2008 and 2012, suggesting low risk at this site.

Although the site is surrounded by National Forest, the lands immediately adjacent to the road are under private ownership, presenting a potential challenge for mitigation opportunities. The highest connectivity flowline runs along the North Fork of the Salmon River directly through the unincorporated community of North Fork, situated at the fork's confluence with the main river. Many wildlife underpasses are located at stream crossings because they can be accomplished by simply widening and reinforcing stream banks beneath the road to allow passage of wildlife (e.g, Figure 20). This may be an option in North Fork.

While portions of forest service land extend very near the road along both flowlines crossing this highway segment, the only continuous public lands corridor between adjacent national forest blocks in this area is along a forest access road at approximately mile 330.6, which is not expected to provide a viable crossing opportunity. No private lands in the area appear to be currently under conservation easement, but private lands conservation may be an avenue worth exploring. The Idaho Transportation Department is unlikely to invest in wildlife mitigation measures unless easements can be secured that span the highway and connect the adjacent blocks of Salmon-Challis National Forest. This site is within the service areas of the Lemhi Regional Land Trust and The Nature Conservancy of Idaho. Our analysis supports prioritization of this site by these groups in order to support wildlife movement across US-93. Adjacent land protections and mitigation of this highway segment is expected to secure a high-value connectivity flowline between national forest lands on a local scale and between the Greater Yellowstone and Salmon-Selway Ecosystems on a regional scale. The Lemhi Regional Land Trust places particular emphasis on conserving river corridors through easements.

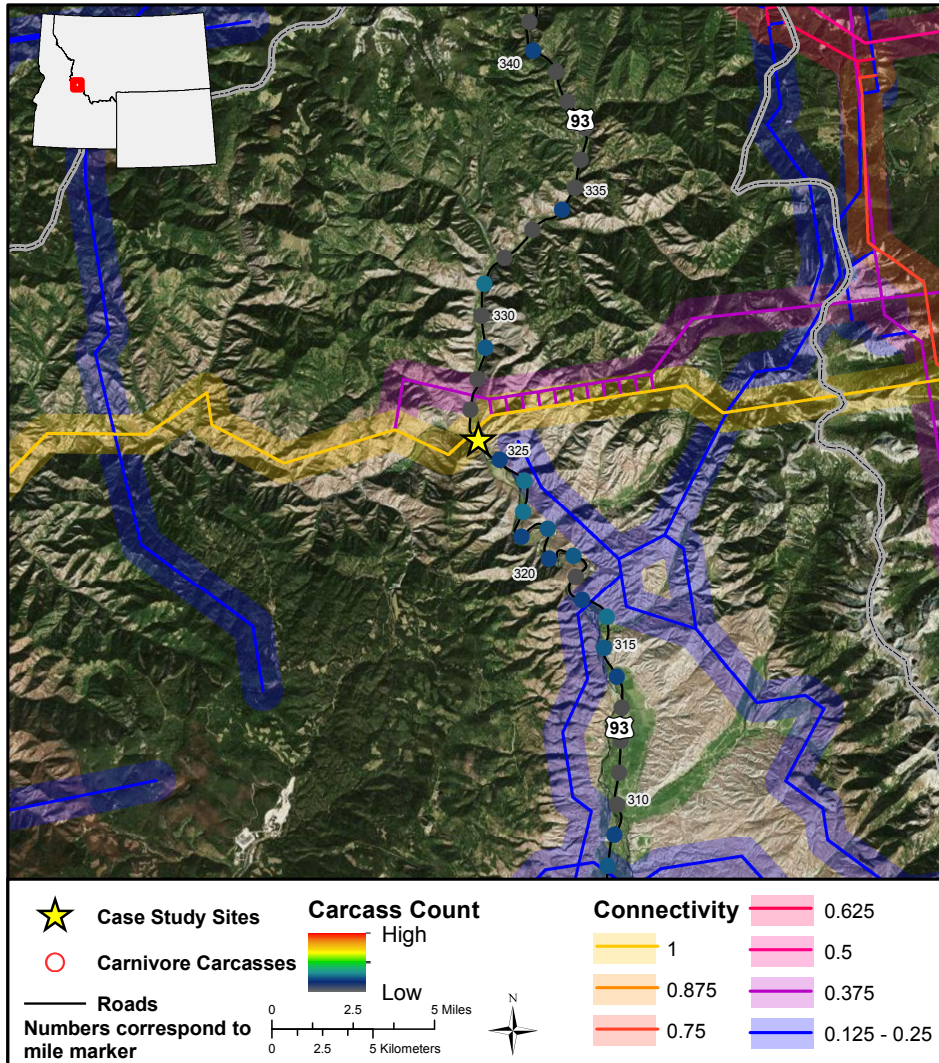


Figure 19. Site 2b, US-93 milepost 326, North Fork, ID.



Figure 20. Example of stream crossing that is also designed as a wildlife underpass. Photo taken June 2, 2014 by M. McClure on US-93 between Hamilton and Stevensville, MT.

Set 3: High to Moderate Connectivity, Moderate Risk

Site 3a: US-287 milepost 17-18, South of Ennis, MT (Madison County).

This site is located on US-287 between Cameron, MT to the North and the junction with US-87 to the South (Figure 21). The site lies west of Yellowstone National Park, between the Beaverhead-Deerlodge National Forest to the West and the Lee Metcalf Wilderness Area within the Gallatin National Forest to the East. This segment of US-287 is a paved, two-lane highway with an average annual daily traffic volume of 950 - 1,490 vehicles. The site has high predicted connectivity value, with three flowlines passing between mileposts 17 and 18 (scaled values of 1, 0.75, and 0.375). It presents moderate risk to wildlife, with 11 recorded carcasses between 2008 and 2012, including elk, mule deer, and white-tailed deer. A black bear was also killed at milepost 19 just north of this site in 2011.

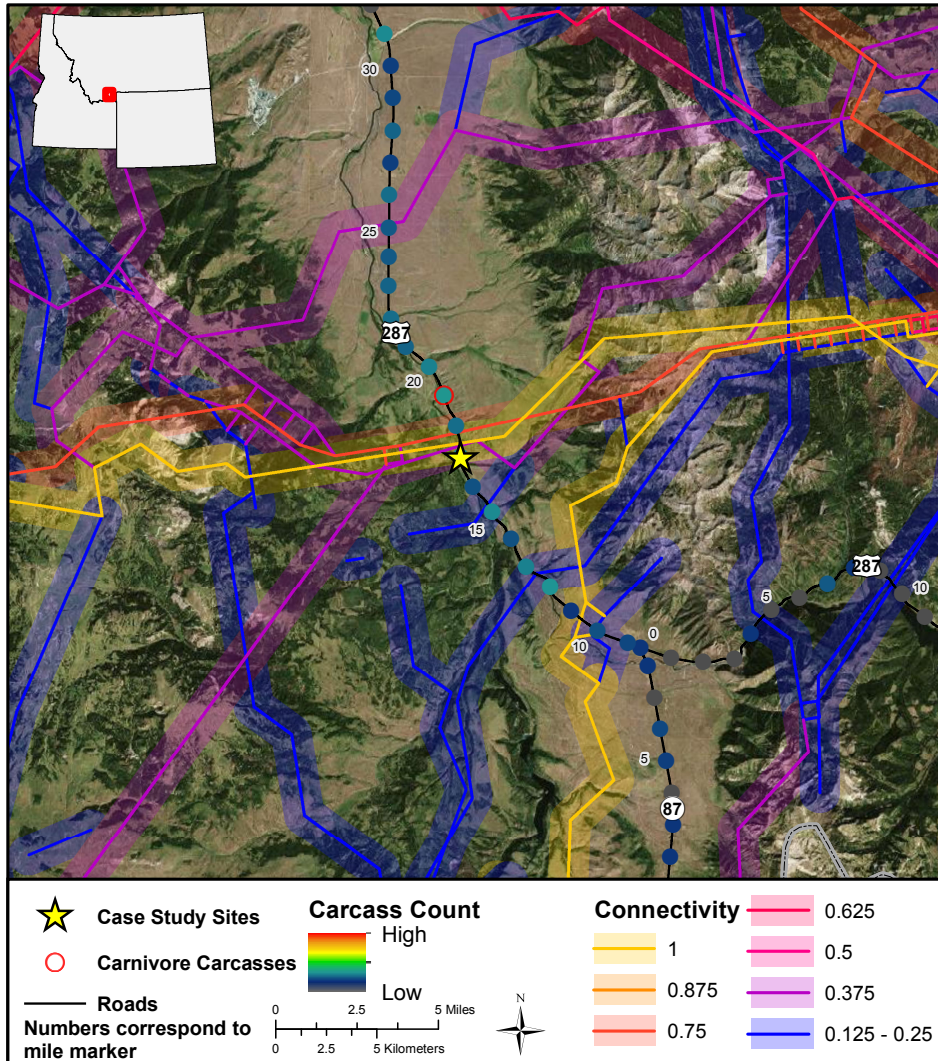


Figure 21. Site 3a, US-287 milepost 17-18, South of Ennis, MT.

Additional studies have indicated high connectivity value at this site. An analysis of habitat quality and connectivity in the Madison Valley conducted by Wildlife Conservation Society in 2005 highlighted this site as the best predicted grizzly bear linkage zone in the Madison Valley⁴³. It is also the site at which core areas of grizzly bear habitat extend closest to the road.

A survey of this site indicated a potential retrofit opportunity to create an underpass for wildlife at mile 18. A small culvert runs beneath the road at this site (Figure 22). If widened, it could provide wildlife passage from a wildlife trail approaching the road from the East to the Madison River to the West. Inspection of the area around the culvert showed evidence of wildlife approaching the culvert (tracks, trails) on both sides. However, in order for MDT to invest in widening the culvert to create an underpass, lands on both sides of the roadway would need to be secure. While the East side of the road is bordered by a large conservation easement from the Sun Ranch to the U.S. Forest Service through the Montana Natural Heritage Program (MNHP), the West side of the road consists of private land. Land trusts working in the area (e.g., MNHP and Montana Land Reliance) may wish to prioritize efforts to work with the landowner(s) to support safe wildlife passage or to potentially secure an easement at this site. Alternatively, mitigation could focus on nearby sites at which lands on both sides of the highway

are secure (e.g., mile 13.7 - 13.8, 21 - 21.4). However, these sites are not predicted to offer high connectivity value and they are far enough removed that it may be unlikely that they would support wildlife movement currently expected to pass primarily through mile 17-18.



Figure 22. Potential retrofit opportunity at site 3a in the Madison River Valley, MT. Photo taken May 24, 2014 by M. McClure at milepost 18.

Site 3b: US-95 milepost 493-495, between Sandpoint and Bonners Ferry, ID (Bonner County).

This site is located just south of Naples, ID on US-95, between Sandpoint to the South and Bonner's Ferry to the North (Figure 23). This section of US-95 bisects large blocks of the Idaho Panhandle National Forest. It is a paved, two-lane, undivided highway, with an average annual daily traffic volume of 5,400 - 6,100 vehicles. The site exhibits high predicted connectivity with three flowlines (scaled values of 1, 0.875, and 0.375) passing through it. It also exhibits moderate risk to wildlife, with 15 carcasses reported in the five-year period of this study. These consisted of white-tailed deer and two moose. One red fox and two coyotes were also killed within 6 miles of the site.

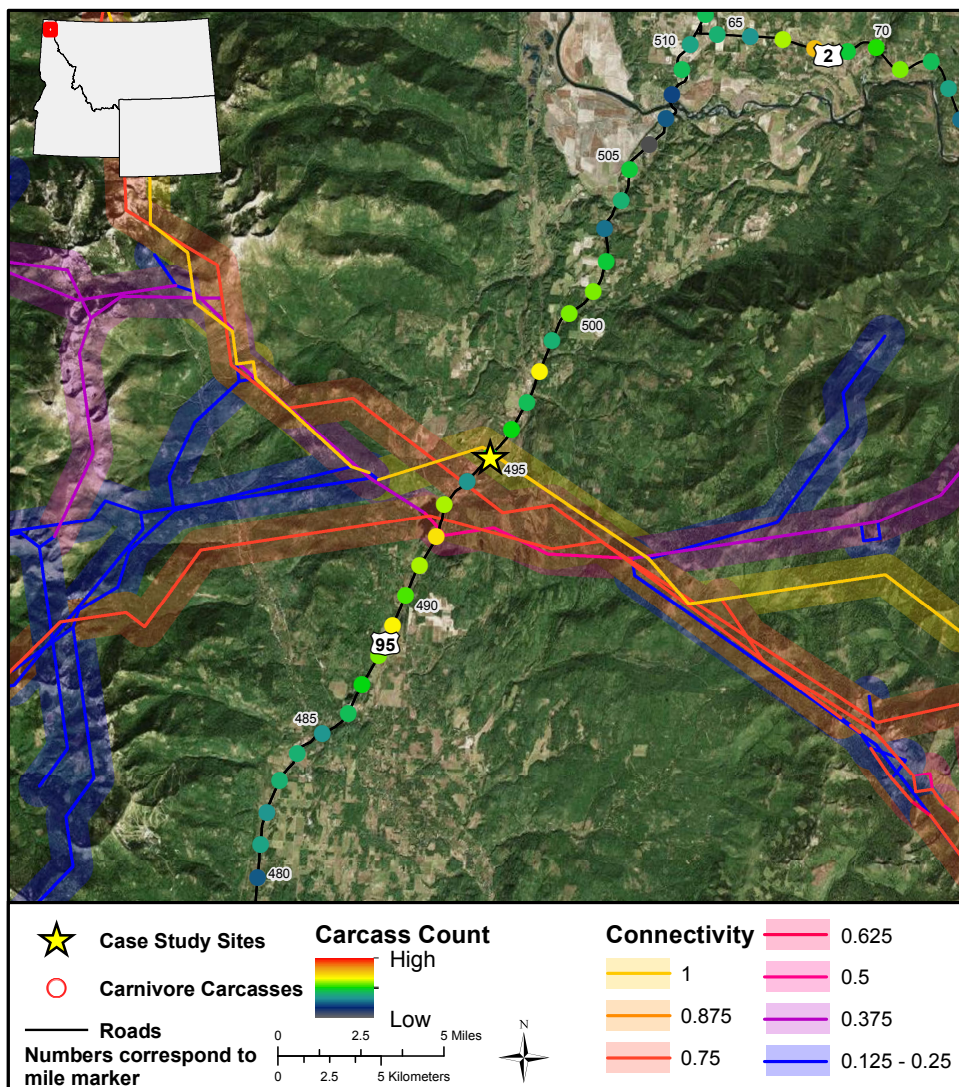


Figure 23. Site 3b, US-95 milepost 493-495, between Sandpoint and Bonners Ferry, ID.

As described under site 1b above, an animal detection system (ADS) was tested on this segment of US-95 south of Naples from December 2013 to March 2014⁴⁴. During this trial, no animals were struck by vehicles in the detection zone while the ADS was in operation. An ADS is considered the best mitigation option for this site because fencing miles of road between crossing structures is not considered realistic or appropriate for maintaining wildlife movement in this area. An ADS also has lower upfront costs and can be moved or turned off during non-migratory seasons. It is not known whether this system will be reinstalled at this site in the future, but the high connectivity value and relatively high risk to wildlife at this site, along with its observed effectiveness, suggests that reinstallation would be highly beneficial for both people and wildlife.

Set 4: High Connectivity, Risk to Carnivores

Site 4a: I-90 milepost 136-138, East of Missoula, MT (Granite County).

This site is found on I-90 between Clinton and Drummond, MT, 30 miles east of Missoula (Figure 24). Here, I-90 separates the Lolo National Forest to the South from the Garnet Mountain Range to the

North. This segment is a paved, four-lane, divided interstate highway with an average annual daily traffic volume of 7,690 - 8,970 vehicles. The site has high predicted connectivity value; a connectivity flowline with a scaled value of 0.75 passes just east of mile 136, and a flowline with a scaled value of 1 passes just east of mile 137. The site presents moderate risk to wildlife, with an average of 17 carcasses recorded for each of the two miles over the five-year study period. Most of these carcasses consisted of white-tailed deer, mule deer, and a few elk. However, a black bear and a mountain lion carcass were also recorded here, along with a second black bear two miles to the East. This relatively high carnivore carcass density suggests high risk to carnivores along this segment.

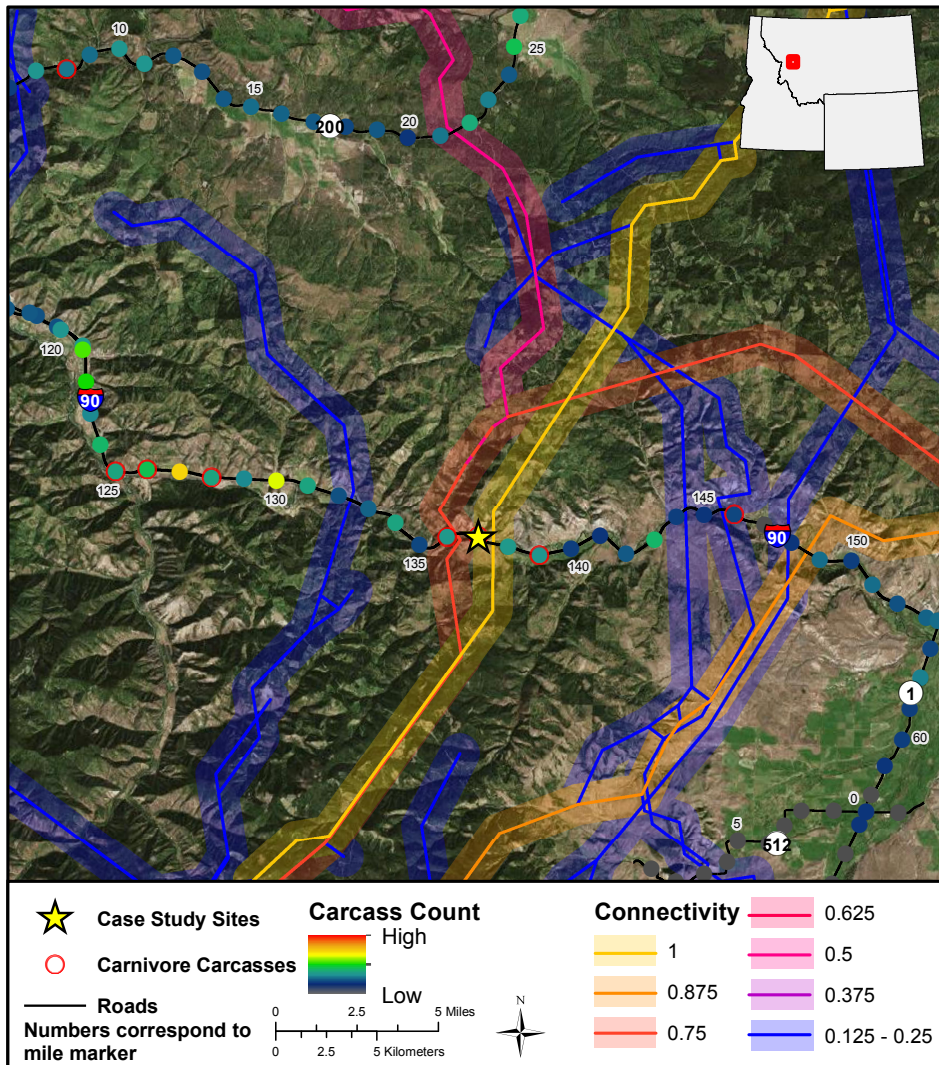


Figure 24. Site 4a, I-90 milepost 137, East of Missoula, MT.

Mitigation opportunities are rather limited at this site. The surrounding topography is not conducive to underpass or overpass installation, and the highway is paralleled by a Montana Rail Link railroad line and the Clark Fork River (Figure 25). Additionally, this site is surrounded by extensive private lands. The only road-adjacent public lands in this area, managed by the Bureau of Land Management and the Montana State Highway Commission, span a narrow segment of the highway at milepost 135.5. The black bear carcass identified above was found at this location. However, mitigation at this precise location does not appear feasible due to the above factors.



Figure 25. Poor opportunities for mitigation at site 4a. Photo taken Oct. 10, 2014 by M. McClure at milepost 136.

The best and perhaps only feasible mitigation opportunity along this segment appears to be where the Clark Fork River passes beneath the highway and the railway at mile 137.4, very near where the highest value connectivity flowline is predicted to cross the highway. Wide road and rail bridges span the river here, and while there are currently only narrow banks on each side beneath these bridges, these could be widened to allow for wildlife passage (Figure 26).

MDT is most likely to be willing to pursue retrofit of this bridge to allow for wildlife movement if adjacent lands are secure. Mitigation at this site may therefore be highly dependent on opportunities for land trusts to work with private landowners to secure conservation easements or other long-term stewardship commitments to support wildlife movement through lands on either side of the bridge. Some lands in this area are under easement with the Five Valleys Land Trust; there may be an opportunity to build on existing relationships to develop long-term plans on critical adjacent lands to support safe passage of wildlife.

We suggest that it may be particularly important in this case study to look beyond a potential highway mitigation site to assess its broader landscape context. Extensive real estate investment holdings lie between this road segment and public lands leading into the Crown of the Continent Ecosystem to the North. If functional connections are to be maintained in the future between this system and the more isolated Salmon-Selway and Greater Yellowstone Ecosystems, capacity should be invested in purchasing key parcels for protection and/or working with developers in these areas to advocate for and design permeable, wildlife-friendly future developments. This may present an excellent opportunity for organizations that work with local stakeholders to make decisions that support healthy communities, productive working lands, and stewardship of wildlands and wildlife (e.g., Future West, Sonoran Institute⁴⁵).



Figure 26. Potential retrofit opportunity at Clark Fork River crossing, site 4a. Photo taken Oct. 10, 2014 by M. McClure at milepost 137.

Site 4b: US-20 milepost 397-398, Henry’s Lake, ID (Fremont County).

This site is located on US-20 just south of Henry’s Lake, between Macks Inn, ID to the South and the junction with SH-87 to the North (Figure 27). This section of US-20 is a paved three-lane (two lanes and passing lane), undivided roadway with an average annual daily traffic volume of 2,700 - 3,400 vehicles. Mile 397 is intersected by a small “tributary” of connectivity with a scaled value of 0.125. This relatively minor flowline is predicted to “collect” potential movement from the Henry’s Lake area and connect it with a major potential linkage zone between the Greater Yellowstone and Salmon-Selway Ecosystems. A second flowline with a value of 0.75 crosses the road three miles to the South and connects with this linkage zone as well. Overall risk to wildlife on this segment is low, but the species composition of carcasses at this site is unique; one pronghorn, one red fox, and one gray wolf have been killed at this site between 2008 and 2012. The area is known to support movement of diverse wildlife, including pronghorn, elk, deer, moose, grizzly bears, and wolves.

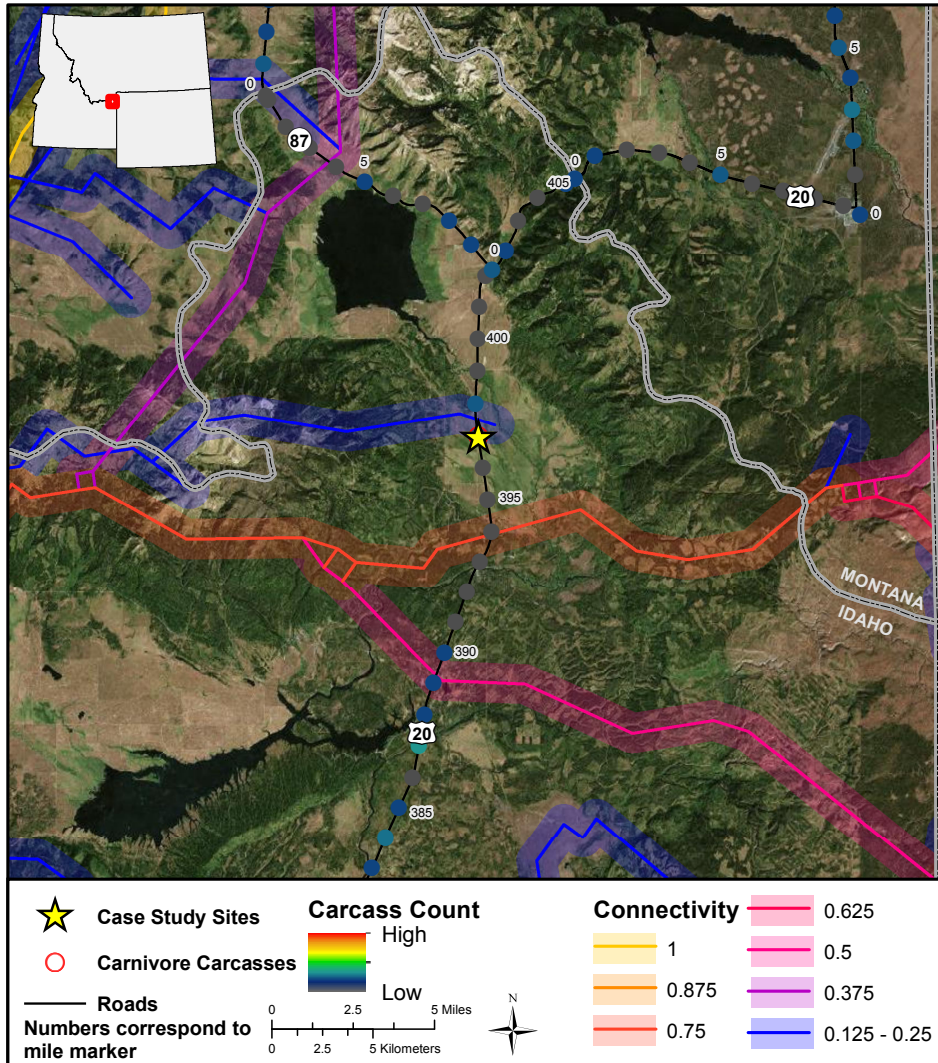


Figure 27. Site 4b, US-20 milepost 397, North of Island Park, ID.

The Henry's Lake community has been active in supporting fish and wildlife passage opportunities. 4,500 acres of land in the area are under easement through The Nature Conservancy, while the Bureau of Land Management has purchased easements on an additional nearly 5,000 acres after designating Henry's Lake as an Area of Critical Environmental Concern. In 2006 the Henry's Lake Foundation, in collaboration with regional non-profit organizations, state agencies, and the Idaho Department of Transportation (ITD), fast-tracked restoration of natural migration passages under SH-87 via Targhee and Howard Creek for Yellowstone cutthroat trout⁴⁶.

While the area currently fosters high levels of movement of many species, it faces high risk of fragmentation as pressure mounts to subdivide ranches for development of second homes and recreation opportunities⁴⁷. This development would bring higher traffic volumes and increase the risk that SH-87 and US-20 present to wildlife.

The most promising opportunity for mitigation of this road segment's future impacts may lie one mile North of the case study site, where the Henry's Lake outlet passes beneath the road. As discussed in previous case studies, stream crossings can be retrofitted relatively easily to provide for safe wildlife

passage and often form a natural conduit for movement. The Henry's Lake outlet crossing is a wide, relatively natural underpass rather than a narrow culvert, and thus may already be conducive to some wildlife movement. Further investigation of this site and the range of wildlife it might support could help determine the extent of any modifications needed at this site to promote safe passage of the full suite of species using this landscape.



Figure 28. Aerial view of potential wildlife passage site where Henry's Lake outlet crosses beneath US-20.

Alternatively, because much of the terrain surrounding this site is open and flat, an ADS may be suitable here. Crossing structures accompanied by fencing do not appear to be a good choice because animals are unlikely to be funneled through any particular site by terrain features and because risk appears to be too low to justify their costs. If installed, the ADS should be calibrated so as to detect wildlife of moderate size (i.e., wolves, pronghorn), not just large-bodied animals.

DECISION SUPPORT TOOL AND DATA PRODUCTS

In order to provide the information presented in this report to practitioners wishing to engage in the process of mitigating road impacts on wildlife and to focus on potential mitigation sites that best meet their priorities, we offer the above data products and guidance in the form of a decision support tool hosted on Data Basin⁴⁸. Data Basin is a science-based mapping and analysis platform that supports learning, research, and sustainable environmental stewardship. It was built to “expand individual and collective ability to develop sustainable solutions by empowering more people through access to spatial data, non-technical tools, and collaborative networks”. It is free to use, and allows users to “explore and organize data and information; create custom visualizations, drawings, and analyses; utilize collaborative tools in groups; publish datasets, maps, and galleries; and develop decision-support and custom tools”.

This project's decision support tool offers the following data layers for online exploration (through Data Basin⁴⁹; Figure 28) and download (through ScienceBase⁵⁰):

- Sites of intersection between connectivity flowlines and major roads
- Total carcass counts and carnivore carcass counts per mile of major road
- Connectivity values attributed to each mile of major road
- Risk factor values attributed to each mile of major road
- Case study locations and details

Reference layers for the U.S. Northern Rockies study area, including major road networks, towns, federal land designations, and core ecosystem boundaries

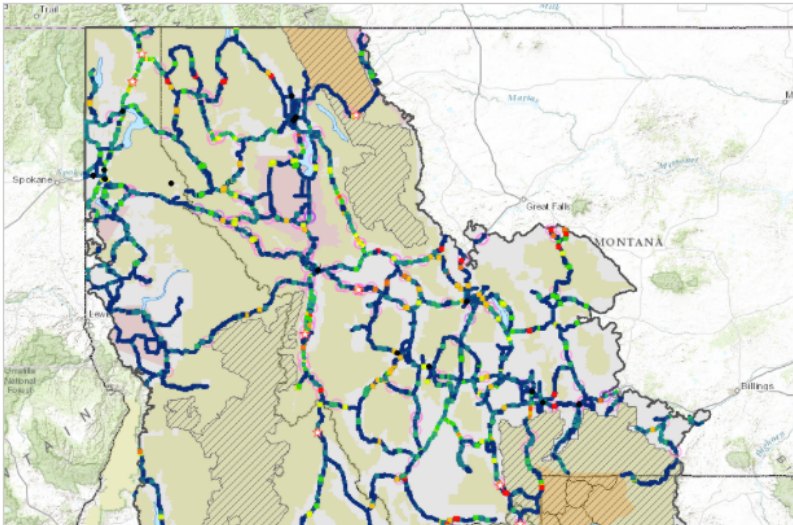
All data layers are accompanied by detailed metadata describing their source, derivation, intended use, and contact information. The layers are expected to be useful for exploring patterns in risk and connectivity values across the study area, as well as for examining risk values, connectivity values, and risk factors present at a particular site of interest. Synopses of project objectives, methods, findings, engagement opportunities, and case studies are also offered.

DATA BASIN | DATASETS | DECISION SUPPORT FOR PRIORITIZING MITIGATION OF ROAD IMPACTS ON WESTERN GOVERNORS' ASSOCIATION WILDLIFE CORRIDORS

Decision Support for Prioritizing Mitigation of Road Impacts on Western Governors' Association Wildlife Corridors

Uploaded by: Meredith McClure Aug 13, 2014 (Last modified Nov 5, 2014)

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Description
This map service was developed to provide decision support for prioritizing opportunities to mitigate the impacts of roads on wildlife connectivity in the U.S. Northern Rockies. It provides spatially explicit information pertaining to modeled wildlife connectivity value across major roads, total wildlife mortality counts along major roads, carnivore mortality counts along major roads, the extent to which wildlife connectivity value and road mortality align, and potential priority sites for mitigation of road impacts on wildlife from diverse stakeholder perspectives.

In the report accompanying this map document, we also discuss potential opportunities for diverse stakeholders (including departments of transportation, state and federal land managers, land trusts, citizen groups, and conservation organizations with a variety of missions) to engage in and contribute to the mitigation process, which are highlighted through a series of case studies.

The report can be downloaded here:
www.largelandscapes.org/library
www.sciencebase.gov/catalog/folder/53d7d5d7e4b06f0f87b74285

Figure 28. Screenshot of the project's web-based decision support tool available via Data Basin.

CONCLUSIONS

We hope that this report and its associated decision support tools aid practitioners working in the U.S. Northern Rockies to engage in mitigation of road impacts on wildlife connectivity and to do so where it matters most to each practitioner's unique perspective and goals. We also hope that this approach can serve as a template for others wishing to prioritize mitigation efforts in different geographies or based on different datasets. For example, connectivity models have been developed for wolverine⁵¹, black bear⁵², lynx⁵³, and grizzly bear⁵⁴ in portions of the Northern Rockies. These models could replace or be

used in conjunction with the multi-species connectivity flowlines that we focus on here in a similar analysis to identify priority sites for species-specific connectivity. The analysis we present could also be applied elsewhere in the 16 Western states included in the WGA's connectivity analysis, or in other regions where alternative connectivity assessments are available.

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