Wildlife Mitigation Opportunities along U.S. Hwy 2, Northwestern Montana

by

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FINAL REPORT

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DISCLAIMER

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16. Abstract
This report explores wildlife issues along U.S. Highway 2 in Northwestern Montana between the Idaho/Montana border and Kalispell. It details the identification and prioritization process of hotspots for wildlife-vehicle collisions based on crash and carcass removal data. In addition, the report lists road sections that may be of special concern to biological conservation based on carcass removal data for rare, threatened or endangered species and important wildlife habitat. The report also contains cost-benefit analyses for selected mitigation measures to explore for which road sections it may be more costly to do nothing than to implement effective wildlife mitigation measures.

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EXECUTIVE SUMMARY

This report explores wildlife issues along U.S. Highway 2 in Northwestern Montana between the Idaho/Montana border and Kalispell. It details the identification and prioritization process of hotspots for wildlife-vehicle collisions based on crash and carcass removal data. These collision data are dominated by large mammal species that are of concern to human safety. In addition, the report lists road sections that may be of special concern to biological conservation based on carcass removal data for rare, threatened or endangered species and important wildlife habitat. The report also contains cost-benefit analyses for selected mitigation measures to explore for which road sections it may be more costly to do nothing than to implement effective wildlife mitigation measures.

The data also showed that there was only partial overlap in the road sections that are a concern for human safety and those that are a concern for biological conservation. This means that there are also road sections that are only a concern for human safety and other road sections that are only a concern for biological conservation. This is important as it illustrates that a mitigation strategy that focuses on human safety may identify different road sections than a process that focuses on biological conservation. The researchers do not suggest that one strategy is better than the other. The data merely illustrate that the departure point for the analyses (human safety versus biological conservation) has, at least partially, different outcomes.

The dominating current practice in North America is to select road sections with a concentration of wildlife-vehicle collisions and to then mitigate these road sections with fencing and crossing structures. Our study illustrated that mitigation measures at the crash and carcass hotspot in typically also benefit biological conservation. However, with the current dominating practice, mitigation is never discussed for the vast majority (in our case 93%) of the road sections that are of concern to biological conservation. This has important consequences for organizations whose mission includes promoting measures that benefit biological conservation. Rather than assuming that mitigation along road sections that have a concentration of wildlife-vehicle collisions will also sufficiently benefit biological conservation, a separate strategy may be required to implement mitigation measures along highway sections that are of greatest concern for biological conservation.

1. INTRODUCTION

1.1. Background

Wildlife-vehicle collisions affect human safety, property (damage to vehicles) and wildlife. The total number of large mammal–vehicle collisions has been estimated at one to two million in the United States annually (Conover et al,. 1995; Huijser et al., 2009). These collisions were estimated to cause 211 human fatalities, 29 000 human injuries, and over one billion US dollars in property damage annually (Conover et al., 1995). More recent estimates that include costs associated with human injuries and human fatalities estimate the yearly costs associated with wildlife-vehicle collisions between 6-12 billion US dollars (Huijser et al., 2009). In most cases, the animals die immediately or shortly after the collision (Allen & McCullough, 1976). In some cases, it is not just the individual animals that suffer. Road mortality may also affect some species on the population level (e.g., van der Zee et al., 1992; Huijser & Bergers, 2000), and some species may even be faced with a serious reduction in population survival probability as a result of road mortality, habitat fragmentation, and other negative effects associated with roads and traffic (Proctor, 2003, Huijser et al., 2007). In addition, some species also represent a monetary value that is lost once an individual animal dies (Romin & Bissonette, 1996; Conover, 1997).

U.S. Highway 2 in Northwestern Montana between the Idaho/Montana border and Kalispell is considered a human safety as well as a biological conservation concern because of wildlife-vehicle collisions and the barrier effect of the road for wildlife (Ament et al., 2014; Proctor et al., 2015).

1.2. Project Goals and Objectives

This project is at the request of the Yellowstone to Yukon Conservation Initiative (Y2Y). The project aims to explore wildlife issues along U.S. Highway 2 in Northwestern Montana between the Idaho/Montana border and Kalispell (Figure 1).

This project focuses on the following:

- Identification of potential hotspots for wildlife-vehicle collisions based on crash and carcass removal data. Note that these data are dominated by large mammal species that are of concern to human safety.
- Identification of road sections that may be of special concern to biological conservation (i.e. rare, threatened or endangered species).
- Identification of road sections where the implementation of mitigation measures may be financially most attractive.
- Prioritization of road sections that may qualify for the implementation of mitigation measures based on human safety, biological conservation and economics.

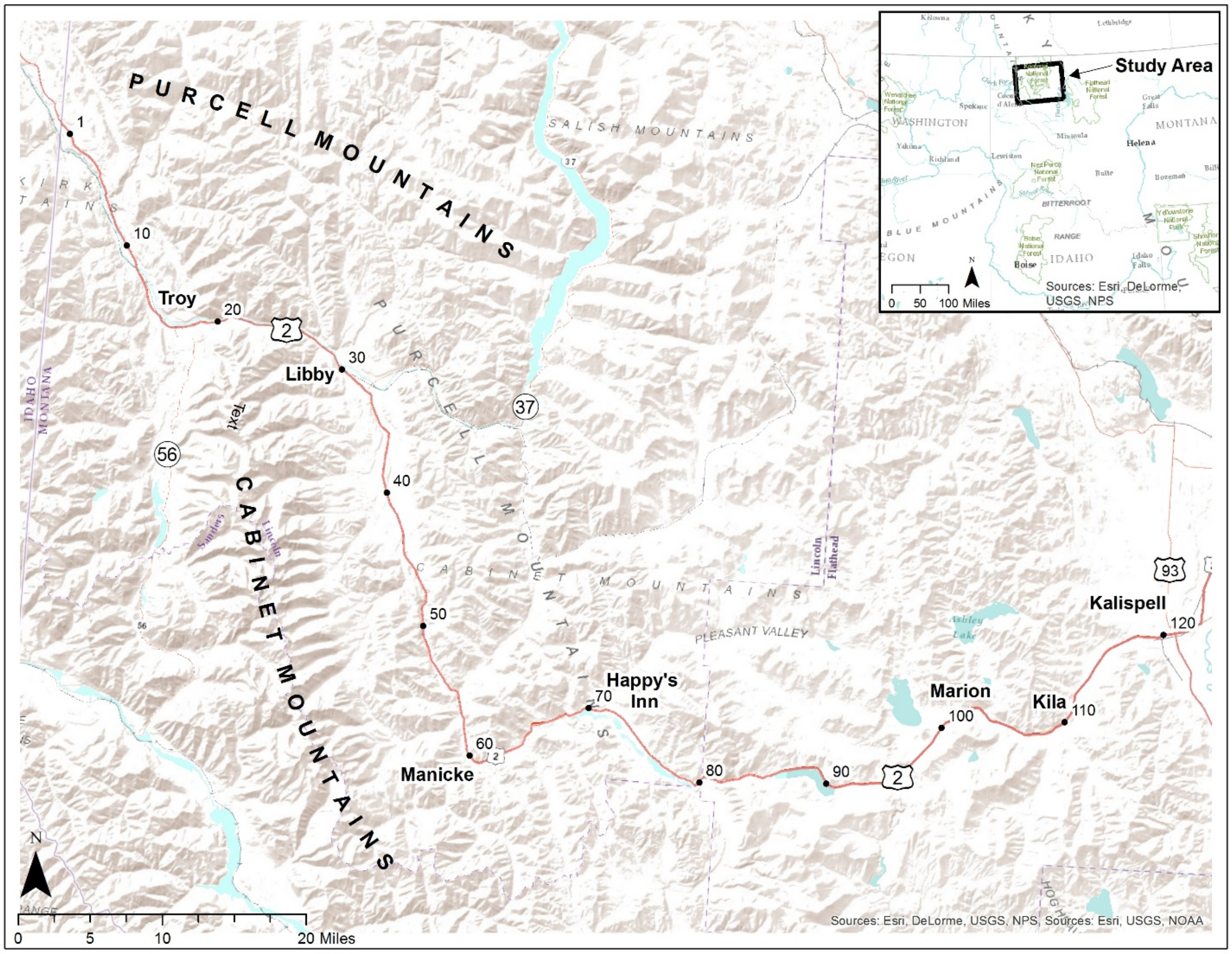

Figure 1: U.S. Highway 2 (including mile reference posts at 10 mi intervals) in Northwestern Montana between the Idaho/Montana border and Kalispell, Montana, USA.

2. DEFINE PROBLEM AND DECIDE ON APPROACH

2.1. Define the Problem

In North America wildlife mitigation measures along highways are often primarily based on wildlife-vehicle collision data and a desire to improve safety for humans. Along most roads in North America there are two types of wildlife-vehicle collision data:

- Crash data: These data are typically collected by law enforcement personnel. For a crash to be entered into the database there is often a threshold (e.g. minimum estimated vehicle repair cost at least US $1,000) and/or human injuries and human fatalities (Huijser et al., 2007). Forms for crash data typically allow law enforcement personnel to note that the collision related to an animal, but in most cases the species involved is not indicated.
- Carcass removal data: These data are typically collected by road maintenance crews when they remove carcasses of large mammals that are on the road or that are very visible from the road in the right-of-way and that are an immediate safety hazard or a distraction to drivers (Huijser et al., 2007). Note that carcass removal data or carcass observation data are sometimes also collected by personnel from natural resource management agencies, researchers, or the general public (Paul et al., 2014).

Both types of data tend to relate to large mammals only; medium sized and small sized mammals and other species groups such as amphibians, reptiles and birds are usually inconsistently recorded or not recorded at all (Huijser et al., 2007). Furthermore, crash data typically represent only a fraction (14-50%) of the carcass data, even if both data sets relate to large mammals only (Tardif and Associates Inc., 2003; Riley & Marcoux, 2006; Donaldson & Lafon, 2008). Finally the carcass data are far from complete as well; animals that are not very visible (e.g. small species or large species that may be in the vegetated right-of-way) may not be removed and do not get recorded. Wounded animals that make it beyond the right-of-way fence before they die are also usually not recorded at all. If only wildlife-vehicle collision data are used to identify and prioritize locations along highways that that may require wildlife mitigation measures, then the concern is typically primarily with human safety and reducing collisions with large mammals, specifically the most common ungulates such as white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*) and moose (*Alces alces*).

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

While there is much emphasis on mitigating for wildlife-vehicle collisions in North America, crashes, dead animals, and associated costs and risks to humans are not the only reason mitigation for wildlife along highways may be considered. The authors of this report distinguish five different categories of effects of roads and traffic on wildlife (Figure 2):

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

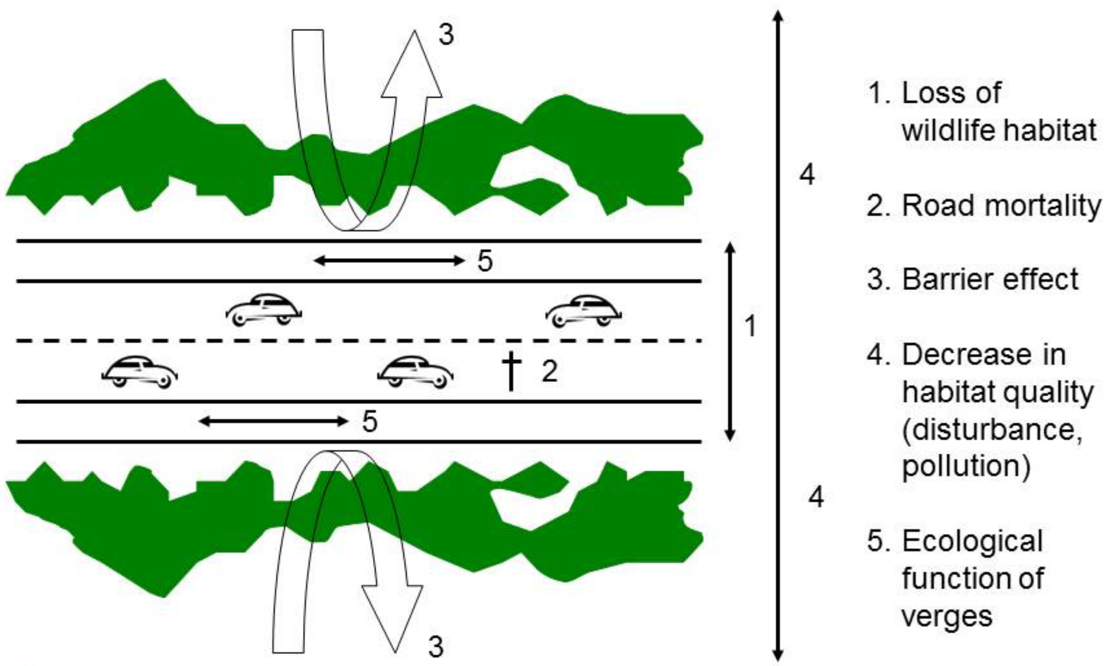

Figure 2: The effects of roads and traffic on wildlife.

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

2.2. Decide on the Approach: Avoidance, Mitigation, or Compensation

While mitigation (reducing the severity of an impact) is common, avoidance is better and should generally be considered first (Cuperus et al., 1999). For example, the negative effects of roads and traffic may be avoided if a road is not constructed, or the most severe negative effects may be avoided by re-routing away from the most sensitive areas (Figure 3). If the effects cannot be avoided, mitigation is a logical second step. Mitigation is typically done in the road-effect zone (Figure 3) and may include measures aimed at reducing wildlife-vehicle collisions and reducing the barrier effect (e.g., through providing for safe wildlife crossing opportunities) (Huijser et al., 2008; Clevenger & Huijser, 2011). However, mitigation may not always be possible or the mitigation may not be sufficient. Then a third approach may be considered: compensation or mitigation off-site. Compensation may include increasing the size of existing habitat patches, creating new habitat patches or improving the connectivity between the habitat patches that would allow for larger, more connected, and more viable network populations. Finally, in some situations a combination of avoidance, mitigation, and compensation may be implemented.

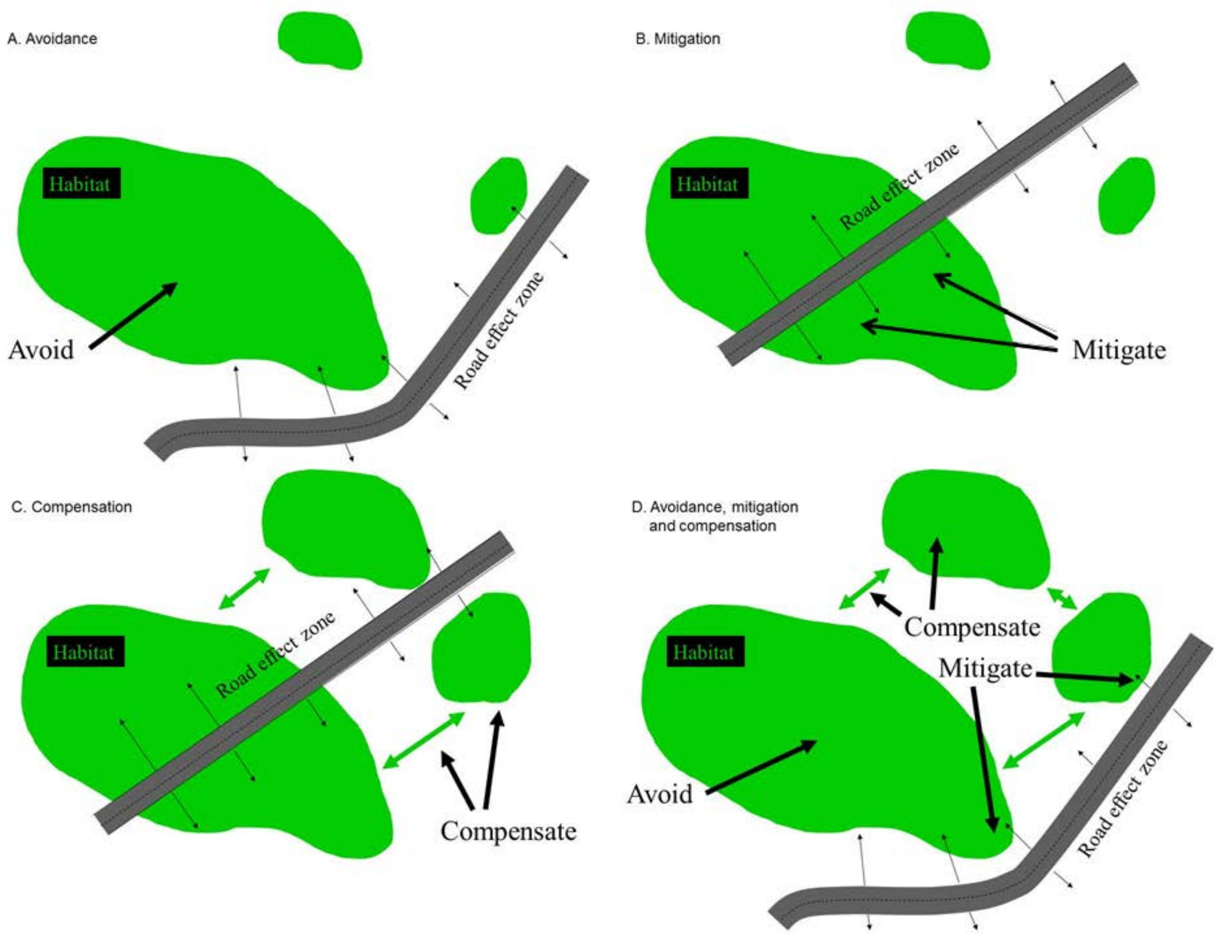

Figure 3: A three step approach: A. Avoidance, B. Mitigation, C. Compensation, D. Combination of avoidance, mitigation and compensation.

2.3. Project Specific Approach

For the current project the problem, as defined by the Yellowstone to Yukon Conservation Initiative, is the high number of collisions with large mammals, the associated risks for human safety, and the ability for large mammals, specifically rare, threatened or endangered species, to cross highways. In this case the highway of interest is U.S. Hwy 2 between the Idaho/Montana border (west) and Kalispell (east).This report describes the procedures used to identify and rank wildlife-vehicle collision hotspots based on human safety (Chapter 3), biological conservation (Chapter 4), and economic parameters (Chapter 5), and the overall prioritization of the hotspots (Chapter 6).

3. WILDLIFE-VEHICLE COLLISION HOTSPOTS

3.1. Identify Wildlife-Vehicle Collision Data Sources and Select Data

The researchers used two datasets to identify wildlife-vehicle collision hotspots:

1. Wildlife-vehicle crash data reported by law enforcement personnel from the Montana Highway Patrol.
2. Carcass removal data reported by maintenance personnel from the Montana Department of Transportation.

The following records were selected from the two datasets: Observations from 1 January 2005 – 31 December 2014 (10 years). The time period was the exact same for the two datasets so that the wildlife-vehicle collision hotspots can be compared between the two datasets. Note that only selecting data for the last one or two years may better indicate where wildlife-vehicle collisions occur currently. However, a spatial pattern that is based on one or only a few years may not be very robust and may misidentify true collision hotspots over a longer time period. On the other hand, if several decades' worth of data is used, the hotspot analyses may identify road sections where collisions were concentrated in the past rather than where they occur now. This not only relates to the changes to the road or in the right-of-way, but also, perhaps even especially, to changes in the surrounding landscape. Though there is no general rule on this matter, around 10 years' worth of data appears to be a good balance between being able to identify current or recent hotspots vs. having a robust dataset to minimize the likelihood of misidentifying hotspots.

3.2. Evaluate Search and Reporting Effort

For the data analyses described in the following section (hotspot analyses) the researchers assumed that the search and reporting effort between the different road sections was consistent. If the search and reporting effort varies between road sections, it may not be appropriate to use the data to investigate if there are concentrations of wildlife-vehicle collisions along certain road sections.

While consistent search and reporting effort is essential for analyzing spatial trends it is not assumed that every wildlife-vehicle collision ends up in the crash database or the carcass removal database. Consistent search and reporting effort can relate to only a fraction of the actual number of collisions. What matters is that a crash or carcass has similar likelihood of being recorded on different road sections.

The search and reporting effort for crash data is typically lower than for carcass removal data (Tardif and Associates Inc,, 2003; Riley & Marcoux, 2006; Donaldson & Lafon, 2008). For a crash to be included in the crash database in the state of Montana there must be human injuries or human fatalities associated with the crash or the estimated damage to property has to be US$ 1,000 at a minimum (Huijser et al., 2007). However, depending on the severity of a reported crash, other tasks, and the distance to the crash site there is not always sufficient law enforcement personnel available to respond and record the crash. For a carcass to be included in the carcass removal database Montana Department of Transportation (MDT) maintenance personnel must have been out along the road and must have removed a carcass.

The Montana Department of Transportation (MDT) indicated that the carcass removal data are a minimum estimate and that the search and reporting effort may vary in different time periods. However, MDT also indicated that they consider the carcass removal data useful for the identification of potential patterns in time and space. The number of reported crashes with large mammals – as reported by law enforcement personnel - are known to be substantially lower than the carcass removal data numbers as not all crashes are reported to law enforcement and the vehicle repair costs also need to reach a minimum value before the crash is accepted into the crash database. Regardless there is no indication that the search and reporting effort is substantially different between different sections of U.S. Highway 2 between the Idaho/Montana border and Kalispell; not for the crash data and not for the carcass removal data.

3.3. Species Selection

The carcass removal data were characterized by large common ungulates with white-tailed deer representing more than 90% of all records. Domestic species were excluded from further analyses as domesticated species, in this case cats, dogs, cattle and horses, are – or should be - controlled by people and livestock fences rather than mitigation measures aimed at wildlife (Table 1). There was one “antelope” (pronghorn) in the carcass removal database (Table 1), but since this is far from the known range of this species it may well be the result of a misidentification and therefore this observation was excluded from further analyses.

The researchers conducted two analyses; one based on human safety, and one based on biological conservation. We selected the species accordingly:

Human safety (Chapter 3; this chapter): For this analysis the researchers only included large species that represent a substantial risk to human safety. Only species were included that were at least similar in size or weight than white-tailed deer (white-tailed deer bucks weigh 250 to 275 lbs, does weigh 160 to 180 (MTFW&P, 2015a)) (Table 1).

Biological conservation (Chapter 4). For this analysis the researchers only included species that are currently listed or have been delisted relatively recently on the federal or state level (USF&WS, 2015; MTFW&P, 2015b) (Table 1).

Consistent with other studies (i.e. Tardif and Associates Inc,. 2003; Riley & Marcoux, 2006; Donaldson & Lafon, 2008), the number of reported crashes with wildlife was much lower (n=404) than the number of reported carcasses of large mammals (n=4,249); the reported crashes were only 9.5% of the reported carcasses.

Table 1: The species included in the carcass removal database and their inclusion in the analyses based on human safety versus biological conservation.

					Biological conservation	
Species	n	%	Removed from data	Human safety	Federal level	State level
White-tailed deer (*Odocoileus virginianus*)	3936	90.28		x		
Mule deer (*Odocoileus hemionus*)	180	4.13		x		
Elk (*Cervus canadensis*)	65	1.49		x		
Moose (*Alces americanus*)	38	0.87		x		
Unknown or not sufficiently specified	35	0.80				
Black Bear (*Ursus americanus*)	14	0.32		x		
Deer spp. (*Odocoileus* spp.)	11	0.25		x		
Coyote (*Canis latrans*)	10	0.23				
Striped skunk (*Mephitis mephitis*)	9	0.21				
Domesticated cat (*Felis catus*)	8	0.18	x	n/a	n/a	
Domesticated dog (*Canis lupus familiaris*)	8	0.18	x	n/a	n/a	
Other wild species, unspecified	8	0.18				
Raccoon (*Procyon lotor*)	5	0.11				
Gray wolf (*Canis lupus*)	4	0.09			Delisted (2011)	Delisted (2011)
Owl (Strigiformes)	3	0.07				
Painted turtle (*Chrysemys picta*)	3	0.07				
Cattle (*Bos taurus*)	2	0.05	x	n/a	n/a	
Grizzly bear (*Ursus arctos*)	2	0.05		x	Threatened	Of concern
Mountain Lion (*Puma concolor*)	2	0.05		x		
Beaver (*Castor canadensis*)	2	0.05				
Bobcat (*Lynx rufus*)	2	0.05				
Common raven (*Corvus corax*)	2	0.05				
Wild turkey (*Meleagris gallopavo*)	2	0.05				
Pronghorn (*Antilocapra americana*)	1	0.02	x	n/a	n/a	
Bighorn sheep (*Ovis canadensis*)	1	0.02		x		
Horse (*Equus ferus caballus*)	1	0.02	x	n/a	n/a	
Domestic, species not recorded	1	0.02	x	n/a	n/a	
Badger (*Taxidea taxus*)	1	0.02				
Bald eagle (*Haliaeetus leucocephalus*)	1	0.02			Delisted (2011)	Special status
Golden eagle (*Aquila chrysaetos*)	1	0.02				Of concern
Red fox (*Vulpes vulpes*)	1	0.02				
Turkey vulture (*Cathartes aura*)	1	0.02				
Total	4360	100				

3.4. Hotspot Analyses

The researchers defined a hotspot as an area, or a road section, that has a cluster or relatively high concentration of collisions. The researchers conducted two separate analyses to identify wildlife-vehicle collision hotspots along U.S. Hwy 2: one based on crash data and one based on carcass removal data. The procedure for the two analyses was the same and consisted of the following steps:

Step 1: Integrate the crash and carcass locations in a spatial database. The crash and carcass data were recorded to the nearest 0.1 mile based on the mile reference posts along U.S. Hwy 2. The researchers obtained the coordinates for the mile reference posts (whole miles) from the Montana Department of Transportation and divided each 1 mile long road section in 10 sections of equal length; the 0.1 mile reference post locations. This then allowed the researchers to integrate the crash and carcass removal data in a spatial database (ArcGIS Release 9.3).

Step 2: Conduct a Kernel density (ArcGIS Release 9.3) analysis for point features. The analyses included all crash data or all carcass removal data from U.S. Hwy 2 between the Idaho/Montana border and Kalispell. For the Kernel density analyses the researchers divided the study area into a grid with a cell size of 82 x 82 ft (25 x 25 m). The relatively small cell size resulted in a relatively fine or smooth map. The locations of the crashes and carcasses are considered points and the Kernel density analysis calculates the density of crashes or carcasses in a neighborhood around each cell. Consistent with Gomes et al. (2009) we set the search radius at 500 meters (m) from each cell. On a straight road this basically means that crashes or carcasses that are up to about 0.3 mi (500 m) away are included in the density analyses for each cell. Crashes or carcasses that were further than 0.3 mi (500 m) from a cell did not influence the hotspot analyses for that cell. For the Kernel density analyses we first calculated the area for the 95% Kernel polygon (Table 2) (see Bingham & Noon (1997) for a detailed description of the procedure). This means that the researchers omitted the 5% of cells that had the least spatial concentration of crashes or carcasses; these cells did not have any effect on the hotspot analyses. Secondly the researchers calculated the area covered within nine additional Kernel isopleths (range 5%-85%) (Table 2). An isopleth is the smallest possible area around a cell that contains a certain percentage of the data points (in this case collisions). The area covered within the 95% Kernel isopleth was set at 100% and the areas covered within the additional nine isopleths were expressed as a percentage of the area for the 95% Kernel isopleth (Table 2).

Table 2: The Kernel isopleths and the area covered within these isopleths.

	Crash data		Carcass data	
Isopleth	Area (m^2)	Area %	Area (m^2)	Area %
95	46,775,625	100.00%	52,541,875	100.00%
85	20,013,125	42.79%	17,461,250	33.23%
75	8,210,625	17.55%	5,907,500	11.24%
65	3,505,625	7.49%	1,983,750	3.78%
55	1,357,500	2.90%	604,375	1.15%
45	551,250	1.18%	145,625	0.28%
35	171,250	0.37%	66,250	0.13%
25	92,500	0.20%	58,125	0.11%
15	47,500	0.10%	54,375	0.10%
5	23,750	0.05%	25,000	0.05%

Step 3: Conduct an exponential regression analysis ($y=ae^{bx}$). The ten Kernel isopleths (5%-95%) represented the value of the independent variable (x) on the horizontal axis, and the area covered within each of the Kernel isopleths expressed as a percentage of the area covered within the 95% isopleth represented the dependent variable (y) on the vertical axis (Figure 1 and 2). If the distribution of the cells with the density of the crashes or carcasses within the 95% AK isopleth would be perfectly uniform, then the regression of x on y would be a straight line through the origin with a slope of exactly 1; for each percentage increase of the Kernel isopleths, the area within these isopleths also increases one percentage. Should there be a concentration of crashes or carcasses, then the regression of x on y will fall below the line y=x ; i.e., *b* will be less than 1. We conducted an exponential regression analysis ($y=ae^{bx}$). The estimates for *a* and *b* for the crash and carcass data are shown in (Figure 4 and 5).

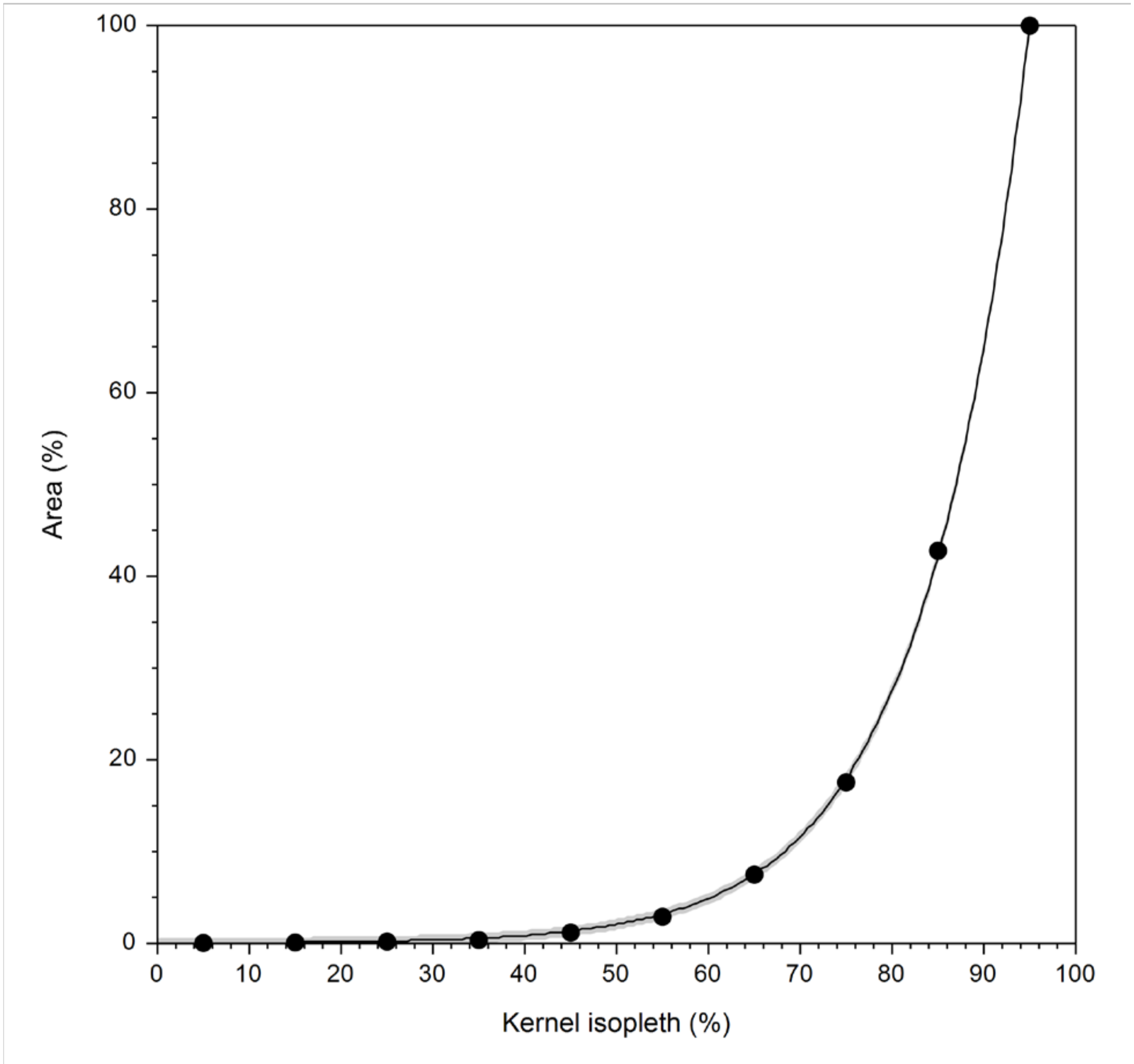

Figure 4: The Kernel isopleths (x-axis) for the crash data and the area within the isopleths (y-axis)) expressed as a percentage of the area within the 95% isopleth. The function is $y = 0.01033*e^{0.08609*x}$. The shaded area around the function represents the upper and lower 95% prediction limit. Slope equals 1 at the 69.9% Kernel isopleth (11.5% of the total area within the 95% isopleth).

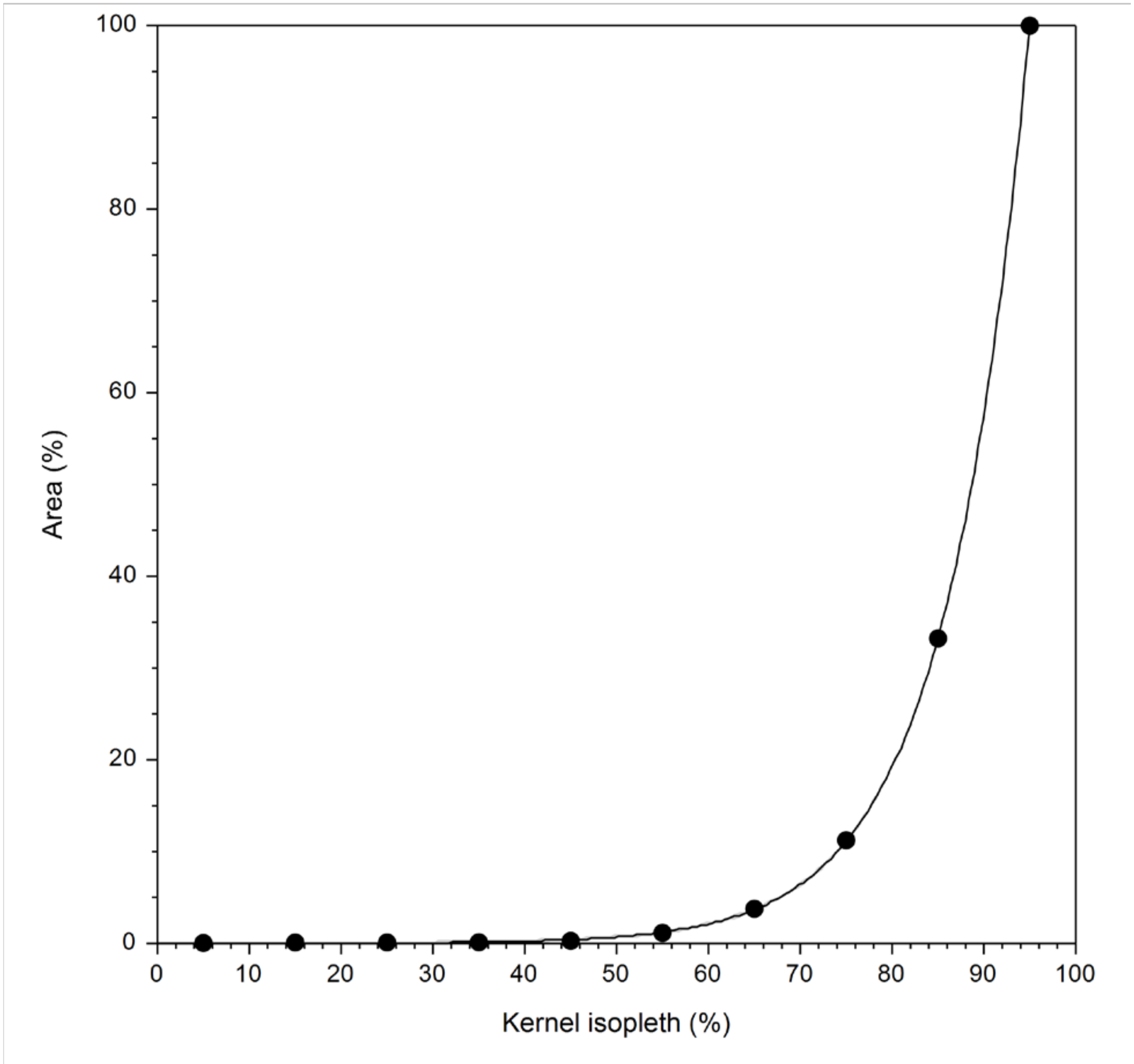

Figure 5: The Kernel isopleths (x-axis) for the carcass data and the area within the isopleths (y-axis)) expressed as a percentage of the area within the 95% isopleth. The function is y = 0.00108*e $^{0.10986*x}$. The shaded area around the function represents the upper and lower 95% prediction limit. Slope equals 1 at the 73.1 Kernel isopleth (9.0% of the total area within the 95% isopleth).

Step 4: Identify road sections with the cells that have the densest concentration of crashes or carcasses (see step 2 for description of the cells and how their values were calculated) up to where the crashes or carcasses are no longer concentrated (i.e. Kernel isopleth slope > 1). In our case these are the cells that have the densest crashes or carcasses up to 11.5% of the total area within the 95% isopleth (for crash data; Figures 6 and 7) or up to 9.0% of the total area within the 95% isopleth (for carcass data; Figures 8 and 9) (i.e. Kernel isopleth slope < 1). For crash data the mile reference posts for the start and end points of the two hotspots were 117.3-117.6 (crash A) and 119.2-119.4 (crash B). For carcass removal data the mile reference posts for the start and end points of the hotspot was 34.9-35.3 (Carcass A).

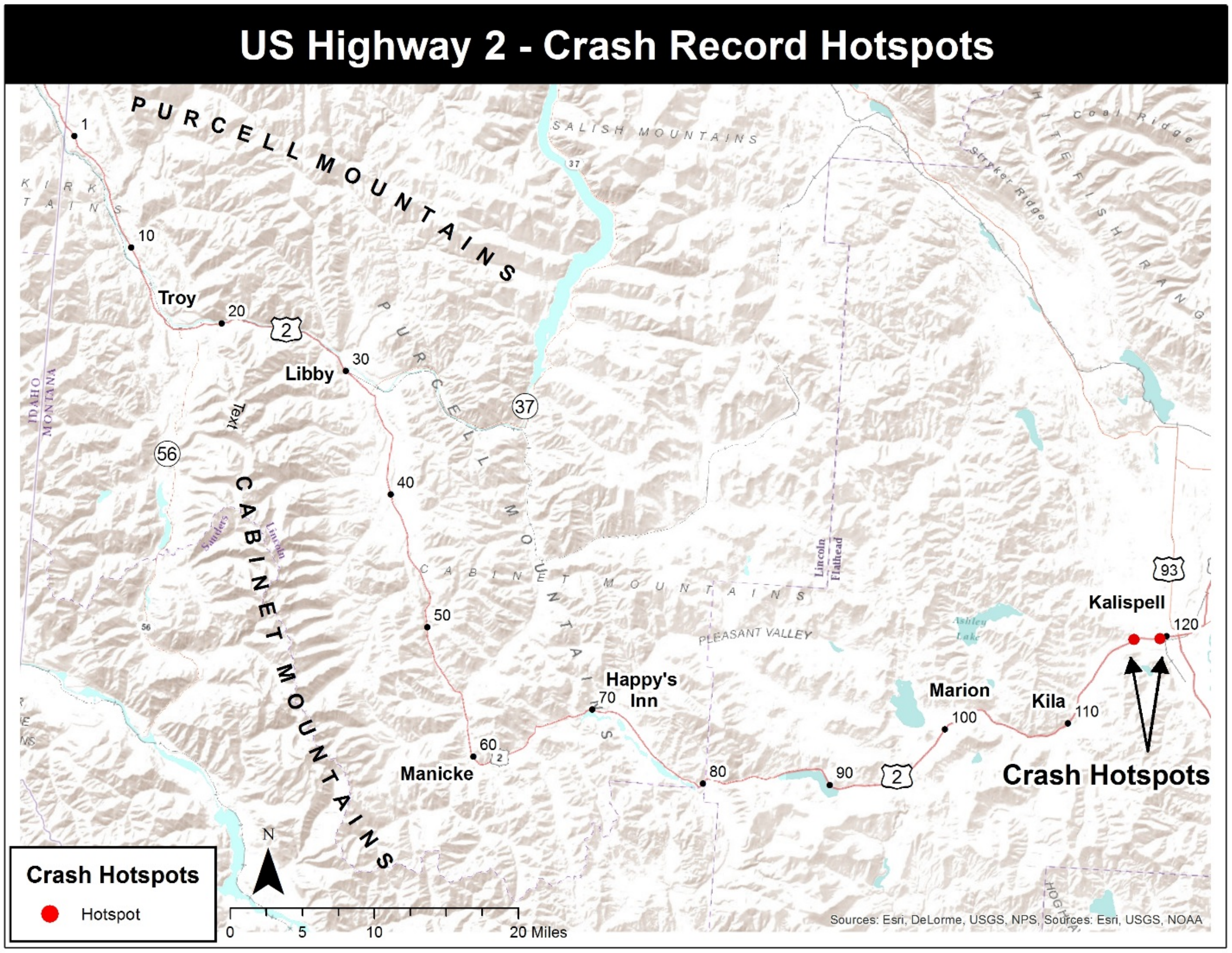

Figure 6: The road sections (in red, Kernel isopleth >69.9%, Crash A and Crash B) where the cells based on the crash data have a concentrated distribution (i.e. slope <1 in Figure 1). The black arrows indicate the location of the hotspots.

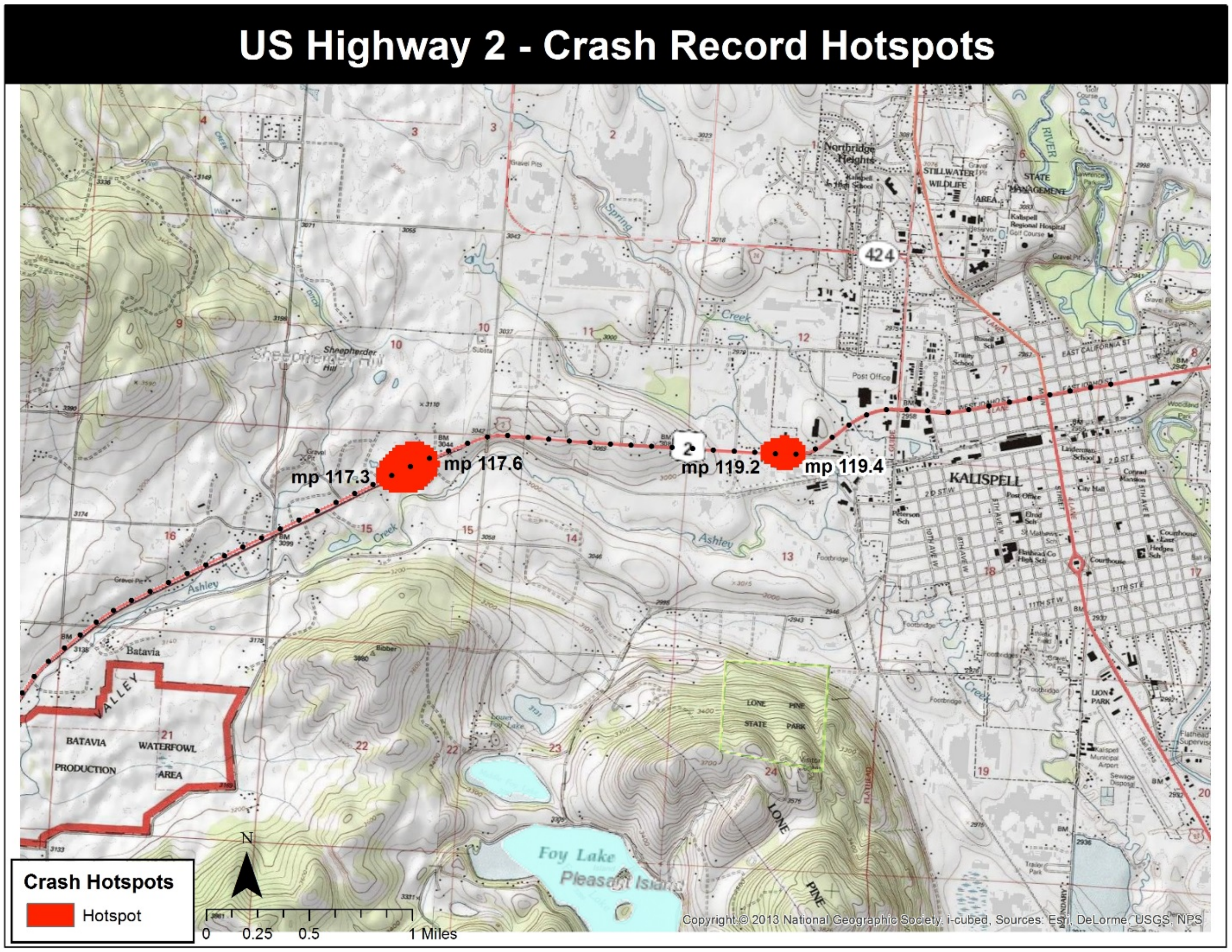

Figure 7: Area enlarged. The road sections (in red, Kernel isopleth >69.9%, Crash A and Crash B)) where the cells based on the crash data have a concentrated distribution (i.e. slope <1 in Figure 1).

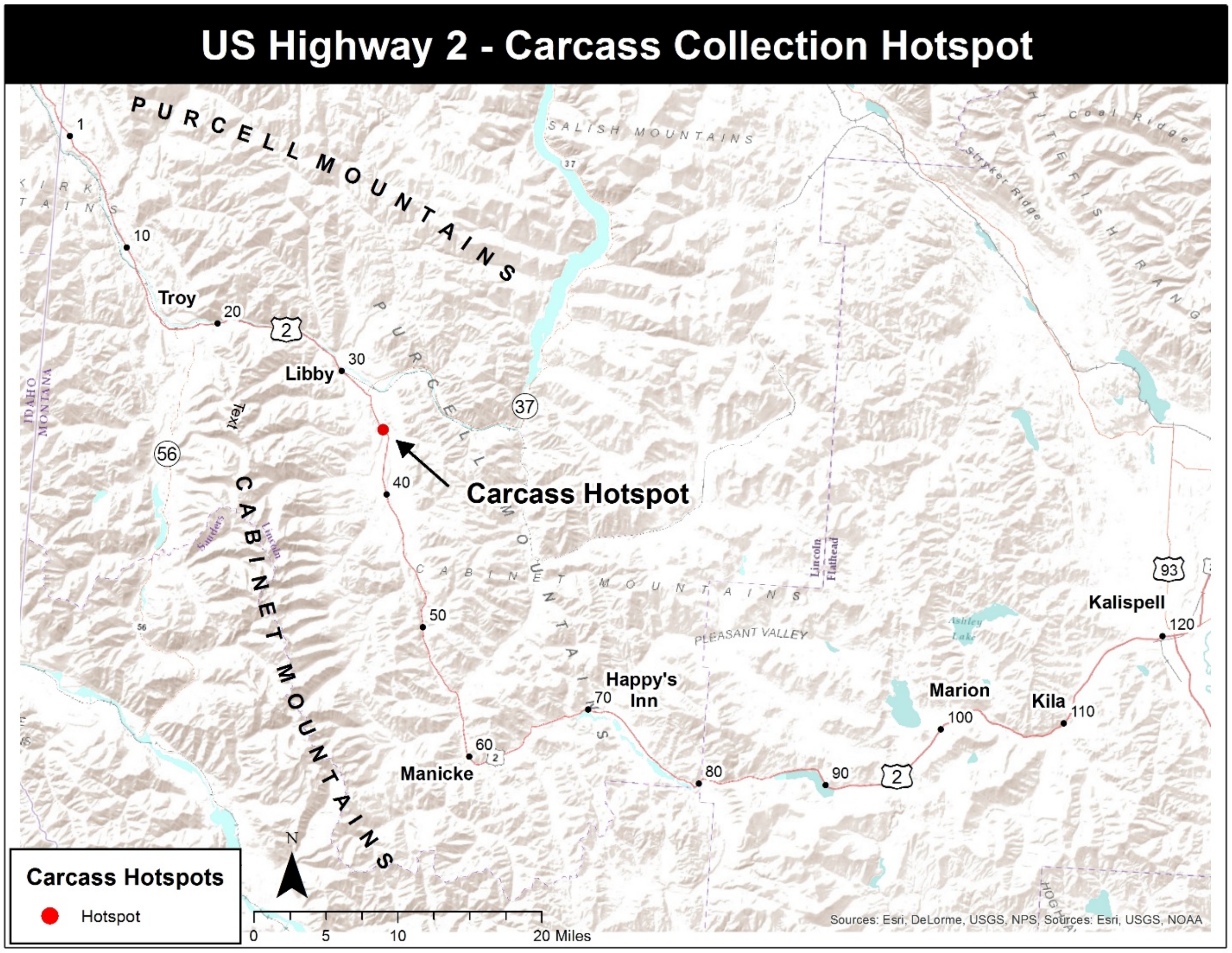

Figure 8: The road section (in red, Kernel isopleth >73.1%, Carcass A) where the cells based on the carcass data have a concentrated distribution (i.e. slope <1 in Figure 2). The black arrow indicates the location of the hotspot.

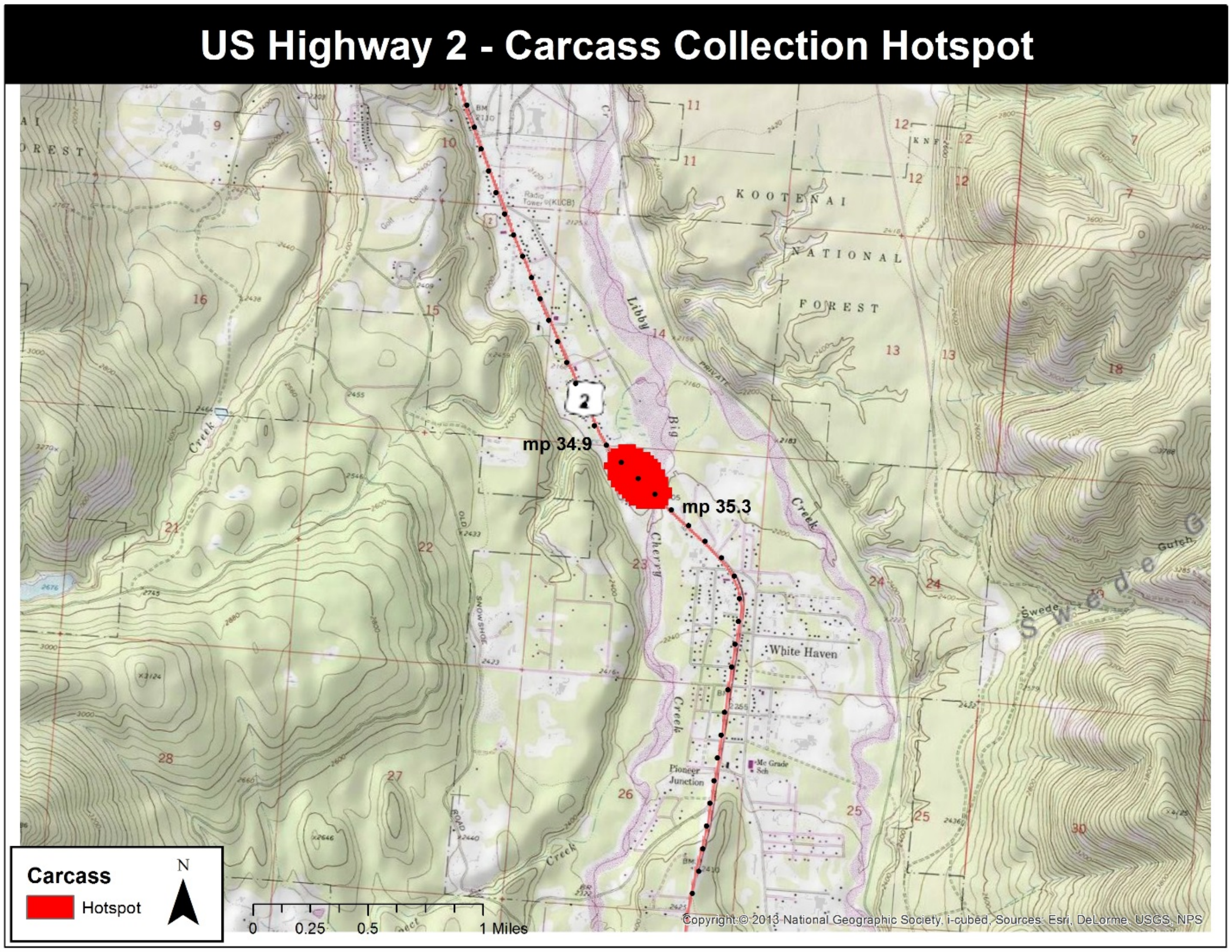

Figure 9: Area enlarged. The road sections (in red, Kernel isopleth >73.1%, Carcass A) where the cells based on the carcass data have a concentrated distribution (i.e. slope <1 in Figure 2).

Step 5: Identify additional road sections that may be considered for mitigation. While it is useful to identify road sections that have a concentrated distribution of crashes or carcasses, there may be a desire to identify additional road sections that do not have a concentration that deviates from a uniform distribution, but that still have a relatively high concentration of crashes or carcasses. For this purpose the researchers considered road sections with no crashes or carcasses and road sections that fell into the two lowest density categories (50-100%) (Provided that the density is greater than 0) to be “background”. Road sections that had higher densities (“top 50%”) were considered a “hotspot” (i.e. orange or red in Figures 10-15 (crash data) and Figures 16-20 (carcass removal data)). Note that if there was “yellow” in between two “orange” road sections it was regarded as one hotspot rather than two.

The crash data are shown in Figure 7-12 while the carcass data are shown in Figure 13-17.

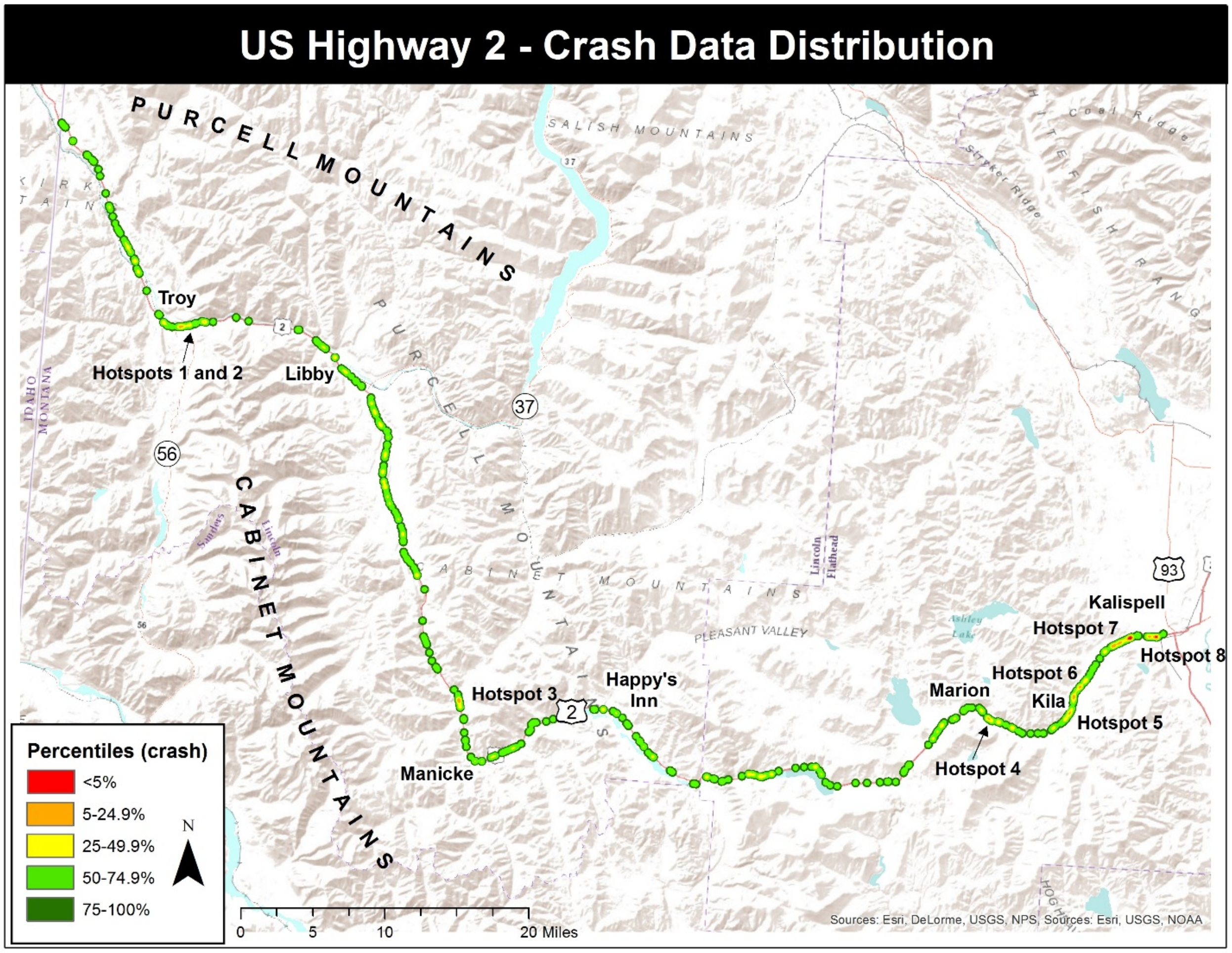

Figure 10: The hotspots based on crash data along U.S. Hwy 2.

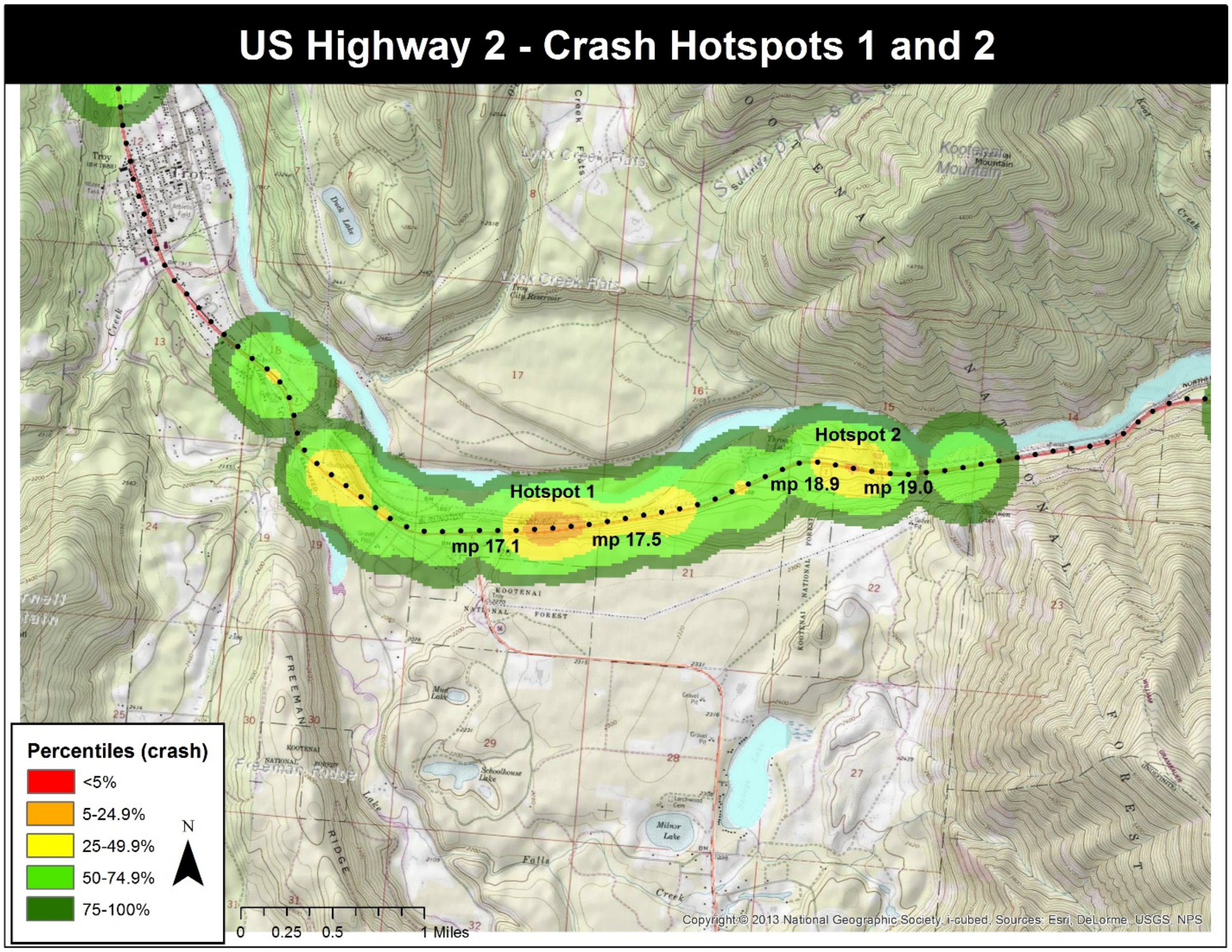

Figure 11: The hotspots based on crash data along U.S. Hwy 2; Area enlarged for hotspot 1 and 2.

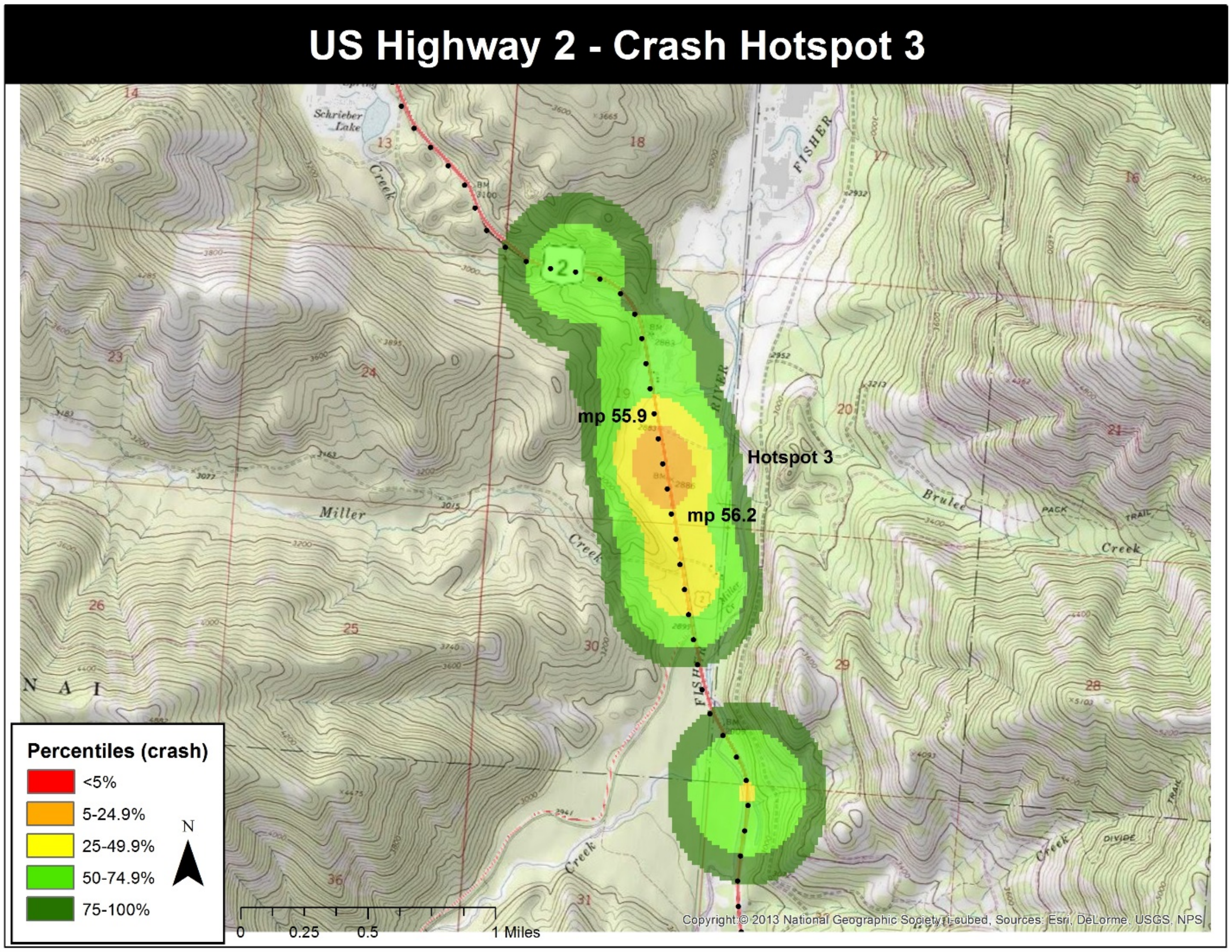

Figure 12: The hotspots based on crash data along U.S. Hwy 2; Area enlarged for hotspot 3.

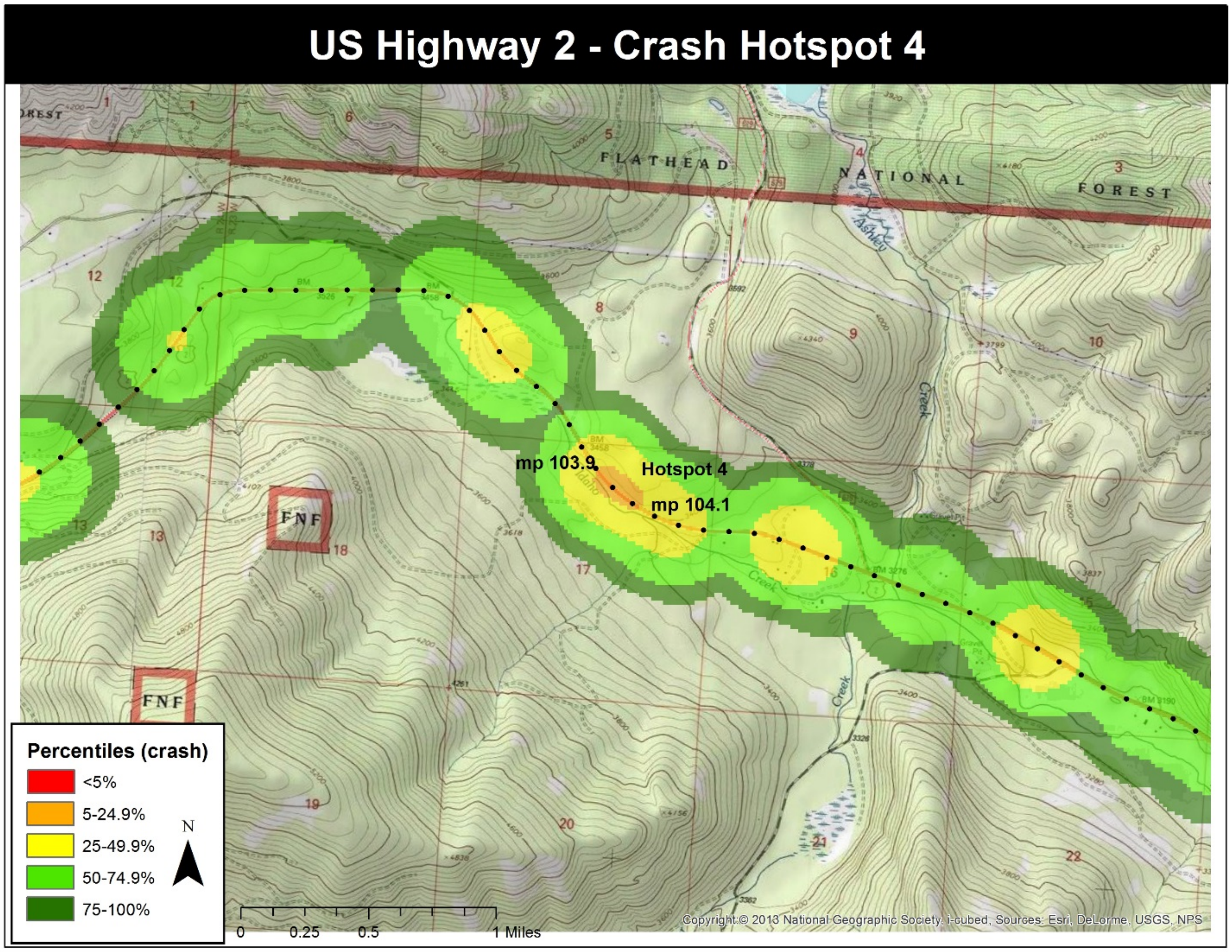

Figure 13: The hotspots based on crash data along U.S. Hwy 2; Area enlarged for hotspot 4.

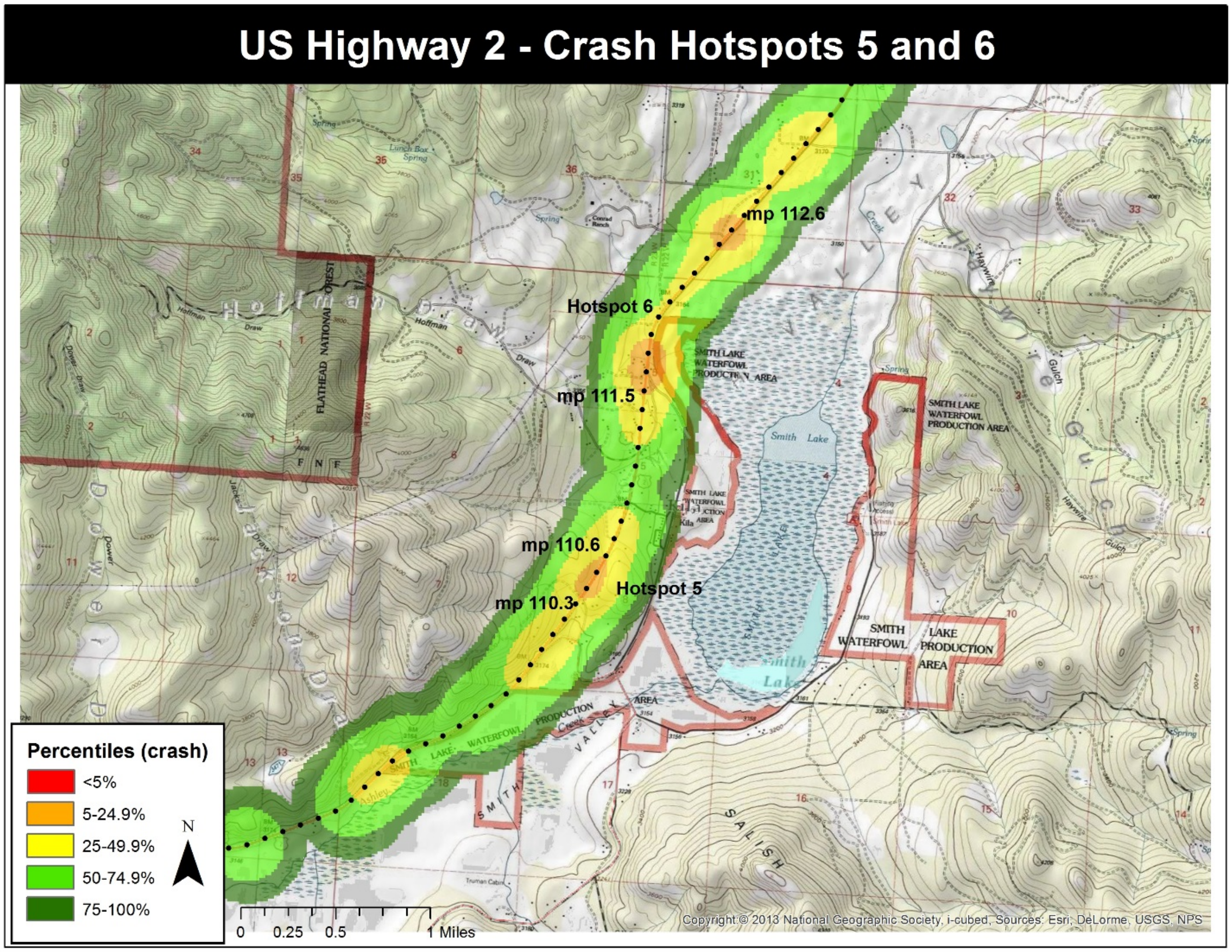

Figure 14: The hotspots based on crash data along U.S. Hwy 2; Area enlarged for hotspot 5 and 6.

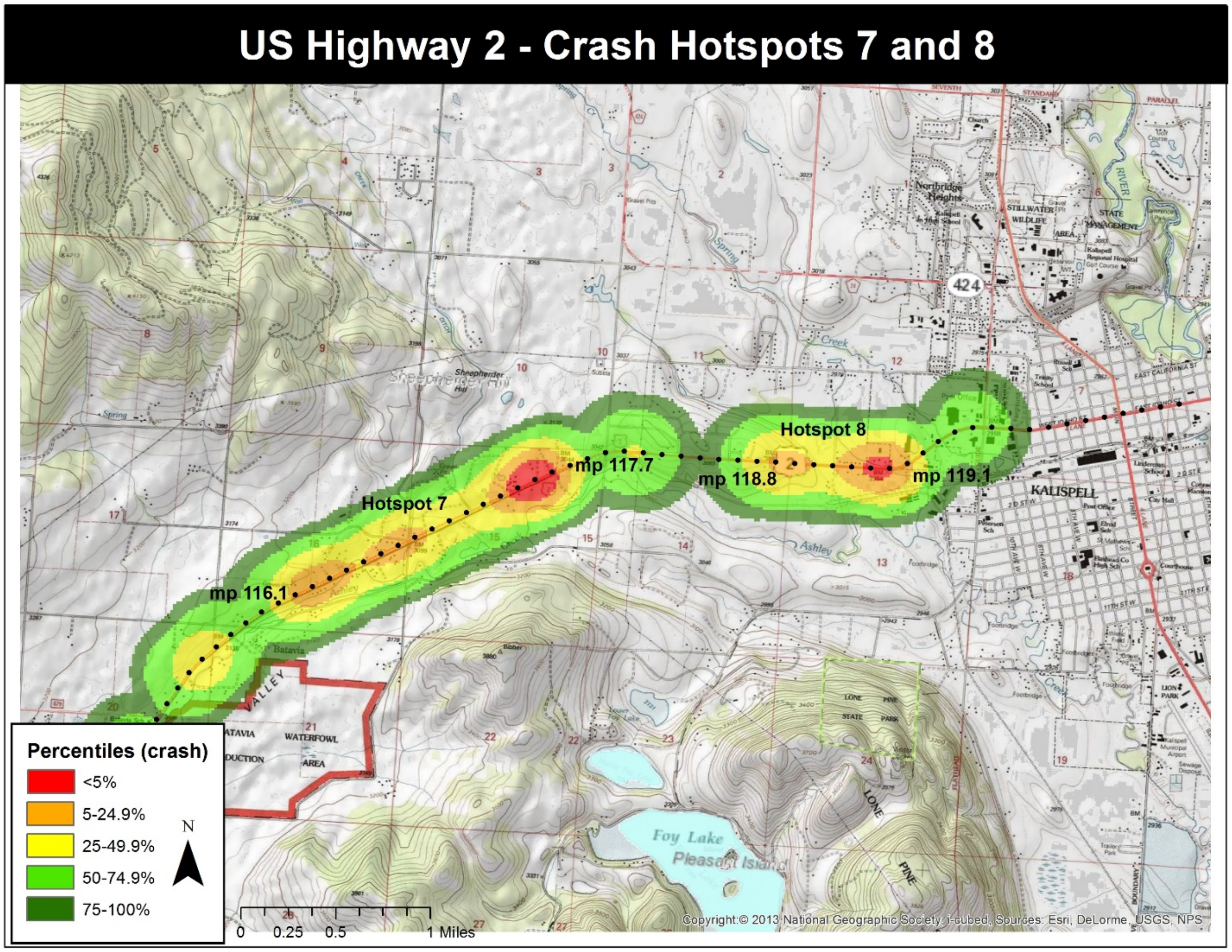

Figure 15: The hotspots based on crash data along U.S. Hwy 2; Area enlarged for hotspot 7 and 8.

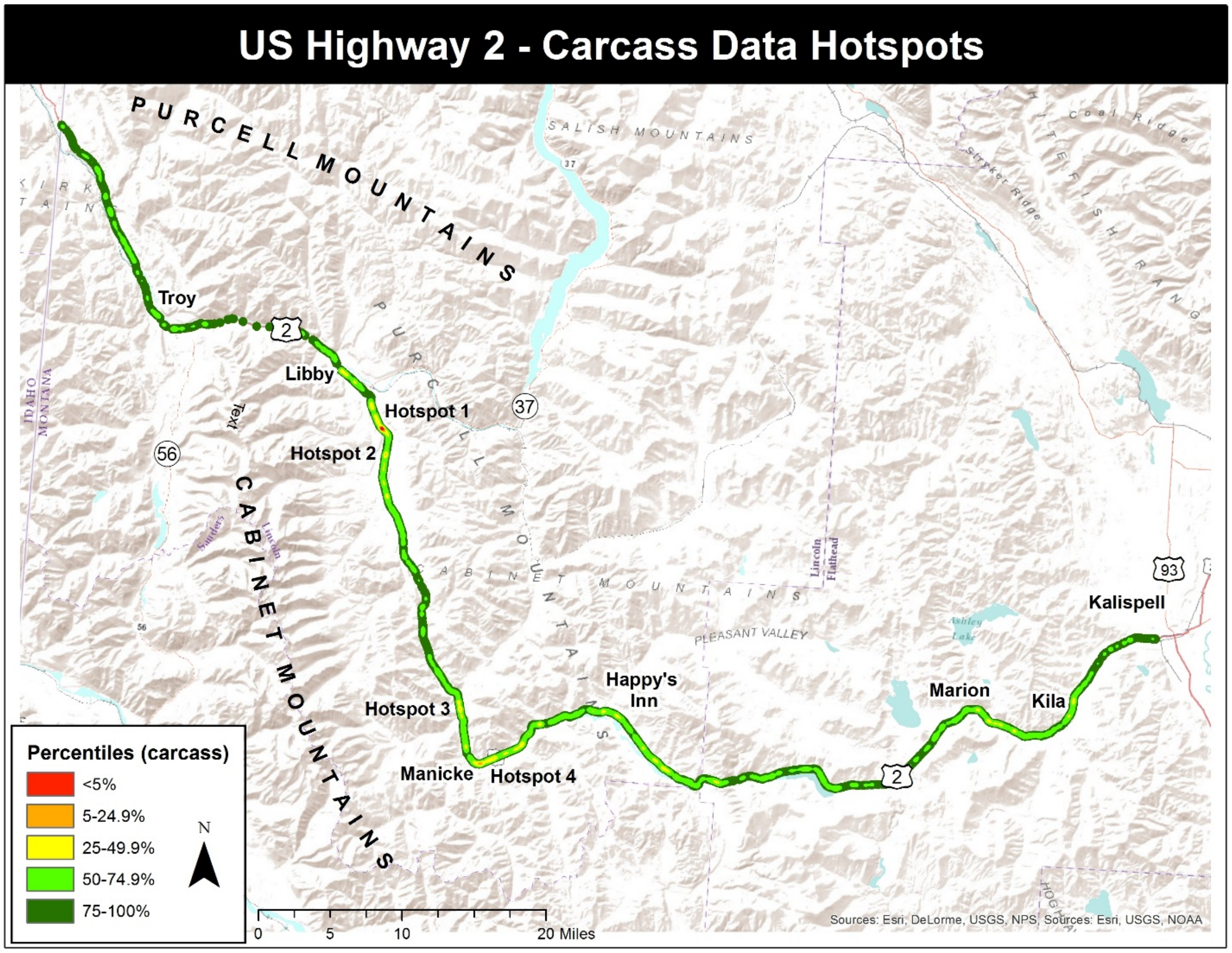

Figure 16: The hotspots based on carcass removal data along U.S. Hwy 2.

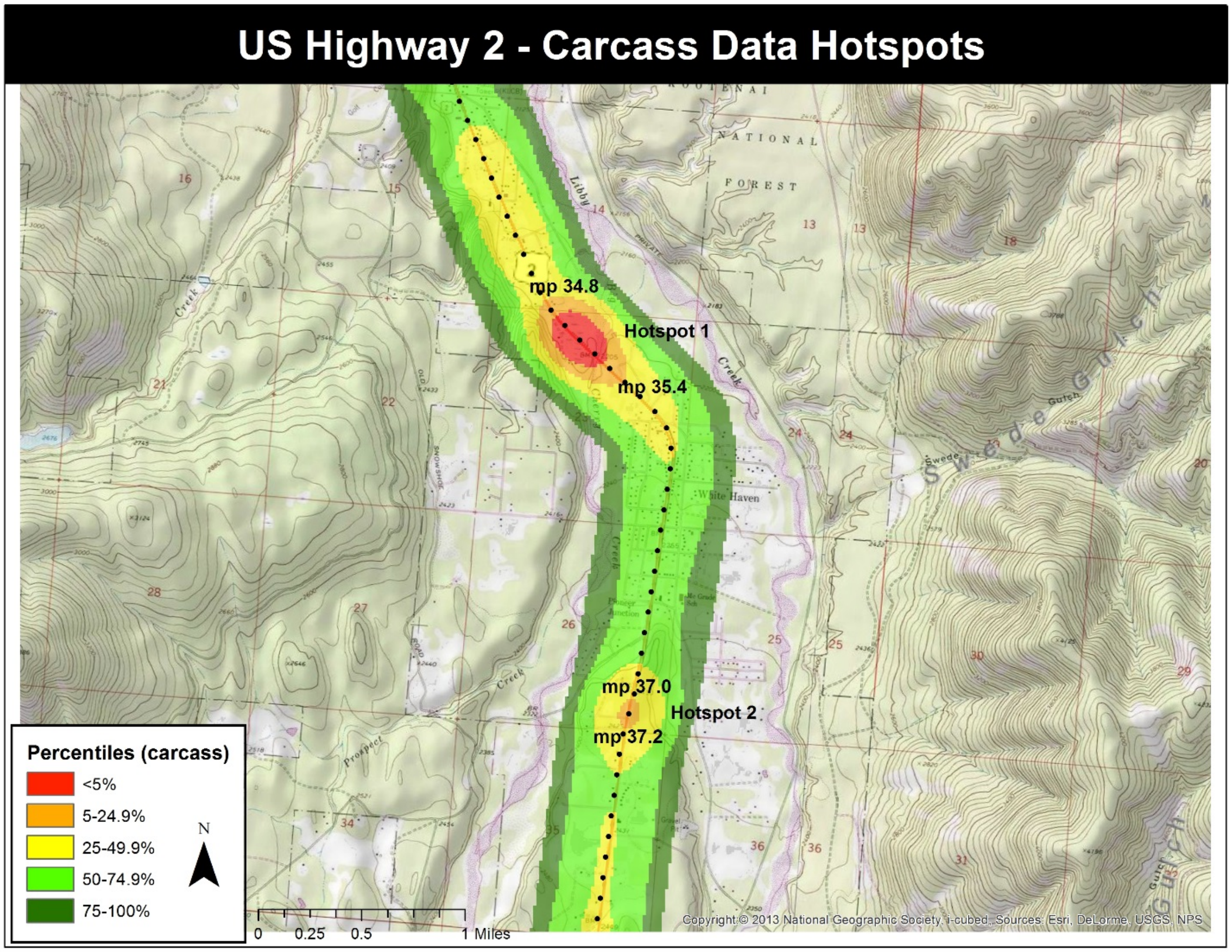

Figure 17: The hotspots based on carcass removal data along U.S. Hwy 2. Area enlarged for hotspot 1 and 2.

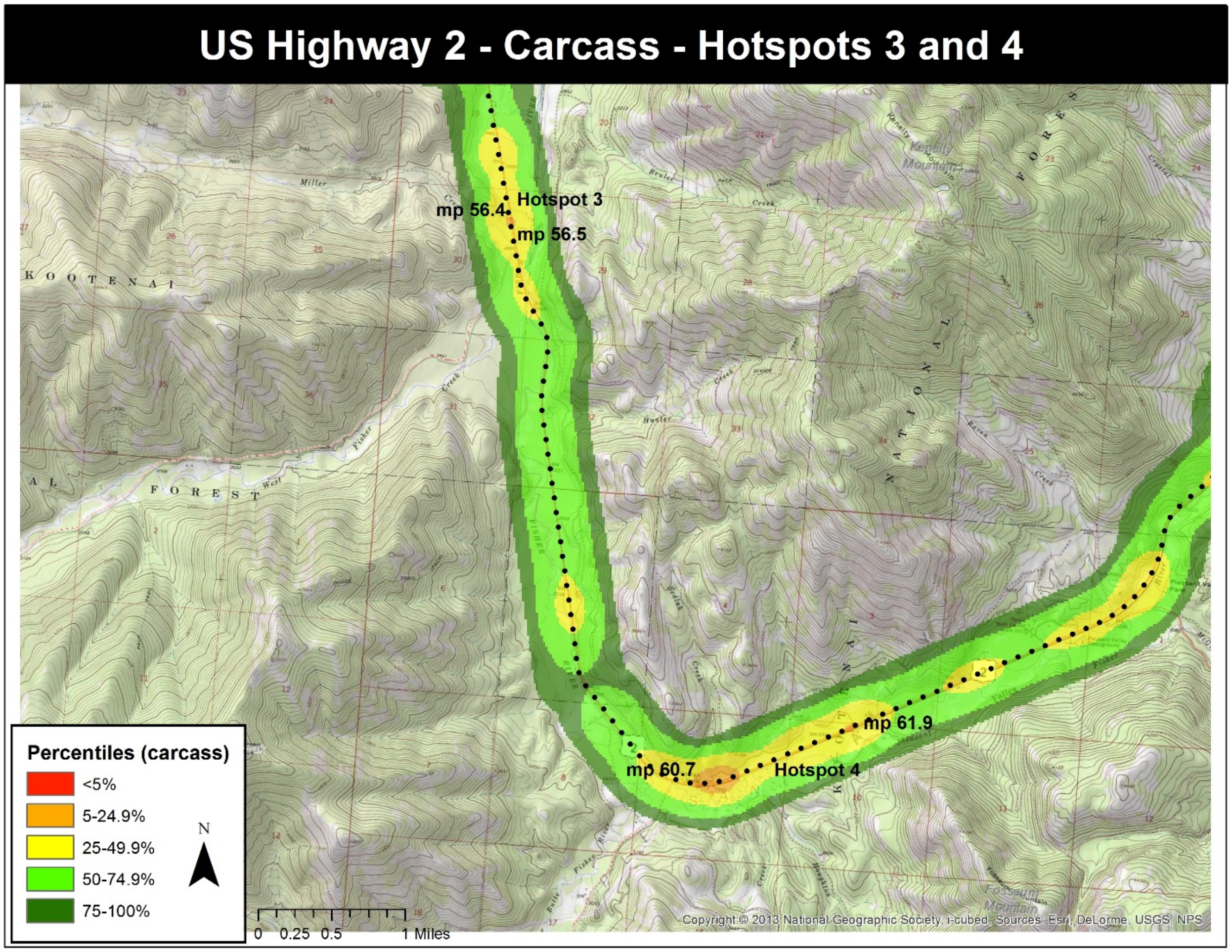

Figure 18: The hotspots based on carcass removal data along U.S. Hwy 2. Area enlarged for hotspot 3 and 4.

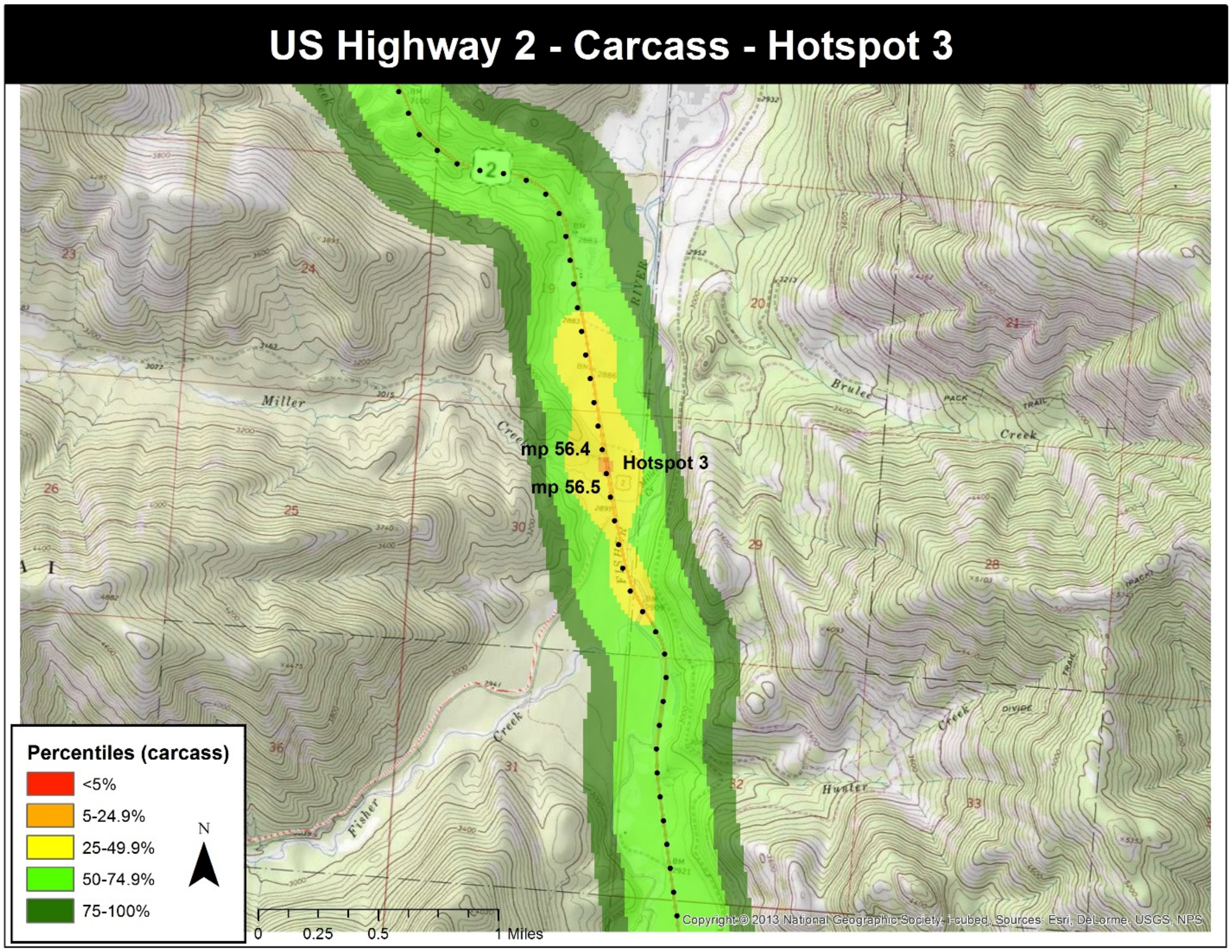

Figure 19: The hotspots based on carcass removal data along U.S. Hwy 2. Area enlarged for hotspot 3.

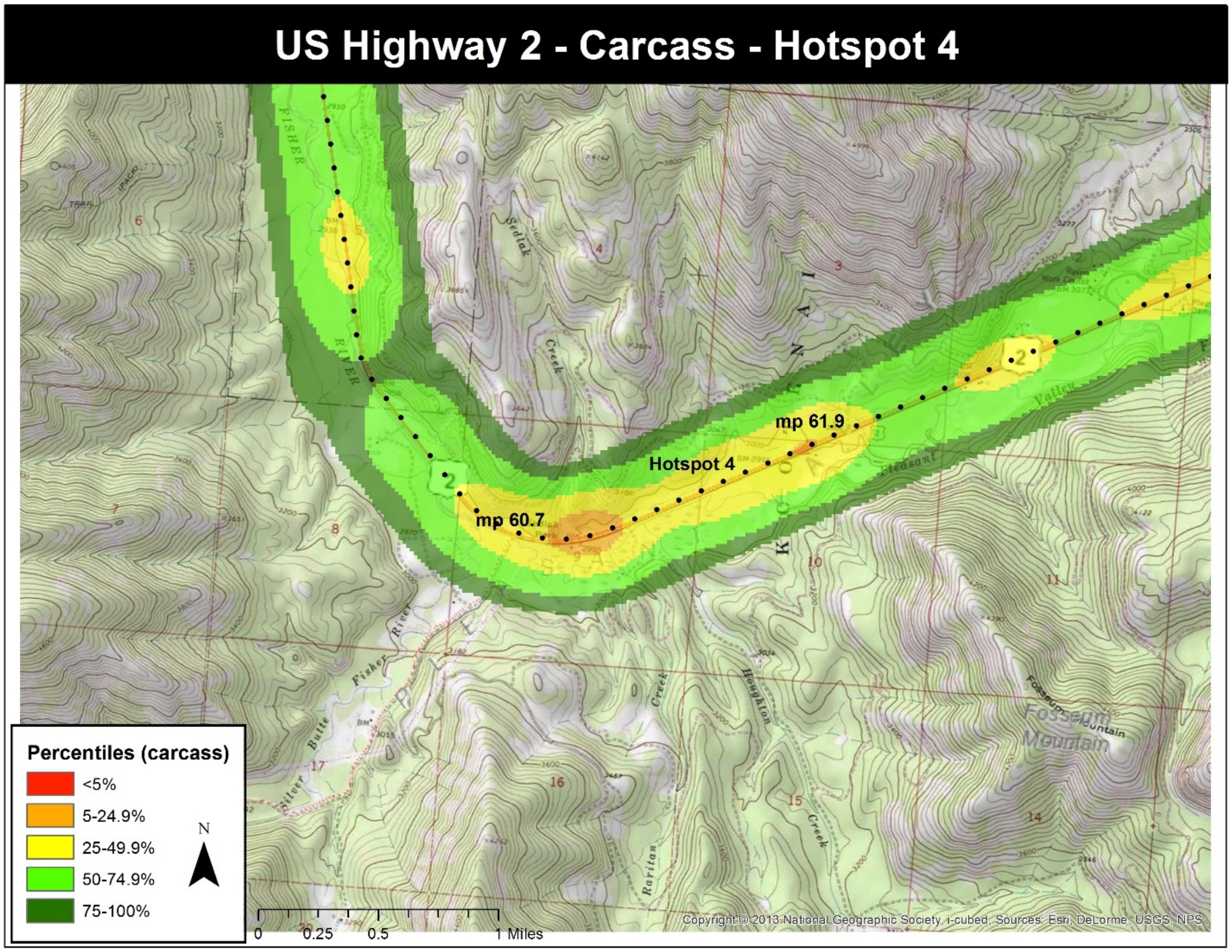

Figure 20: The hotspots based on carcass removal data along U.S. Hwy 2. Area enlarged for hotspot 4.

The exact location of the crash and carcass hotspots is listed in Table 3.

Table 3: The start and end points of the hotspots based on the crash data and carcass removal data.

Crash hotspot (mile reference posts)	Carcass removal hotspot (mile reference posts)
Crash 1 (17.1-17.5)	Carcass 1 (34.8-35.4)
Crash 2 (18.9-19.0)	Carcass 2 (37.0-37.2)
Crash 3 (55.9-56.2)	Carcass 3 (56.4-56.5)
Crash 4 (103.9-104.1)	Carcass 4 (60.7-61.9)
Crash 5 (110.3-110.6)	
Crash 6 (111.5-112.6)	
Crash 7 (116.1-117.7)	
Crash 8 (118.8-119.5)	

3.5. Comparison Crash and Carcass Hotspots

The road sections with a disproportionate concentration of crashes and carcasses had no overlap at all (Figures 6 and 8). The same is true for road sections with the highest concentration of crashes and carcasses (Figures 10 and 16, Table 3). However, the hotspot “crash 3” and “carcass 3” were very close to each other (Table 3).

Possible explanations for the dissimilarity of the crash and carcass removal hotspots are:

- Perhaps the search and reporting effort along the highway was not constant after all for either the crash data, carcass removal data, or both.
- Perhaps certain road sections are more likely to result in severe accidents that are more likely to be included in the crash data. This may relate to species and corresponding differences in habitat (e.g. a collision with an elk or moose is more likely to result in human injuries and fatalities than a collision with a deer). It may also relate to the design speed of different highway sections (e.g. if an animal is hit at higher vehicle speed the collision is more likely to result in human injuries and fatalities).

3.6. Prioritization Crash and Carcass Hotspots Based on Human Safety

The hotspots that had the highest concentration of crashes or carcasses were ranked highest (Table 4 and 5).

Table 4: Prioritization of the crash hotspots based on human safety. The number of crashes relates to the period 1 January 2005 – 31 December 2014 (10 years). * = tie.

Crash hotspot (start and end mi)	Length (mi)	Crashes (n)	Crashes/mi (n/mi)	Rank
Disproportionate concentration				
Crash A (117.3-117.6)	0.3	9	30.00	1*
Crash B (119.2-119.4)	0.2	6	30.00	1*
Concentration				
Crash 1 (17.1-17.5)	0.4	6	15.00	5
Crash 2 (18.9-19.0)	0.1	2	20.00	2*
Crash 3 (55.9-56.2)	0.3	7	23.33	1
Crash 4 (103.9-104.1)	0.2	4	20.00	2*
Crash 5 (110.3-110.6)	0.3	5	16.67	4
Crash 6 (111.5-112.6)	1.1	15	13.64	7
Crash 7 (116.1-117.7)	1.6	23	14.37	6
Crash 8 (118.8-119.5)	0.7	12	17.14	3

***= tie**

Table 5: Prioritization of the carcass hotspots based on human safety. The number of carcasses relates to the period 1 January 2005 – 31 December 2014 (10 years).

Carcass hotspot (start and end mi)	Length (mi)	Carcasses (n)	Carcasses (n/mi)	Rank
Disproportionate concentration				
Carcass A (34.9-35.3)	0.4	114	285.00	1
Concentration				
Carcass 1 (34.8-35.4)	0.6	129	215.00	3
Carcass 2 (37.0-37.2)	0.2	47	235.00	2
Carcass 3 (56.4-56.5)	0.1	37	370.00	1
Carcass 4 (60.7-61.9)	1.2	165	137.50	4

4. ROAD SECTIONS OF CONCERN TO BIOLOGICAL CONSERVATION

4.1. Introduction

The hotspot identification process described in the previous chapter (Chapter 3) resulted in hotspots that are primarily based on human safety data. This is important to recognize as an alternative process that would identify hotspots based on – for example - nature conservation may result in the identification of very different road segments as this may include different species that are not recorded in the crash and carcass removal databases and species that may use different habitat. This is not necessarily a problem, but it is important to recognize that the "departure point" for the identification and prioritization process influences the results. To illustrate this point the researchers investigated potential differences between road sections that rank highest with regard to human safety and road sections that have the highest concern with regard to biological conservation (Chapter 4, this chapter).

4.2. Carcass Removal Data Biological Conservation

The researchers described the selection process for the species that are of interest to biological conservation in Chapter 3 (Table 1). Since there were only eight carcass observations of species that are of concern to biological conservation, a hotspot analyses was not conducted. Instead the locations of the individual carcasses was plotted on a map (Figure 21).

Since potential mitigation measures are likely to be focused on terrestrial mammals rather than birds, the road sections where most rare terrestrial mammals have been hit by traffic are between mile markers 55-64 and between mile markers 79-81.

Note that all of the species that were a concern to biological conservation and that were recorded as roadkill may have been scavenging on other road-killed animals. Consistent with section 2.1 in this report the researchers emphasize that mitigation measures for conservation should not only be based on collision data. It is best if the location for potential future mitigation measures is also based on data for successful highway crossings and maps that indicate where high quality habitat may be present close to the highway.

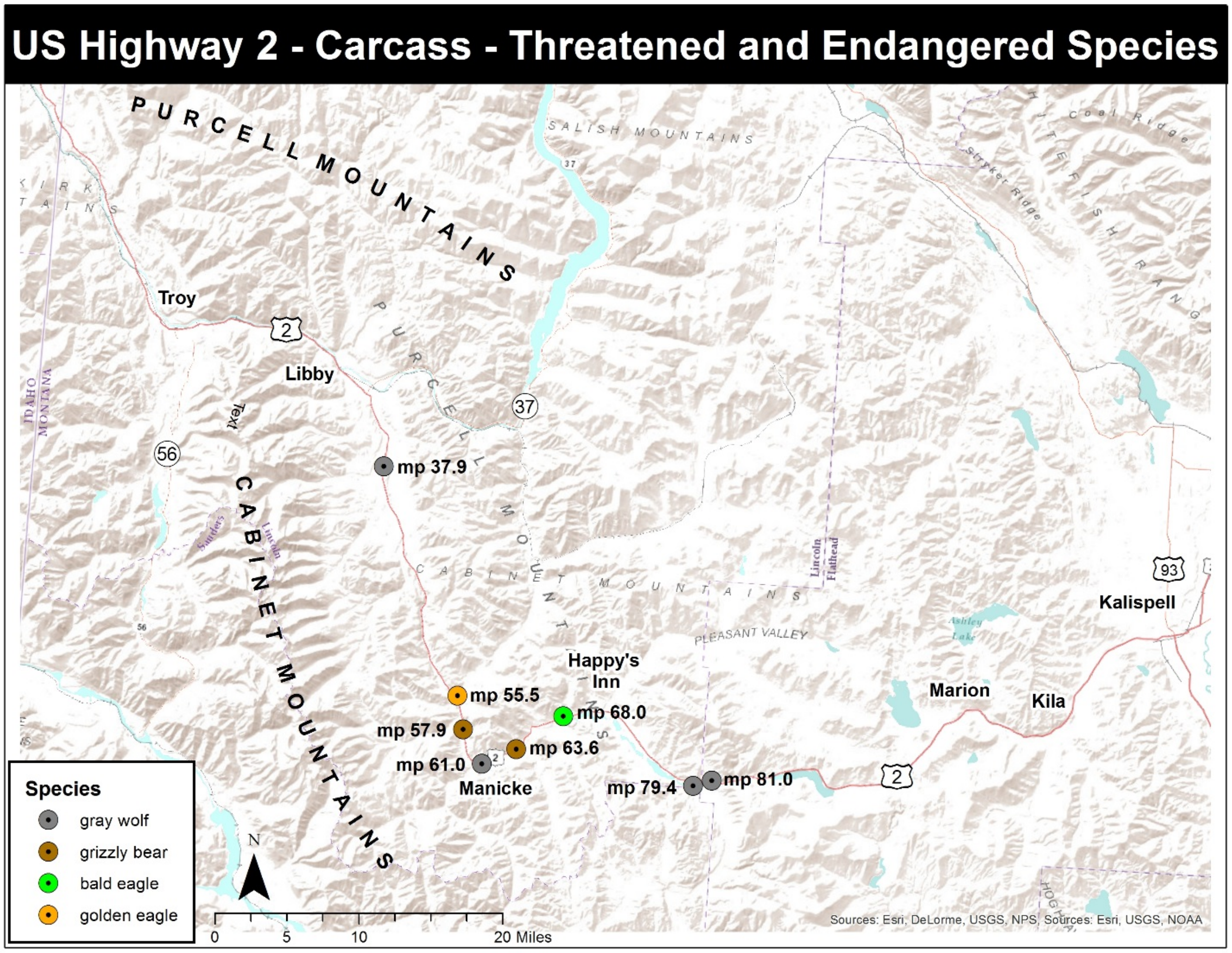

Figure 21: The individual locations of carcasses of species included in the analyses for biological conservation (see Table 1).

4.3. Information from Other Studies

The researchers also used existing data from other publications to identify important wildlife habitat (State Wildlife Agencies of the Western United States, 2015) and wildlife connectivity areas (including for grizzly bears) along U.S. Highway 2 (Ament et al., 2014). The data were plotted on a map that also shows the crash and carcass hotspots (Figure 22, Tables 6-7).

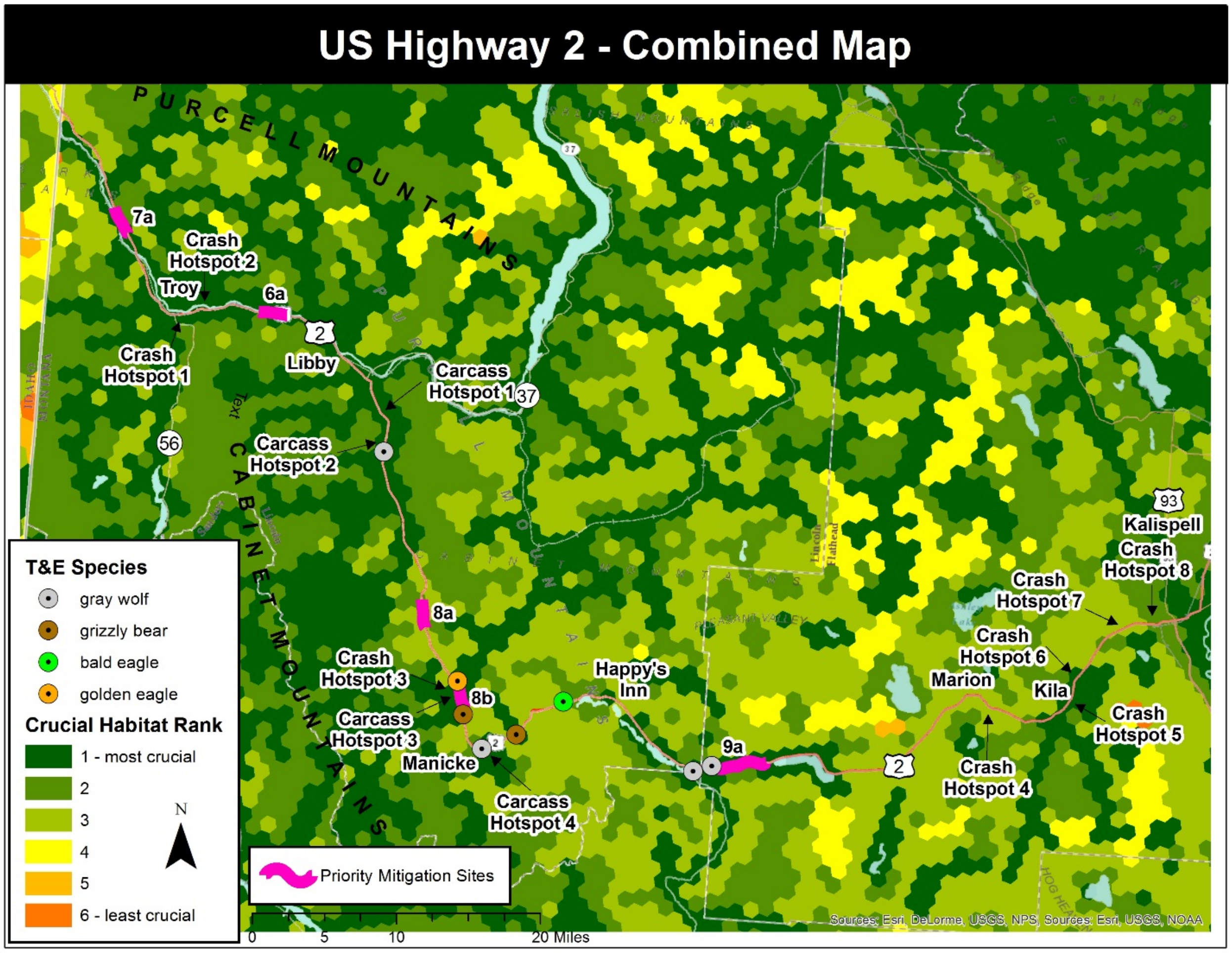

Figure 22: The individual locations of carcasses of species included in the analyses for biological conservation (see Table 1). The map in the background shows the crucial habitat ranks (State Wildlife Agencies of the Western United States, 2015) and the priority mitigation sites (Ament et al., 2014).

Table 6: Highway segments adjacent to crucial wildlife habitat (State Wildlife Agencies of the Western United States, 2015).

Crucial Habitat Rank	Mile reference posts (start – end)
Rank 1	1.0 – 2.5
Rank 1	4.5 – 46.6
Rank 1	54.8 – 58.3
Rank 1	60.6 – 62.6
Rank 1	63.2 – 64.1
Rank 1	70.8 – 71.9
Rank 1	73.3 – 74.9
Rank 1	75.4 – 91.0
Rank 1	107.6 – 112.8
Rank 1	120.9 - off map

Table 7: Highway segments identified as priority mitigation sites (Ament et al., 2014).

Priority Mitigation Sites	Mile reference posts (start - end)
7a	8 – 10
6a	23 – 25
8a	49 – 51
8b	56 – 58
9a	81 – 85

4.4. Road sections Identified Based on Biological Conservation Versus Human Safety

It is evident that there is partial overlap in the road sections that are a concern for human safety (Chapter 3) and those that are a concern for biological conservation (this Chapter). However, there are also road sections that are only a concern for human safety and there are other road sections that are only a concern for biological conservation. This is important as it illustrates that a mitigation strategy that focuses on human safety may identify different road sections than a process that focuses on biological conservation. The researchers do not suggest that one strategy is better than the other. The data merely illustrate that the departure point for the analyses (human safety versus biological conservation) has, at least partially, different outcomes.

The differences in outcome between the two analyses (human safety vs. biological conservation) is primarily related to the species involved. The human safety data are by definition dominated by species that are large enough to be a substantial safety concern to humans. The biological conservation analyses are by definition based on relatively rare species, regardless of their body size. In our case the carcass removal data were dominated by common large ungulates. White-tailed deer alone represent more than 90% of the reported carcasses (see Table 2). Crash and carcass relate to mostly large species because large mammals are more likely to be involved with severe accidents than small species, and carcasses of small species are rarely noticed when road maintenance crews inspect the highway from a moving vehicle. Even if road maintenance crews do observe carcasses of small species they may not stop to remove and record these carcasses as they may not represent a substantial danger or distraction to drivers. Furthermore it is logical that common species are hit more frequently than relatively rare species. Thus, common large species dominate the human safety data. On the other hand, species of concern to biological conservation are by definition relatively rare, and it is also relatively rare to find their carcasses along highways. There may not even be any records in areas known to be important habitat for species such as grizzly bear, Canada lynx or wolverine. Even if collisions with rare large species occur, their carcasses are more likely to be quickly removed (legally or illegally) than carcasses of common species. Therefore, the carcasses of rare species may already be gone by the time road maintenance crews come by to inspect the road. Finally, carcasses of small rare species are the least likely to be observed and reported. Thus human safety analyses and analyses for biological conservation are based on different species. Since different species may use different habitat it is to be expected that analyses based on human safety may identify and prioritize different highway sections than analyses based on biological conservation parameters.

5. COST-BENEFIT ANALYSES

5.1. Introduction

Over 40 types of mitigation measures aimed at reducing collisions with large ungulates have been described (see reviews in Hedlund et al., 2004; Knapp et al., 2004; Huijser et al., 2008). Examples include warning signs that alert drivers to potential animal crossings, wildlife warning reflectors or mirrors (e.g., Reeve & Anderson, 1993; Ujvári et al., 1998), wildlife fences (Clevenger et al., 2001; Clevenger & Huijser, 2011), and animal detection systems (Huijser et al., 2006). However, the effectiveness and costs of these mitigation measures vary greatly. When the effectiveness is evaluated in relation to the costs for the mitigation measure, important insight is obtained regarding which mitigation measures may be preferred, at least from a monetary perspective.

5.2. Methods

For the purpose of this report the researchers conducted cost-benefit analyses for four different types and combinations of mitigation measures for U.S. Highway 2 between the Idaho/Montana border and Kalispell. The types and combinations of mitigation measures evaluated for this report included:

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

For details on the effectiveness and estimated costs of the mitigation measures per 0.62 mile (1 km) per year and other methodological aspects of the cost-benefit analyses see Huijser et al. (2009). This publication also provides a rationale for the estimated costs associated with each deer-, elk- and moose-vehicle collision.

For the purpose of these cost-benefit analyses the researchers used only the carcass data as the crash data did not identify the animal species. Note that the analyses are only based on the reported carcasses and that the benefits of reducing collisions are primarily based on human safety related parameters. If passive use values would be included in the cost-benefit analyses, then species with a high conservation value could have a substantial influence on the outcome of the analyses.

For the purpose of the cost-benefit analyses, the category “deer” (see Huijser et al., 2009) included carcasses of white-tailed deer, mule deer, bighorn sheep, mountain lion, black bear, and grizzly bear. “Elk” included only elk, and “moose” included only moose.

5.3. Results

Figure 23 shows for which road sections the costs associated with wildlife-vehicle collisions (based on carcass removal data) were high enough to meet or exceed thresholds for the implementation of four different types of mitigation measures.

Generally speaking there were 3 road sections where the costs associated with wildlife-vehicle collisions exceeded the thresholds for the four different mitigation measures: 1. Between mile marker 30 and 42; 2. Between mile marker 53 and 82; and 3. Between mile marker 99 and 112 (Figure 23).

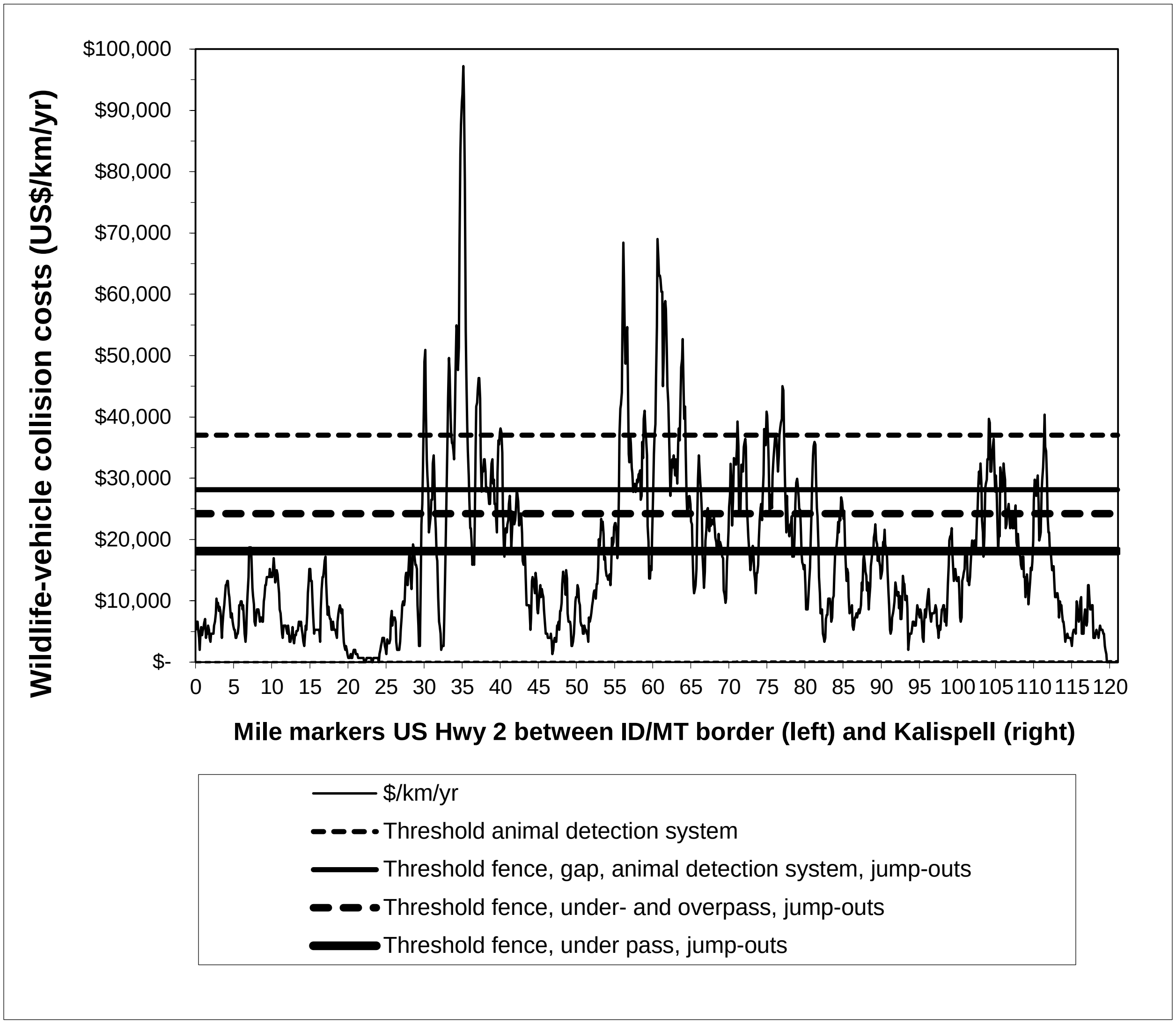

Figure 23: U.S. Hwy 2 from the Idaho/Montana border (left side graph) to Kalispell (right side graph). The costs (jagged line, in 2007 US$) associated with wildlife-vehicle collisions per year (annual average based on carcass data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer.

The crash and carcass removal hotspots were prioritized based on the economic costs associated with each hotspot (Table 8).

Table 8: Prioritization of the carcass hotspots based economics.

Carcass hotspot (start and end mi)	Length (mi)	Carcass costs ($/yr)	Carcass costs ($/mi/yr)	Rank
Disproportionate concentration				
Carcass A (34.9-35.3)	0.4	$ 82,677	$ 206,692	1
Concentration				
Carcass 1 (34.8-35.4)	0.6	$ 92,602	$ 154,337	3
Carcass 2 (37.0-37.2)	0.2	$ 31,100	$ 155,499	2
Carcass 3 (56.4-56.5)	0.1	$ 29,070	$ 290,704	1
Carcass 4 (60.7-61.9)	1.2	$ 27,791	$ 23,160	4

5.4. Discussion and Conclusions

The costs associated with wildlife-vehicle collisions along substantial lengths of U.S. Hwy 2 between the Idaho/Montana border and Kalispell meet or exceed the thresholds for one or more mitigation measures or combinations of mitigation measures. This suggests that implementing effective mitigation measures such as wildlife fencing in combination with under- and overpasses and animal detection systems are likely a wise investment.

While the researchers strongly advise to use the cost-benefit analyses as a decision support tool they also urge users to recognize that these analyses are only one of the factors that may or should be considered in the decision making process. Human safety should perhaps not only be evaluated in dollar values and passive use values for wildlife are currently not included in the cost-benefit analyses.

For carcass data – such as the ones used in this analysis - it is also important to realize that not all carcasses are reported (Tardif and Associates Inc., 2003; Sielecki, 2004; Riley & Marcoux, 2006; Donaldson & Lafon, 2008). Carcass data depend on forms filled out by road maintenance crews that pick up carcasses and dispose of them (Huijser et al., 2007). Animals that die outside of the right-of-way or carcasses that may not be in sight of the drivers may not be picked up and remain unrecorded. Thus even carcass removal data should be regarded as a minimum count rather than an absolute count of the number of large animal-vehicle collisions that occur.

The costs for the average deer-vehicle collision are mostly based on collisions reported to the insurance industry or to law enforcement agencies (Huijser et al., 2009), and one could argue that unreported collisions are likely to be less costly than reported collisions. Therefore, by using carcass data we may have overestimated the average costs of a collision with a deer. On the other hand, insurance industry reports and police accident reports may underestimate ungulate-vehicle collisions by about 50% (Tardif & Associates Inc., 2003; Riley & Marcoux, 2006), and law enforcement agencies may only record a fraction (14%) of the deer–vehicle collisions reported to the insurance industry (Donaldson & Lafon, 2008). Furthermore, in most states and provinces in the United States and Canada, no accident report is filled out by law enforcement agencies if the estimated vehicle damage is less than US$ 1,000 (Huijser et al., 2007). The most conservative approach would be to only include collisions that were reported to the insurance industry or law enforcement agencies and screen the data for potential duplicates. However, based on the studies cited above, it is clear that such an approach may lead to a serious underestimation of the actual costs of collisions with large ungulates, and one may choose to include carcass reports, recognizing that although this may overestimate the average costs associated with a deer–vehicle collision, it may still underestimate the actual number of ungulate–vehicle collisions by about 50%.

The cost-benefit analyses presented in this chapter are based on a four lane divided highway. However, U.S. Hwy 2 is currently only two lanes. If mitigation measures are put in place without widening the road then the thresholds are likely lower than projected in this chapter; there are likely more and longer road sections where the costs associated with wildlife-vehicle collisions meet or exceed the thresholds. This relates especially to the costs for wildlife crossing structures as the number of lanes does not affect the costs for fencing or animal detection systems. If the road is completely reconstructed and widened at the same the mitigation measures are installed there can be overall cost savings, but the costs for the crossing structures will increase compared to those for a two lane road.

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

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

6. PRIORITIZE CRASH AND CARCASS HOTSPOTS BASED ON HUMAN SAFETY, NATURE CONSERVATION AND ECONOMIC PARAMETERS

The crash and carcass hotspots and their rankings with regard to human safety (Chapter 3), nature conservation (Chapter 4) and economics (chapter 5) are summarized in Table 9 and 10. Hotspot "Crash 3" is the hotspot that would have highest priority based on human safety, biological conservation and economics (Table 9).

Table 9: Prioritization of the crash hotspots based on human safety, biological conservation, and economics. The economic thresholds relate to the four mitigation measures described in Chapter 5 (see also Appendix A).*= tie.

Crash hotspot (start and end mi)	Human safety rank	Identified as biological conservation concern?	Economic thresholds exceeded (n)
Disproportionate concentration			
Crash A (117.3-117.6)	1*	No	3
Crash B (119.2-119.4)	1*	No	0
Concentration			
Crash 1 (17.1-17.5)	5	Crucial habitat	0
Crash 2 (18.9-19.0)	2*	Crucial habitat	0
Crash 3 (55.9-56.2)	1	Carcass rare species, Crucial habitat, Priority mitigation site	4
Crash 4 (103.9-104.1)	2*	No	4
Crash 5 (110.3-110.6)	4	Crucial habitat	3
Crash 6 (111.5-112.6)	7	Crucial habitat	3
Crash 7 (116.1-117.7)	6	No	0
Crash 8 (118.8-119.5)	3	No	0

Note that all the carcass hotspots exceeded all four possible economic thresholds (Table 10). This is logical as the cost-benefit analyses were based on the concentration of carcasses (Huijser et al., 2009). Hotspot "Carcass 3" is the hotspot that would have highest priority based on human safety, biological conservation and economics (Table 10).

Table 10: Prioritization of the carcass removal hotspots based on human safety, biological conservation and economics. The economic thresholds relate to the four mitigation measures described in Chapter 5 (see also Appendix A).

Carcass hotspot (start and end mi)	Human safety rank	Identified as biological conservation concern?	Economic thresholds exceeded (n)
Disproportionate concentration			
Carcass A (34.9-35.3)	1	Crucial habitat	4
Concentration			
Carcass 1 (34.8-35.4)	3	Crucial habitat	4
Carcass 2 (37.0-37.2)	2	Crucial habitat	4
Carcass 3 (56.4-56.5)	1	Crucial habitat, Priority mitigation site	4
Carcass 4 (60.7-61.9)	4	Carcass rare species, Crucial habitat	4

7. COMPARISONS BETWEEN USING HUMAN SAFETY, BIOLOGICAL CONSERVATION AND ECONOMICS AS A DEPARTURE POINT

In the previous chapter the crash and carcass hotspots were prioritized based on human safety, biological conservation, and economic parameters. However, the departure point was the crash or carcass hotspots (i.e. a concentration of large mammal-vehicle collisions, particularly with large ungulates) which were then prioritized. In the current chapter we compare the road sections that would have been identified for potential mitigation if a different departure point would have been chosen.

Table 11 is based on the raw data in Appendix A. When we identify all road sections that are a crash or carcass hotspot (based on the definitions and procedures decried in Chapter 3), we end up with 8.0 miles (6.6%) out of the 121.0 miles in the study area (first line, first column in Table 11). Of course, there is 100% overlap with the road sections that are a human safety concern (first column, first row in Table 11). Road sections there were identified as a concern for biological conservation based on the presence of carcasses of rare species, crucial habitat or priority mitigation sites (Chapter 4), covered 76.8 miles (63.5%) out of the 121.0 miles in the study area (second line, second column in Table 11). Road sections where the economic thresholds were exceeded for at least one out of the four mitigation measures (Chapter 5) covered 46.4 miles (38.3%) out) of the 121.0 miles in the study area (third line, third column in Table 11). Thus, it is immediately clear that the crash and carcass hotspots related to a much smaller length of the road in the study area (8.0 miles) than the road sections that were identified to be a concern to biological conservation (76.8 miles), or road sections where it may be financially attractive to invest in mitigation measures (46.4 miles).

Table 11: Prioritization of the carcass removal hotspots based on human safety, biological conservation and economics. The raw data are in Appendix A.

	Secondary		
Departure point (primary)	Human safety	Biological conservation	Economics
Human safety	8.0 (100%)	5.2 (65%)	4.3 (54%)
Biological conservation	5.2 (7%)	76.8 (100%)	31.4 (41%)
Economics	4.3 (9%)	31.4 (68%)	46.4 (100%)

Of the road sections that were identified as a concern to human safety (8.0 miles), 5.2 miles (65%) were also of concern to biological conservation, and 4.3 miles (54%) also exceeded at least one of the four economic thresholds related to the implementation of mitigation measures (Table 11). On the other hand, of the road sections that were identified as a concern for biological conservation, only 5.2 miles (7%) were also of a concern to human safety, and 31.4 miles (41%) exceed at least one of the four economic thresholds for the mitigation measures. Finally, of the road sections that exceeded at least one of the four economic thresholds for the mitigation measures, only 4.3 miles (9%) were also of a concern to human safety, and 31.4 miles (68% were also of concern to biological conservation.

Table 11 shows that if human safety is used as a departure point and if mitigation measures are implemented along the road sections that were identified, that – in most cases - these measures would also benefit biological conservation (65% of the mitigated road length). On the other hand, at if biological conservation is used as a departure point and if mitigation measures are implemented along the road sections that were identified, only a small percentage (7%) would also cover the road sections that were identified as a concern for biological conservation. In other words, if mitigation measures are implemented for all crash and carcass hotspots, then most (65%), but not all, of these sites would also benefit biological conservation. But the vast majority of the sites that are a concern for biological conservation would be left unmitigated (93%) as they were not identified as road sections that were also a concern for human safety.

The data above relate to one particular road section of 121 miles. In addition, the outcome of the comparisons in Table 11 depends heavily on the procedures and cut-off levels that may be used. However, the authors believe that the data presented in Table 11 are indicative of a general principle. The dominating current practice in North America is to select road sections with a concentration of wildlife-vehicle collisions and to then mitigate these road sections with fencing and crossing structures. The data in Table 11 suggest that mitigation measures at the crash and carcass hotspot in typically also benefit biological conservation. However, with the current dominating practice, mitigation is never discussed for the vast majority (in this case 93%) of the road sections that are of concern to biological conservation. This has important consequences for organizations whose mission includes promoting measures that benefit biological conservation. Rather than assuming that mitigation along road sections that have a concentration of wildlife-vehicle collisions will also sufficiently benefit biological conservation, a separate strategy may be required to implement mitigation measures along highway sections that are of greatest concern for biological conservation.

8. CONCLUSIONS AND SUGGESTIONS

- If only wildlife-vehicle collision data are used to identify and prioritize locations along highways that that may require wildlife mitigation measures, then the concern is typically primarily with human safety and reducing collisions with large mammals, specifically the most common ungulates such as white-tailed deer, mule deer, elk and moose.

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

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

- The dominating current practice in North America is to select road sections with a concentration of wildlife-vehicle collisions and to then mitigate these road sections with fencing and crossing structures. Our study illustrated that mitigation measures at the crash and carcass hotspot in typically also benefit biological conservation. However, with the current dominating practice, mitigation is never discussed for the vast majority (in our case 93%) of the road sections that are of concern to biological conservation. This has important consequences for organizations whose mission includes promoting measures that benefit biological conservation. Rather than assuming that mitigation along road sections that have a concentration of wildlife-vehicle collisions will also sufficiently benefit biological conservation, a separate strategy may be required to implement mitigation measures along highway sections that are of greatest concern for biological conservation.

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10. APPENDIX A

Grey cell = present in the 0.1 mi road section concerned.
Human safety = First group of parameters
Biological conservation = Second group of parameters
Economics = Third group of parameters (only 1 column)

Mile reference post	Crash hotspot, disproportionate concentration	Crash hotspot, concentration	Carcass hotspot, disproportionate concentration	Carcass hotspot, concentration		Carcasses rare species (This report)	Crucial habitat (State Wildlife Agencies of the Western United States, 2015)	Priority Mitigation site (Ament et al., 2014)		Economic thresholds exceeded (n)
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