Identification and prioritization of road sections with a relatively high concentration of large wild mammal-vehicle collisions in Gallatin County, Montana, USA

Final Report

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16. Abstract

The primary objective of this project is to identify and prioritize the road sections in Gallatin County that have a relatively high concentration of collisions involving large wild mammals. These road sections may then later be evaluated for potential future mitigation measures aimed at 1. Reducing collisions with large wild mammals, and 2. Providing safe passage across roads for large wild mammals, as well as other wildlife species in the area. We acquired the 3 datasets related to large wild mammal-vehicle collisions in Gallatin County: 1. Wildlife-vehicle crash data collected by law enforcement personnel, 2. Carcass removal data collected by road maintenance personnel; and 3. Grizzly bear road mortality data by the U.S. Geological Survey. The carcass removal data and grizzly bear road mortality data were merged into one carcass database. We conducted separate analyses for the crash data and the carcass data. We conducted two different types of analyses to identify and prioritize road sections with the highest number of wildlife-vehicle crashes and carcasses: 1. Kernel Density Estimation (KDE) analysis that identifies road sections with the highest concentration of collisions, and 2. Getis-Ord Gi* analysis identifies road sections that have statistically significant spatial clusters of collisions. There was great similarity between the hotspots identified through the Kernel Density Estimation analyses for 2008-2022 and 2018-2022 for both the crash and carcass removal data. The same was true for the Getis-Ord Gi* analyses. Especially sections of I-90 and US Hwy 191 between I-90 through Four Corners to the mouth of Gallatin Canyon had the highest concentration of wild animal crashes and large wild animal carcasses. Based on the Getis-Ord Gi* analyses, these road sections generally had concentrations of crashes and carcasses that were significantly higher than expected should the crashes and carcasses have been randomly distributed. In other words, these road sections do not only have the highest concentration of crashes and carcasses, but the identification of these road sections is not based on coincidence. These road sections have a concentration of crashes and carcasses that is beyond random.

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Carcasses, cars, collisions, connectivity, conservation, crashes, crossings, deer, ecology, elk, Getis-Ord Gi* grizzly bears, highways, hotspot, Kernell Density Estimation, mitigation, roads, safety, traffic, ungulates, vehicles, wildlife			
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Disclaimer

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1 Introduction

1.1 Wildlife-vehicle collisions and other impacts of roads and traffic on wildlife

Wildlife-vehicle collisions are becoming increasingly common across much of North America, posing risks to both human safety and the individual animals involved (Huijser et al., 2008; Abraham & Mumma, 2021). In the United States alone, several million collisions with large wild mammals occur annually (Huijser et al., 2009; Conover, 2019). These collisions nearly always result in vehicle damage and costly repairs, but they also cause tens of thousands of human injuries and hundreds of human fatalities each year (Huijser et al., 2008; Huijser et al., 2009; Conover, 2019). In the United States, the financial costs related to vehicle repairs, human injuries, and human fatalities have been estimated to amount to multiple billions of US dollars annually (Conover et al., 1995; Huijser et al., 2009, 2022a).

While there is much emphasis on mitigating vehicle collisions involving large mammals in North America, these types of collisions are not the only reasons to consider wildlife mitigation along highways (Van der Ree et al., 2015). We identify five categories of road and traffic impacts on wildlife (Figure 1):

- Habitat loss: This includes the paved road surface, the heavily altered roadbed with non-native substrate, and the clear zone where native vegetation has been removed and where seeded species and regular mowing occur.
- Direct wildlife mortality: Animals are killed through collisions with vehicles.
- Barrier to wildlife movement: Roads function as barriers, reducing the likelihood that animals cross the road as frequently as they would in habitat without roads. Only a fraction of the animal crossing attempts are successful.
- Decrease in habitat quality near roads: Areas adjacent to roads suffer from noise and light pollution, air and water contamination, and increased human access, all of which degrade habitat quality.
- Right-of-way habitat and corridors: The right-of-way along roads can either promote the spread of non-native or invasive species in largely natural or semi-natural landscapes or serve as a refuge for native species in heavily human-impacted landscapes.

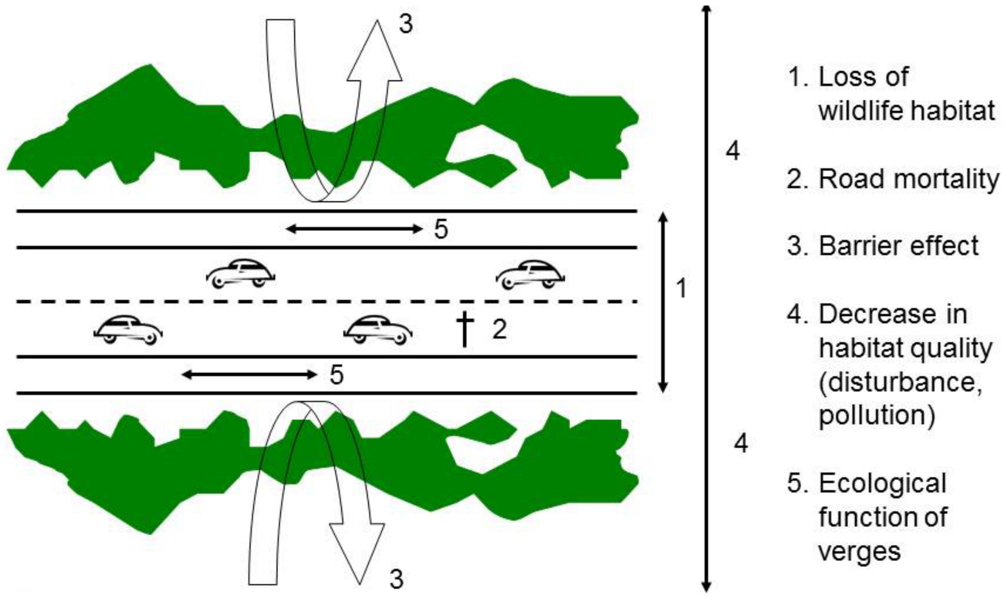

Figure 1: The effects of roads and traffic on wildlife.

In some cases, it is not just the individual animals that suffer from road mortality; entire populations may be affected (van der Zee et al., 1992; Huijser & Bergers, 2000). For some species, road mortality, habitat fragmentation, and other road-related impacts can substantially reduce population survival probability (Proctor, 2003; Huijser et al., 2008). Additionally, certain species have an economic value that is lost when individual animals are killed (Romin & Bissonette, 1996; Conover, 1997; Huijser et al., 2022a). Finally, if road mortality has already depleted local populations in the past, or if animals rarely cross roads because of a substantial barrier effect, road mortality data alone may not be an accurate indicator of where mitigation efforts are most needed for wildlife conservation (Ewen et al., 2013). This issue is further compounded when road mortality data are biased towards large, common species, with little to no data on smaller or rarer species.

1.2 Taking action; the mitigation hierarchy

While mitigation (i.e., reducing the severity of an impact) is common, avoidance is preferable and should generally be considered first in the mitigation hierarchy (Cuperus et al., 1999; Arlidge et al., 2018). For instance, the negative effects of roads and traffic can be avoided entirely if a road is not constructed, or the most severe impacts may be avoided by re-routing roads away from sensitive areas (Figure 2). When avoidance is not possible, mitigation becomes the next logical step. Mitigation efforts typically take place in the road-effect zone (Figure 2) and may include measures aimed at reducing wildlife-vehicle collisions (e.g., installing wildlife fences) and alleviating the barrier effect by providing safe wildlife crossing opportunities (Clevenger & Huijser, 2011; Huijser et al., 2016; Huijser et al., 2021).

However, mitigation may not always be possible, and even when it is, it may not be sufficient. In such cases, a third approach may be considered: compensation or off-site mitigation (Figure 2).

Compensation efforts might involve expanding existing habitat patches, creating new ones, or improving connectivity between the habitat patches to support larger, more connected, and thus more viable populations. Finally, in some situations, a combination of avoidance, mitigation, and compensation strategies may be implemented (Figure 2).

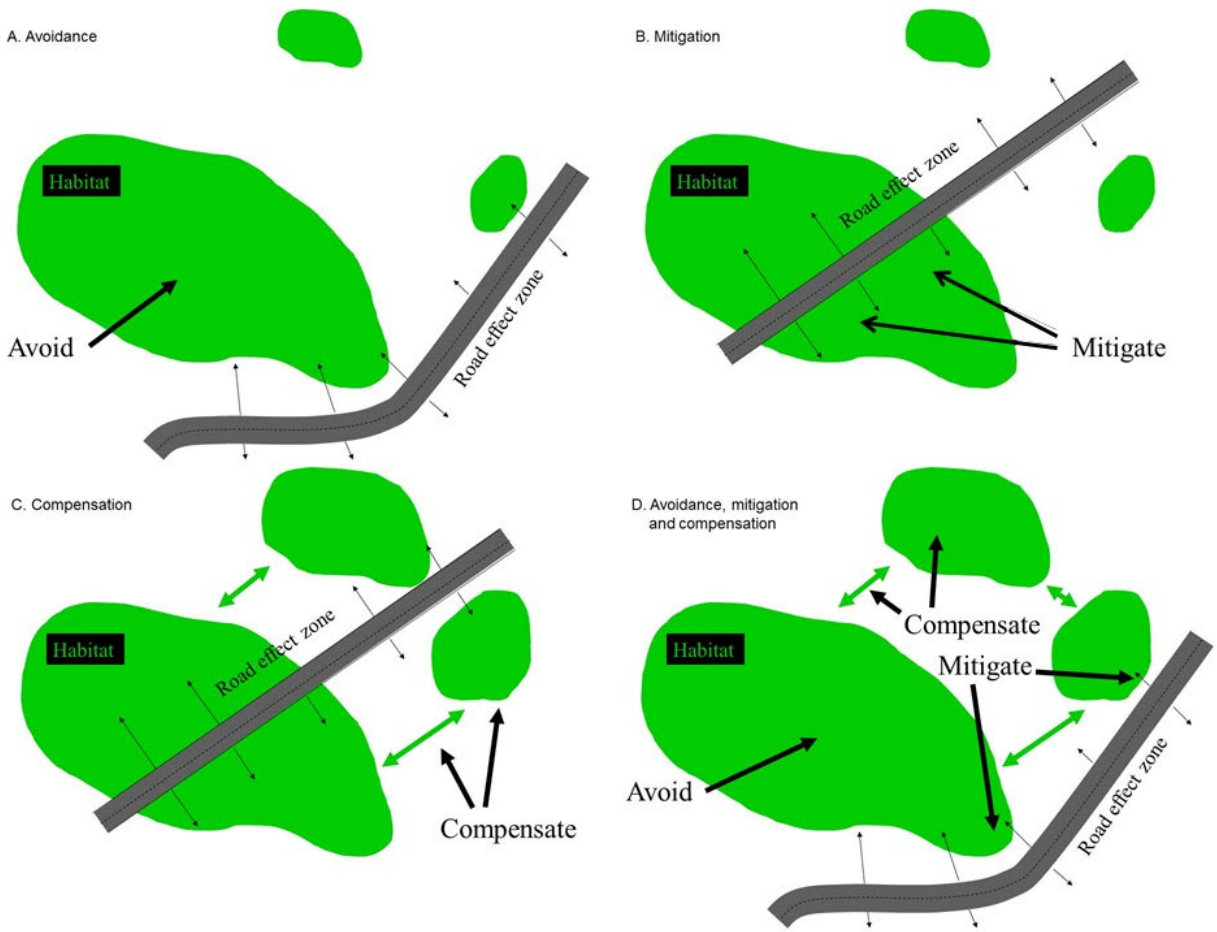

Figure 2: The mitigation hierarchy consists of a three-step approach: A. Avoidance, B. Mitigation, C. Compensation. It is also possible to have a combination of avoidance, mitigation, and compensation (D.).

1.3 Goals and objectives

The goal of this project is to enhance road safety for humans in Gallatin County, Montana, by reducing collisions with large wild mammals, while also ensuring safe crossing opportunities for wildlife.

The primary objective of this project is to identify and prioritize the road sections in Gallatin County that have a relatively high concentration of collisions involving large wild mammals. These road sections may then later be evaluated for potential future mitigation measures aimed at:

- Reducing collisions with large wild mammals.
- Providing safe passage across roads for large wild mammals as well as other wildlife species in the area, including small mammals, reptiles, and amphibians. In wetlands and at stream or river crossings, safe crossing opportunities may also relate to aquatic species, including fish species.

2 Data exploration

2.1 Data sources

We acquired the following data related to large wild mammal-vehicle collisions in Gallatin County:

- **Wildlife-vehicle crash data collected by law enforcement personnel:** These data typically involve more severe crashes, as there are thresholds for the inclusion in a crash database (e.g., a minimum estimated vehicle repair cost of US $1,000 and/or human injuries or human fatalities) (Huijser et al., 2007). In practice, these crashes usually involve large mammal species such as white-tailed deer, mule deer, and elk, though the species name is not always recorded. The crash data were obtained from the Montana Department of Transportation (MDT).
- **Carcass removal data collected by road maintenance personnel:** MDT road maintenance crews collect this data when they remove carcasses of large mammals found on or near the road in the right-of-way. These carcasses may pose an immediate safety hazard or distraction to drivers (Huijser et al., 2007), but not all carcasses that are visible from the road or that are present in the right-of-way are removed or recorded. Typically, these carcasses involve large mammal species such as white-tailed deer, mule deer and elk. Wounded animals that leave the right-of-way before dying are usually not recorded, and carcasses of rare species may be removed by others (legally or illegally) before road maintenance crews arrive. Carcasses of small species are rarely recorded, as they are often not visible from a moving inspection vehicle and do not pose a safety hazard. Therefore, carcass removal data primarily pertain to common large mammals. These data were obtained from MDT.
- **Grizzly bear road mortality data:** Considerable effort was made by the U.S. Geological Survey (USGS) to compile all grizzly bear mortalities in a comprehensive mortality database for the Greater Yellowstone Ecosystem, which includes Gallatin County. We obtained a subset of the data, the records that relate to grizzly bear road mortalities, through the Interagency Grizzly Bear Study Team at USGS.

Note that in this report, the term “collisions” relates to both crashes and carcasses.

2.2 Data selection

- Period: Data from all three sources covered the period from 1 January 2008 through 31 December 2022, totaling 15 full calendar years.
- Roads included: All MDT on-system roads in Gallatin County, such as Interstates, US Highways, and numbered MT Highways, including MT 64 (Figure 3; Figure 4). Other roads were not included.
- Species: Only records that related to wild animal species were included. Records involving domesticated animal species were removed.
- Species size: For the MDT carcass database, only records that related to species larger than coyotes were included.
- Maximum distance from road: Collision records within 25 meters (m) of on-system roads were included, while those beyond 25 m were excluded from the analysis. In cases where locations could be projected onto more than one road, we verified the projections and removed duplicates.
- Carcass data: Carcass removal data, collected by MDT road maintenance personnel, were combined with grizzly bear road mortality data compiled by researchers from USGS into one database.

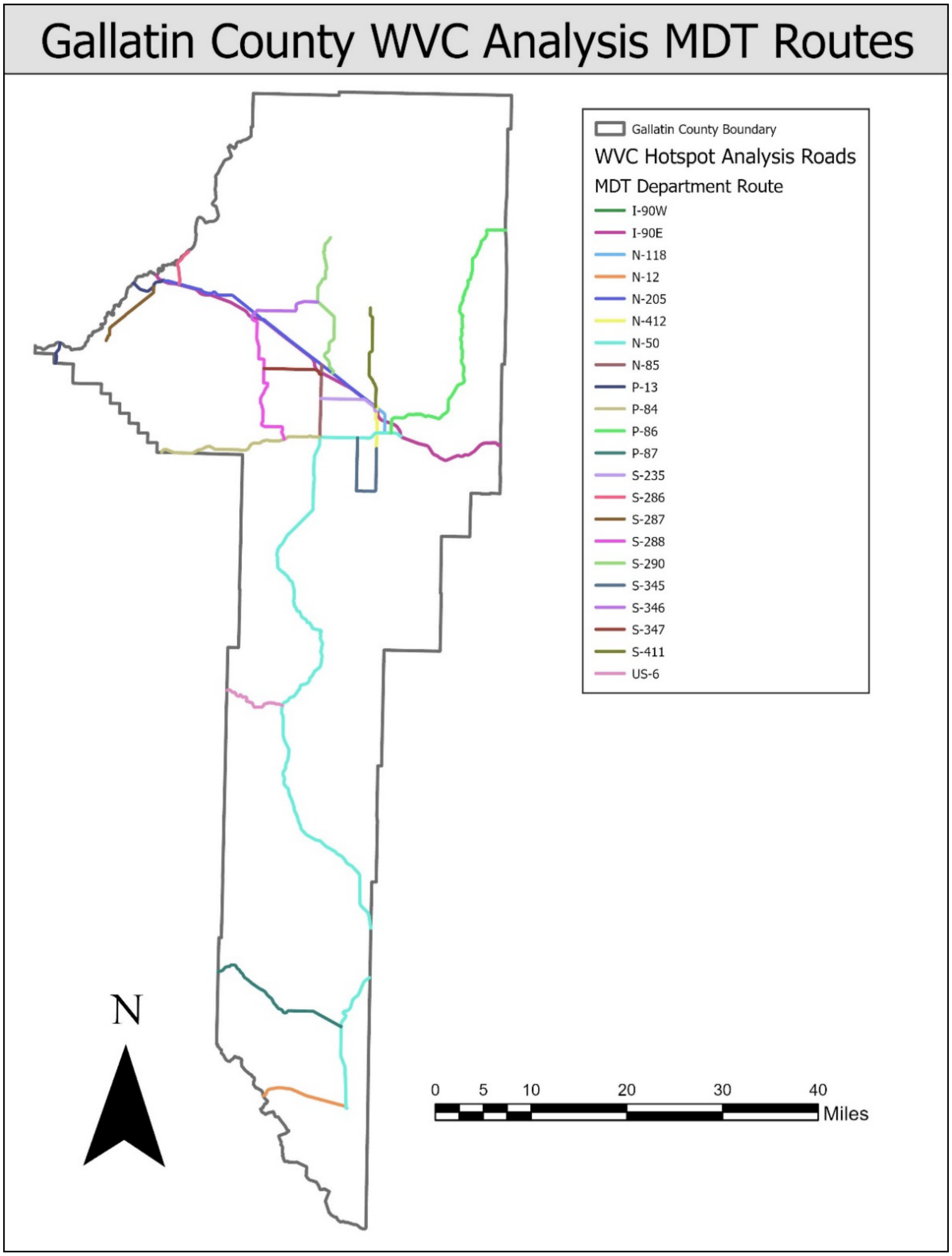

Figure 3: The selected roads in Gallatin County.

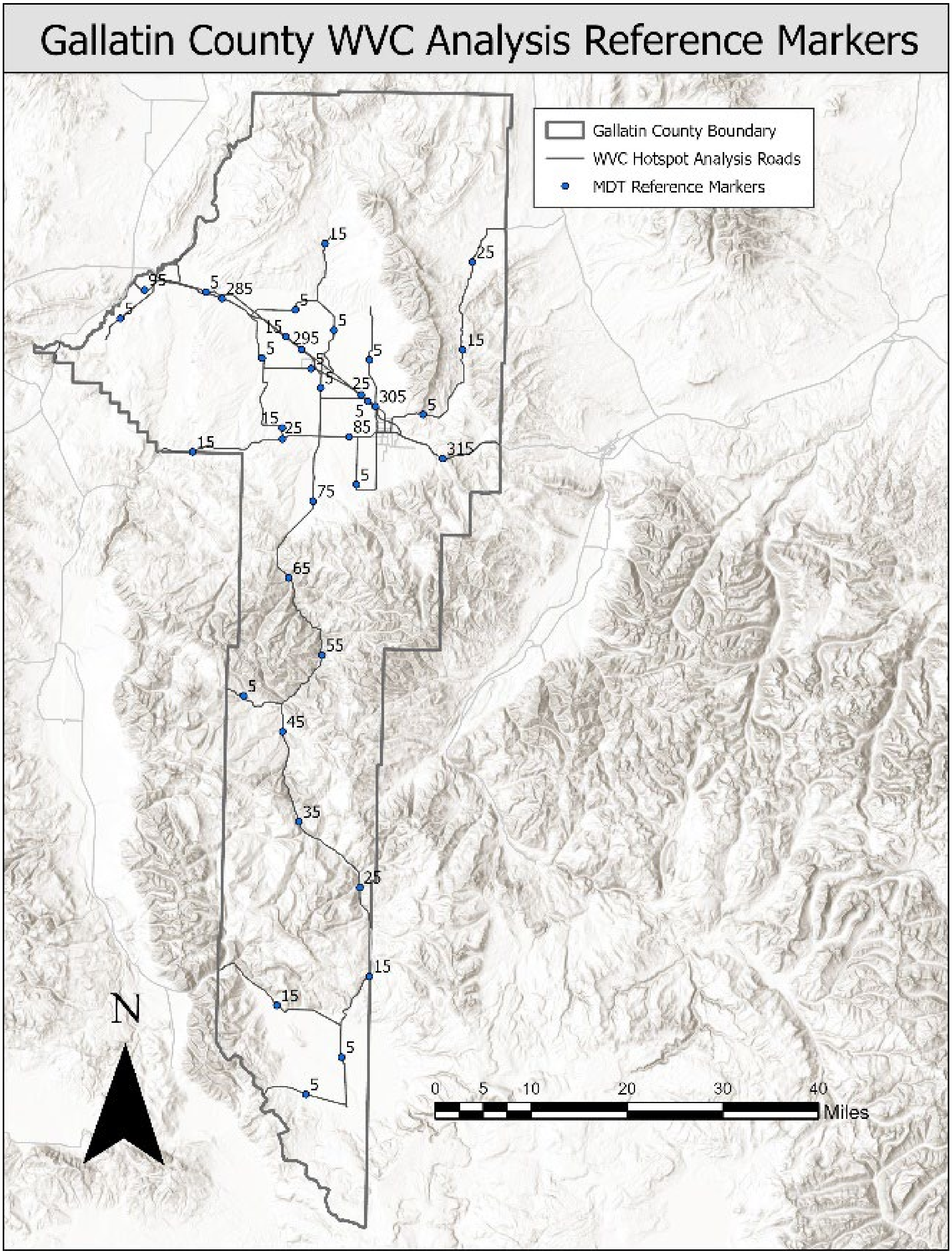

Figure 4: The mile reference posts along the selected roads in Gallatin County.

2.3 Number of records

The data selection resulted in 2,158 crash records and 3,746 carcass records of large wild animal species. Notably, the MDT carcass data included three reported grizzly bear incidents. Two of these were also recorded in the USGS database. However, the third grizzly bear observation, located near Four Corners, was not present in the USGS database. This suggests that the animal may have been a brown-colored or cinnamon-colored black bear, though we have no means to verify the species identification. Therefore, the record was retained. Additionally, the USGS database included six grizzly bear roadkill observations that were not present in the MDT carcass database. This brings the total number of recorded grizzly bear carcasses in Gallatin County between 2008 and 2022 to nine, three observations from MDT and six additional observations by USGS.

2.4 Species retained in the carcass data

The most common species in the selected carcass removal data (a combination of MDT carcass data and USGS grizzly bear road mortality records) was white-tailed deer (70.07% of all records) (Table 1). Mule deer (16.68%) and elk (8.33%) were the second and third most frequently recorded species. Other notable species include bighorn sheep, bison, mountain lion, wolf, black bear, and grizzly bear.

Table 1: Species retained in the carcass database (combination of MDT carcass removal data and grizzly bear road mortality data from USGS).

Species	**Total (N)**	**Total (%)**
Ungulates		
Pronghorn (*Antilocapra americana*)	6	0.16
White-tailed deer (*Odocoileus virginianus*)	2625	70.07
Mule deer (*Odocoileus hemionus*)	625	16.68
Unknown deer species (*Odocoileus* spp.)	15	0.40
Elk (*Cervus canadensis*)	312	8.33
Moose (*Alces alces*)	47	1.25
Mountain goat (*Oreamnos americanus*)	1	0.03
Bighorn sheep (*Ovis canadensis*)	21	0.56
Bison (*Bison bison*)	58	1.55
Carnivores		
Mountain lion (*Puma concolor*)	3	0.08
Gray wolf (*Canis lupus)*	2	0.05
Black bear (*Ursus americanus*)	22	0.59
Grizzly bear (*Ursus arctos horribilis*)	9	0.24
Total	3746	100.00

2.5 Number of collisions per year

The number of reported crashes with wild mammals increased between 2008 and 2015, then stabilized through 2019, followed by a slight decline in crashes recorded after 2019 (Figure 5). In contrast, the number of reported large wild mammal carcasses declined substantially between 2008 and 2022 (Figure 5). In 2008, there were approximately 4.5 reported large wild mammal carcasses for every reported wild mammal crash, whereas between 2020 and 2022 there were only 0.7 to 1.1 carcasses for every reported crash (Figure 6).

A potential explanation for the decline in the number of reported carcasses, relative to crashes, could be the passing of a bill that allowed for the salvage of deer, elk, moose, and pronghorn killed by vehicles, which permits anyone (not just the driver involved) to take the animal, as long as a permit is obtained within 24 hours (Montana Fish, Wildlife & Parks, 2023; State of Montana, 2023). However, this bill only passed in 2013 and does not account for the substantial drop in carcasses reported between 2008 and 2013. Between 2014 and 2022, the average number of salvage permits issued in Gallatin County was 100.44 (SD=13.93) (Appendix A). If we assume that all the carcasses for which a salvage permit was issued would have been recorded by MDT maintenance crews, it can explain some of the “missing” carcass removal data between 2014 and 2022, but not all. A more realistic scenario is that only 1 in 8 carcasses are reported by MDT maintenance crews (Fairbank et al., 2024). Then the salvage permits could potentially account for 12.55 missing carcasses per year between 2014 and 2022. Another possible explanation is a reduction in the search and reporting effort by MDT road maintenance crews.

Research shows that crash data typically represent only a small portion (14-50%) of the carcass data, even if both datasets relate solely to large mammals (Tardif and Associates Inc., 2003; Riley & Marcoux, 2006; Donaldson & Lafon, 2008). It is important to note that carcass data are also incomplete; animals that are not clearly visible from the road may not be removed or recorded. Studies have demonstrated that carcass counts often underestimate the number of large mammals hit by vehicles; correction factors of 2.8 (Lee et al., 2021) and nearly 8.0 (Fairbank et al., 2024) have been reported in other areas.

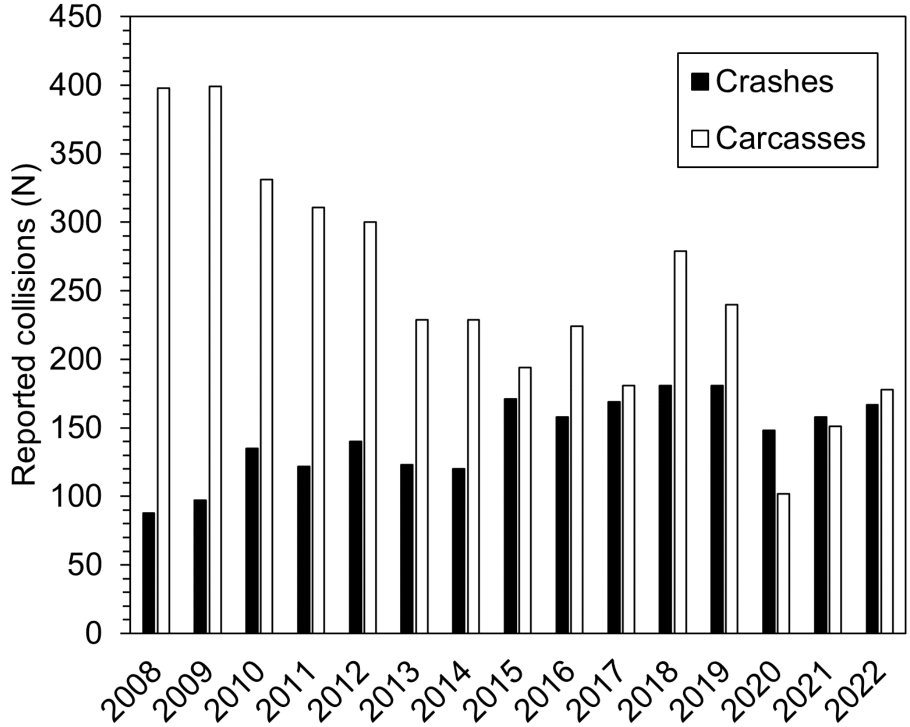

Figure 5: The number of reported crashes with wild animal species and large wild mammal carcasses by year.

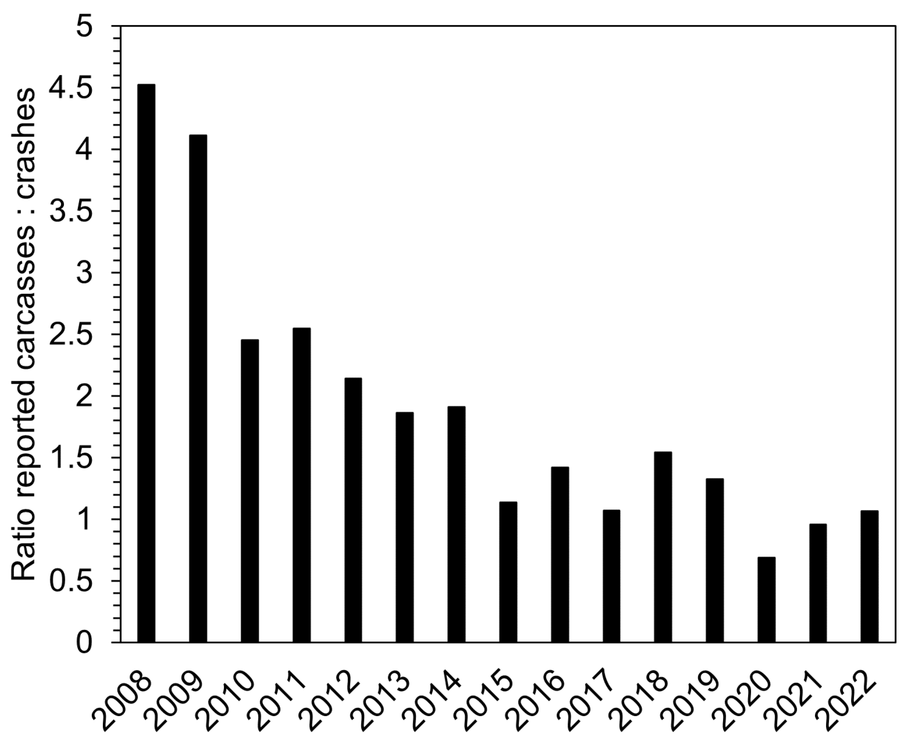

Figure 6: The ratio of the number of reported large wild mammal carcasses and crashes with wild animal species by year.

2.6 Number of collisions per month

The number of reported crashes with wild animals was highest in the fall, particularly in November, and lowest between March and May (Figure 7), consistent with findings by Huijser et al. (2008). The number of reported carcasses with large wild animals was highest during the fall and winter (October through March, with a notable peak in November) and was lowest in the spring and summer (April through September) (Figure 7).

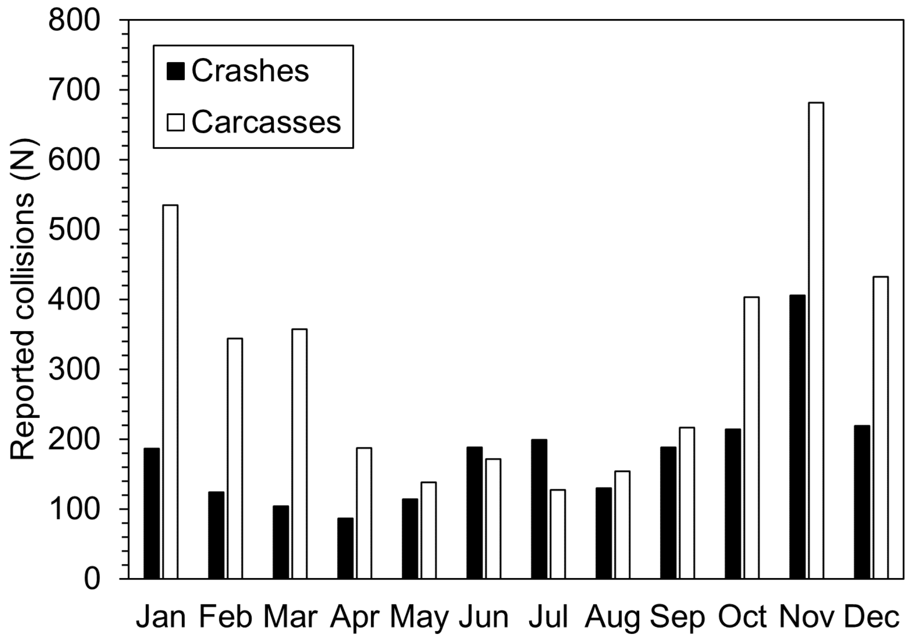

Figure 7: The number of reported crashes with wild animal species and large wild mammal carcasses by month.

2.7 Number of crashes by hour of day

Wild animal crashes occurred predominantly in the early morning (5-7 am) and in the evening and early night (5-10 pm) (Figure 8), which is consistent with Huijser et al. (2008). Fewer collisions were reported between 9 am and 4 pm. It is important to note that the time-of-day data was only available for crash data, not for carcass removal data.

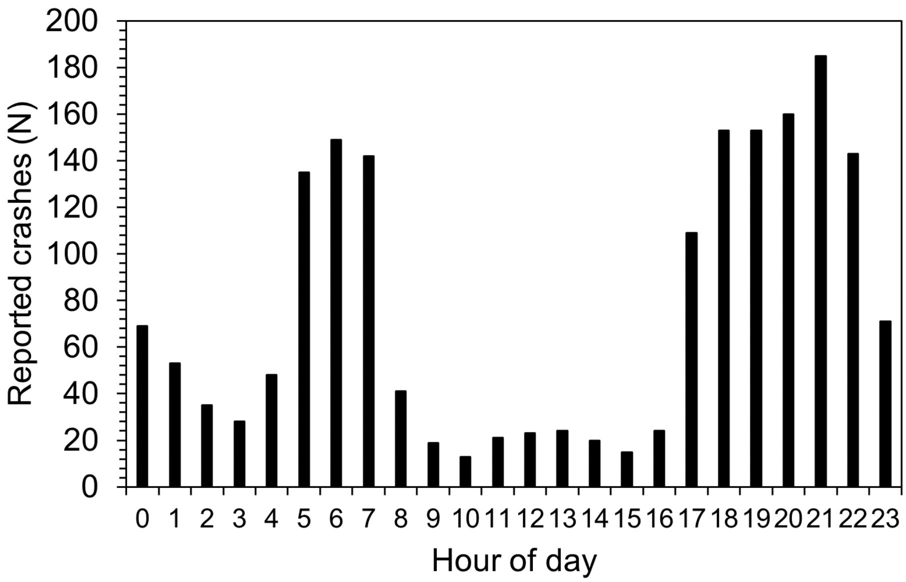

Figure 8: The number of reported crashes with wild animal species by hour of day (2008-2020 only (N=1833), hour of day was not available for 2021 and 2022).

2.8 Severity of the crashes for humans

Most of the reported crashes involving wild animals resulted in property damage only (94%), consistent with Huijser et al. (2008) (Figure 9). Approximately 6% of the crashes resulted in a human injury, and there were no reported human fatalities (Figure 9). Note that data on the severity of collisions for humans was only available for crash data, not for carcass removal data. While human fatalities can occur with large mammal collisions, the probability is generally low but increases with the size of the animal (Huijser et al., 2009).

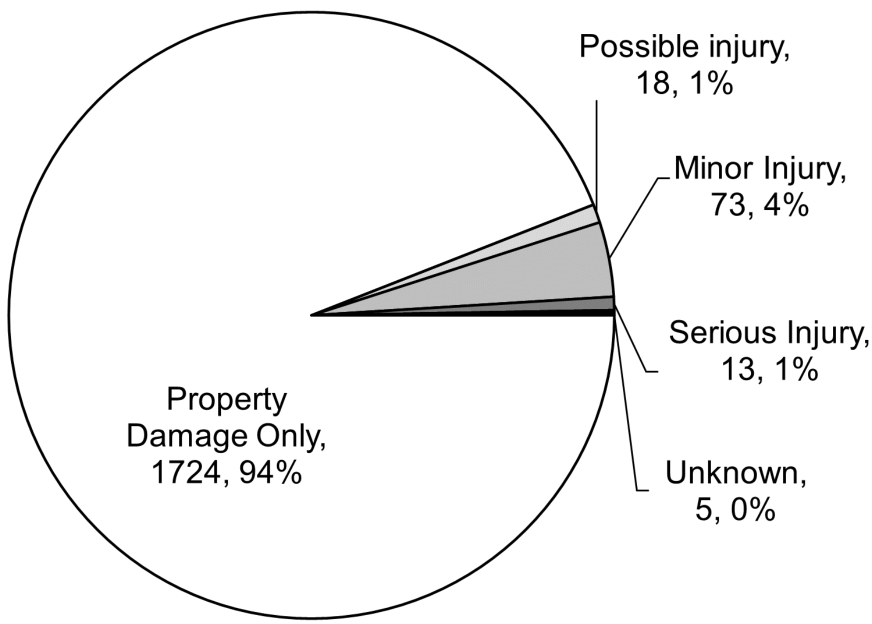

Figure 9: The severity for humans of the reported crashes with wild animal species (2008-2020 only (N=1833), not available for 2021 and 2022).

2.9 Spatial accuracy of the collision data

Crashes are reported by law enforcement who use a GPS to obtain coordinates for the crash location. For our analyses, the crash locations were assigned to the nearest tenth of a mile road segment. As expected with precise GPS coordinates, the number of crash observations for each tenth of a mile (ignoring the whole mile numbers) closely matched what was expected based on the relative frequency of each tenth of a mile along the roads in Gallatin County (the horizontal line in Figure 10). In contrast, the carcass removal data from MDT are typically estimated to the nearest tenth of a mile based on the whole mile reference posts that are present along the system roads. Ideally, if there were no bias in noting the first decimal (the number following the dot), the number of carcass observations for each tenth of a mile (ignoring the whole mile numbers) should also align with the expected frequency along the roads in Gallatin County. However, whole mile markers (“0”) were recorded about 2.5 times more frequently than expected (Figure 10). Half mile markers (“5”) were noted about 1.2 times more frequently than expected. All other first decimals were noted less frequently than expected (Figure 10). This suggests that the location description for crash data is accurate and precise to at least the nearest tenth of a mile, while the carcass removal data from MDT is only accurate to the nearest whole mile.

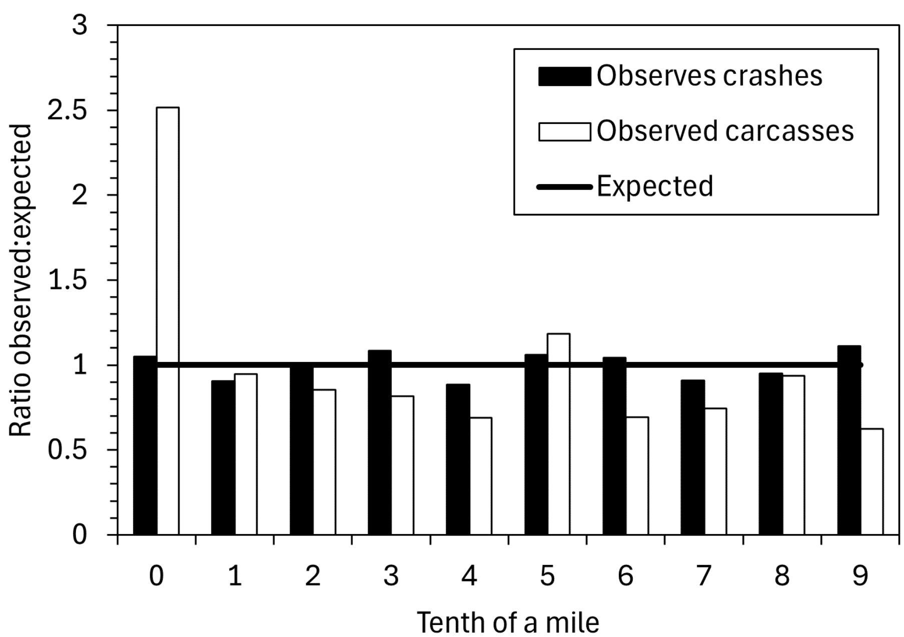

Figure 10: The ratio of number of observed vs. expected wild animal crashes and large mammal carcasses per tenth of a mile (regardless of the whole mile reference post) between 2008-2022.

3 Identification and prioritization of road sections

3.1 Introduction

This chapter focuses on identifying and prioritizing road sections in Gallatin County that have a relatively high concentration of wildlife-vehicle crashes and large mammal carcasses. All spatial data were projected using the NAD 1983 StatePlane Montana FIPS 2500 coordinate system, with meters as the unit of measurement. All spatial analyses were conducted using ArcGIS Pro 3.1.2.

3.2 Methods

3.2.1 Kernel Density Estimate and Getis Ord Gi* hotspot analyses

We conducted two different types of analyses to identify and prioritize road sections with the highest number of wildlife-vehicle crashes and carcasses:

3.2.1.1 Kernel Density Estimation (KDE)

The Kernel Density Estimation (KDE) analysis was used to assess point features of crash or carcass locations. A bandwidth of 0.5 miles (804.67 m) was applied, meaning that crashes and carcasses within 0.5 miles of each tenth-of-a-mile reference point influenced the hotspot analysis. This is consistent with the spatial accuracy of the carcass removal data from MDT and the scale at which mitigation measures (e.g., wildlife fences and crossing structures) need to be implemented, typically over several miles of road (Huijser et al., 2016). The search radius is also aligned with similar studies (Gomes et al., 2009).

The analysis produces a density surface where each cell's size is 100 m by 100 m and its value represents the estimated density of collisions per square kilometer. The resulting heat map was divided into five percentage-based categories (<5%, 5–<25%, 25–<50%, 50–<75%, and 75–100%), identifying road sections with the highest densities of collisions and carcasses. This is a descriptive method that always indicates where the highest concentrations of incidents occur. The KDE analyses were conducted using the Spatial Analyst extension in ArcGIS Pro 3.1.2.

*3.2.1.2 Getis-Ord Gi**

The Getis-Ord Gi* analysis used the Getis-Ord Gi* statistic to identify statistically significant spatial clusters (hotspots and cold spots) of crashes and carcasses. Unlike the KDE, which is purely descriptive, this analysis determines where the concentration of crashes or carcasses significantly deviates from a random distribution. A fixed distance band of 0.5 miles was applied, consistent with the KDE analysis. No standardization of spatial weights was applied; all wildlife species were considered equal in contributing to the collision events. This analysis was conducted using the Hotspot Analysis (Getis-Ord Gi*) tool within the Spatial Statistics toolbox in ArcGIS Pro 3.1.2.

3.2.2 Time period

The crash and carcass data were analyzed separately. Additionally, we conducted the analyses for two different time periods:

- 2008-2022 (15 years): This analysis used all available crash and carcass data over a 15-year period. This extended timeframe provides a relatively robust analysis, as the relatively large sample size of crashes and carcasses increases the likelihood of accurately identifying road sections with the highest concentrations of wildlife-vehicle collisions.
- 2018-2022 (5 years): This analysis used only the most recent 5-year period of available crash and carcass data. Although the sample size is smaller compared to the 15-year dataset, this period is more reflective of recent land use changes and associated potential changes in wildlife-vehicle collisions.

3.3 Results

3.3.1 Kernell Density Estimation (KDE) analyses

The KDE hotspot maps for crashes are depicted in Figure 11 (2008-2022) and Figure 12 (2018-2022). The KDE hotspot maps for carcasses are depicted in Figure 13 (2008-2022) and Figure 14 (2018-2022).

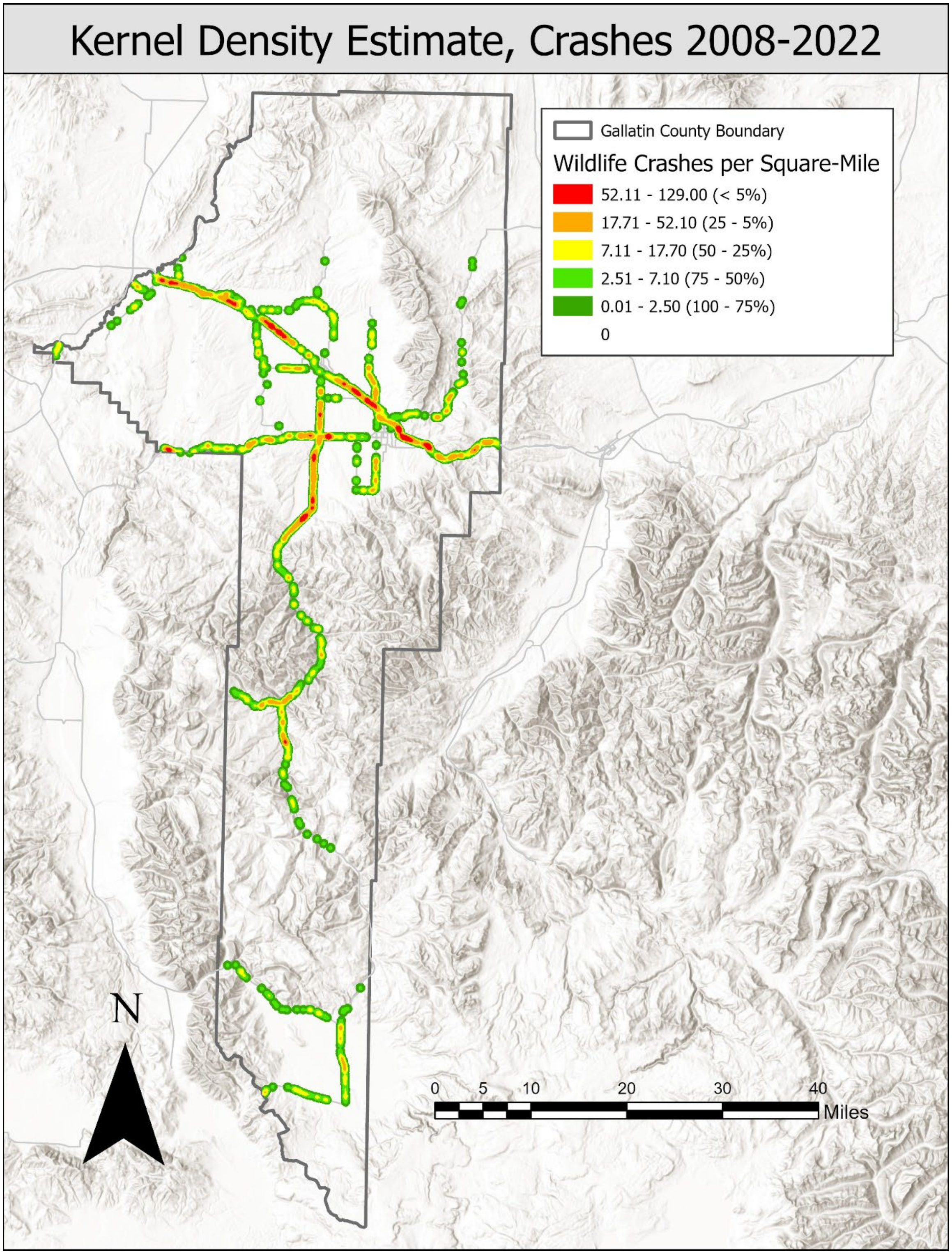

Figure 11: Kernel density hotspot map using percentiles for wildlife-vehicle crashes in Gallatin County, Montana (2008–2022).

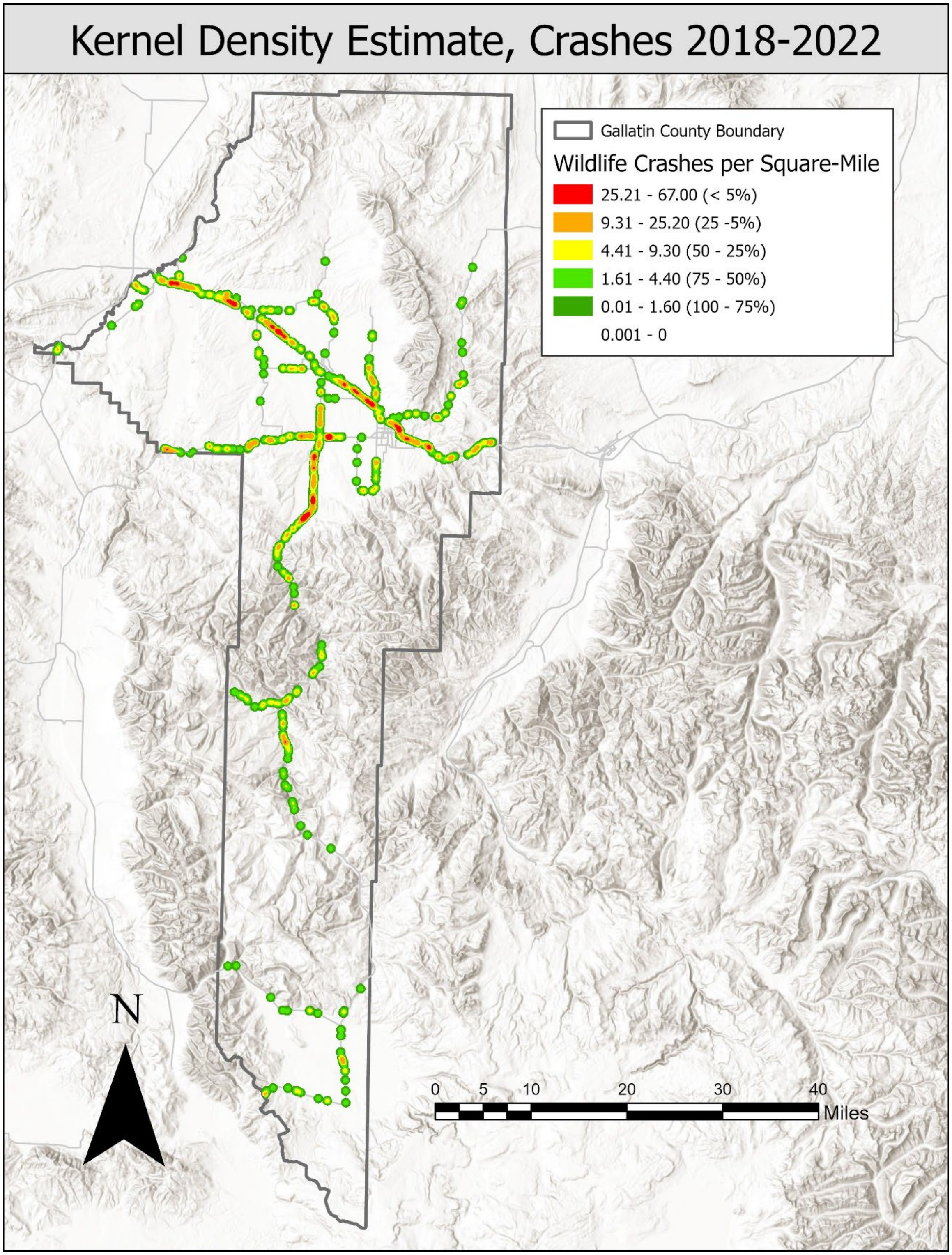

Figure 12: Kernel density hotspot map using percentiles for large wild mammal crashes in Gallatin County, Montana (2018–2022).

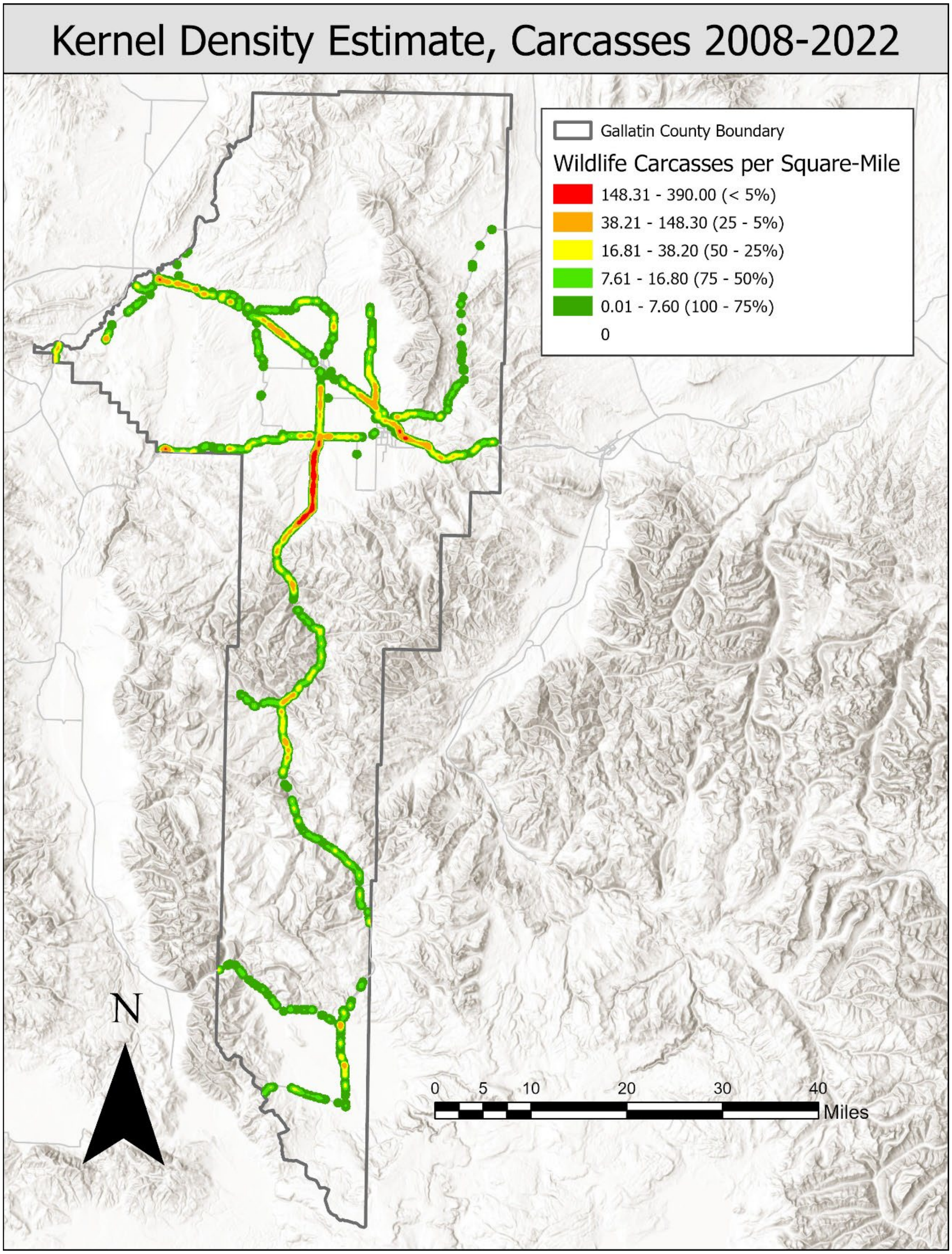

Figure 13: Kernel density hotspot map using percentiles for large wild mammal carcasses in Gallatin County, Montana (2008–2022).

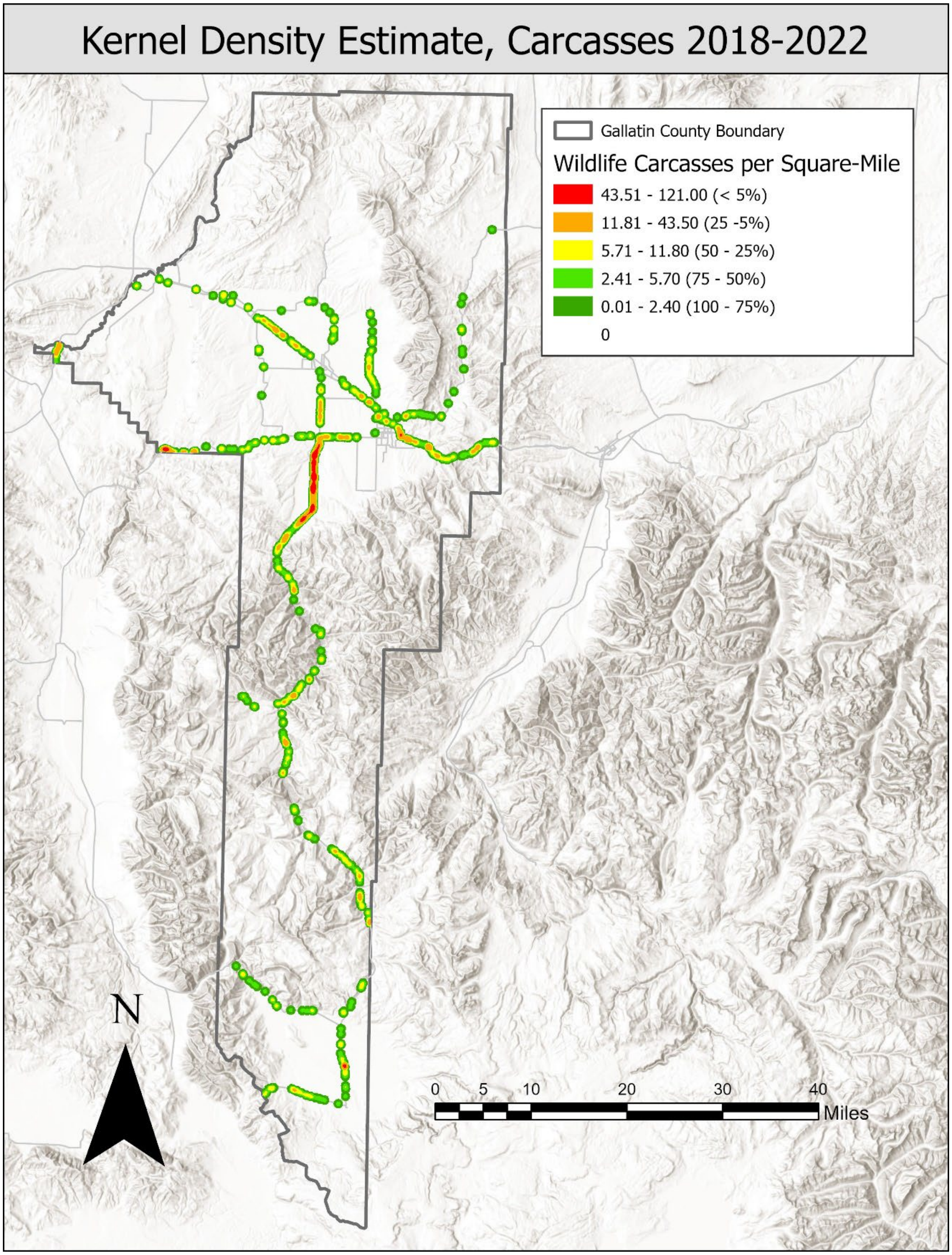

Figure 14: Kernel density hotspot map using percentiles for large wild mammal carcasses in Gallatin County, Montana (2018–2022).

3.3.2 Getis-Ord Gi* analyses

The Getis-Ord Gi* hotspot maps for crashes are depicted in Figure 15 (2008-2022) and Figure 16 (2018-2022). The Getis-Ord Gi* hotspot maps for carcasses are depicted in Figure 17 (2008-2022) and Figure 18 (2018-2022).

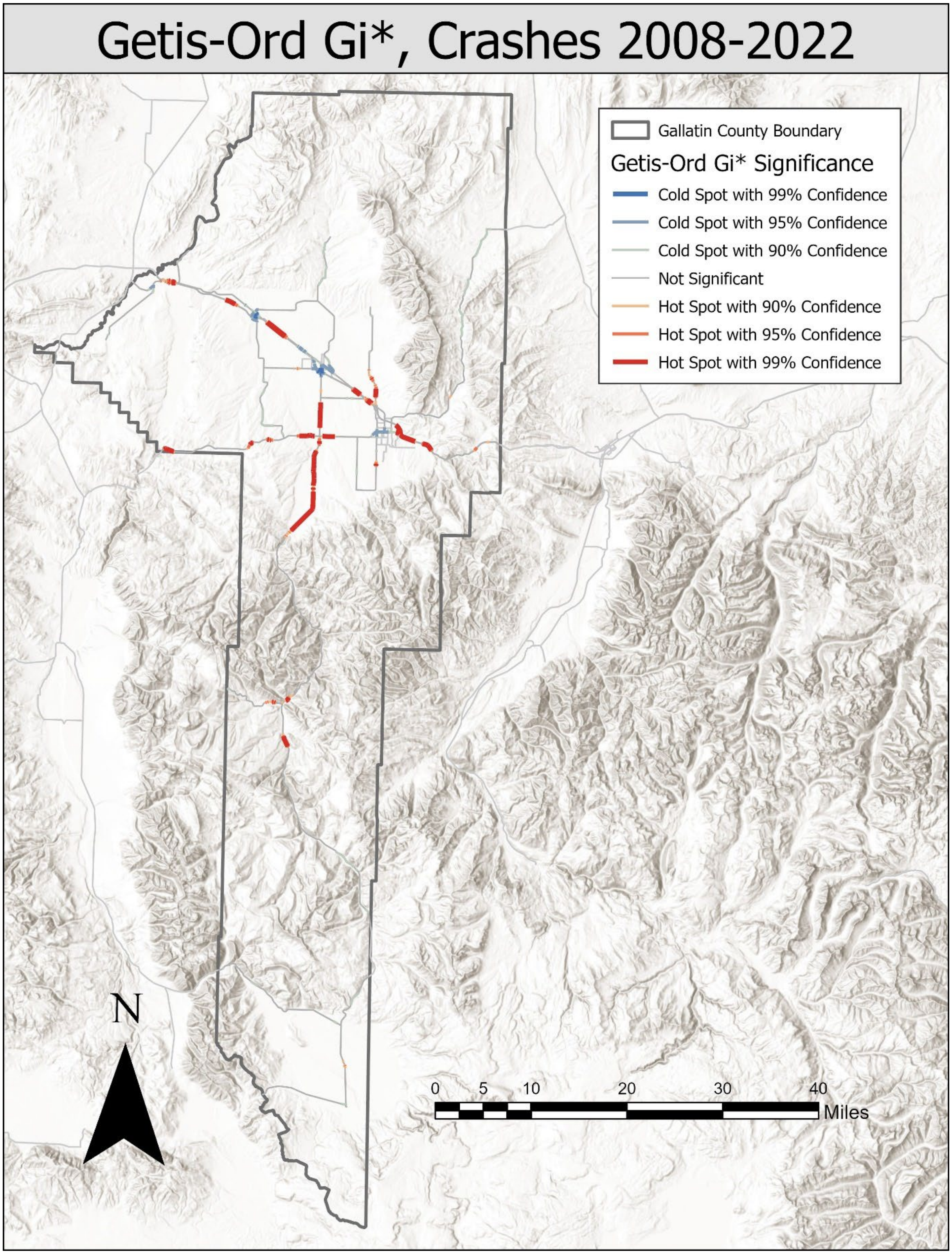

Figure 15: Significant hotspots and cold spots based on Getis-Ord Gi analysis for wildlife-vehicle crashes in Gallatin County, Montana (2008–2022).*

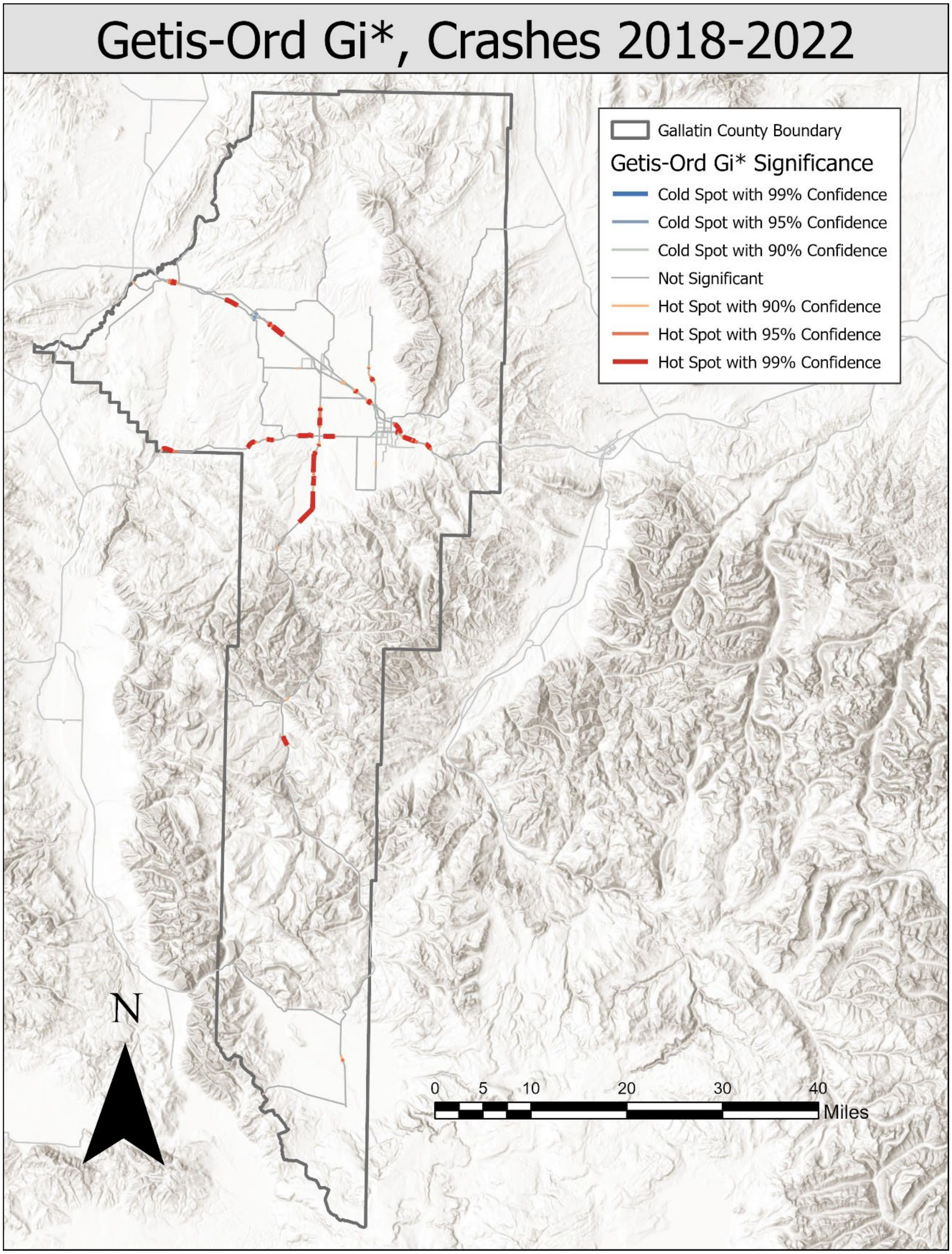

Figure 16: Significant hotspots and cold spots based on Getis-Ord Gi analysis for wildlife-vehicle crashes in Gallatin County, Montana (2018–2022).*

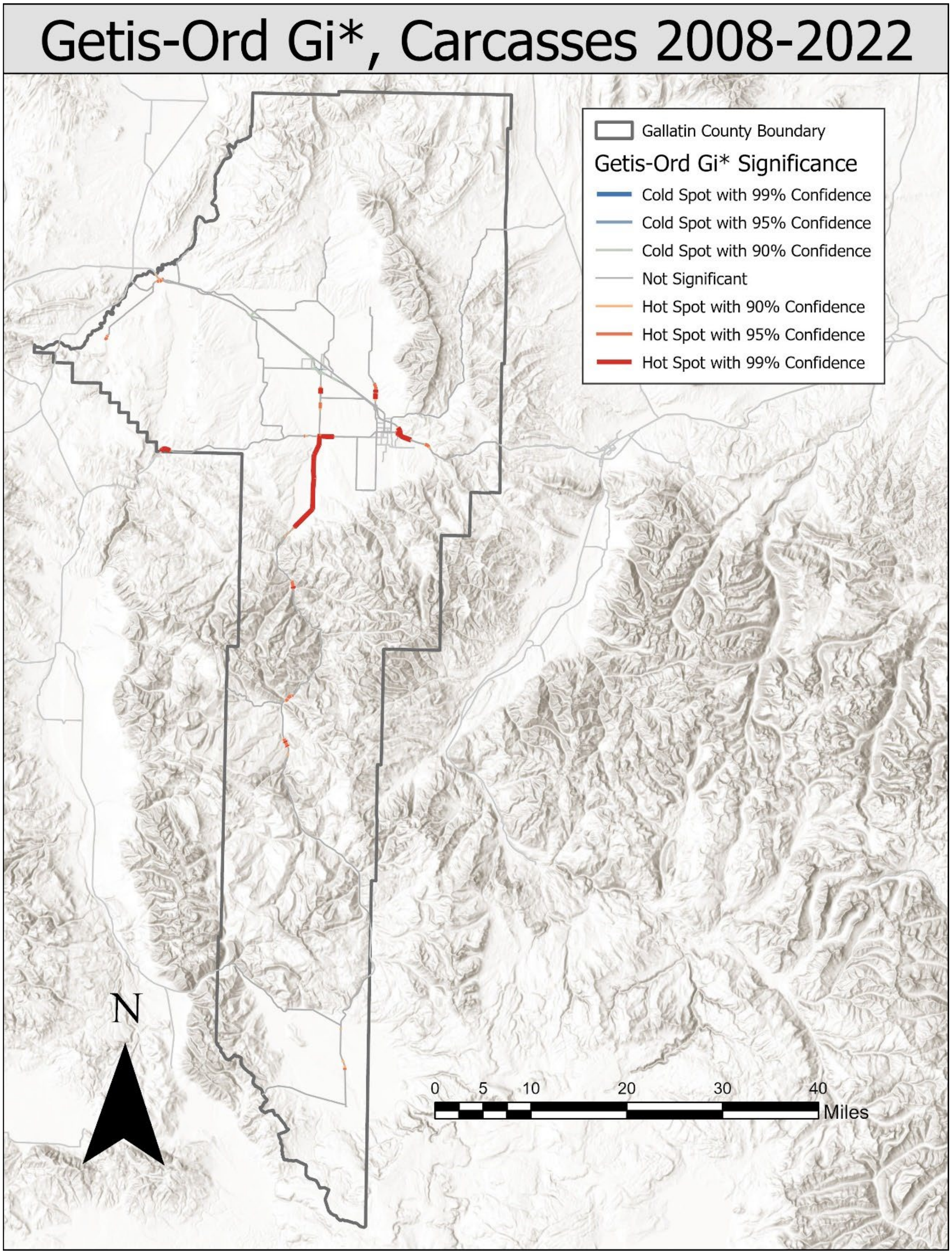

Figure 17: Significant hotspots and cold spots based on Getis-Ord Gi analysis for large wild mammal carcasses in Gallatin County, Montana (2008–2022).*

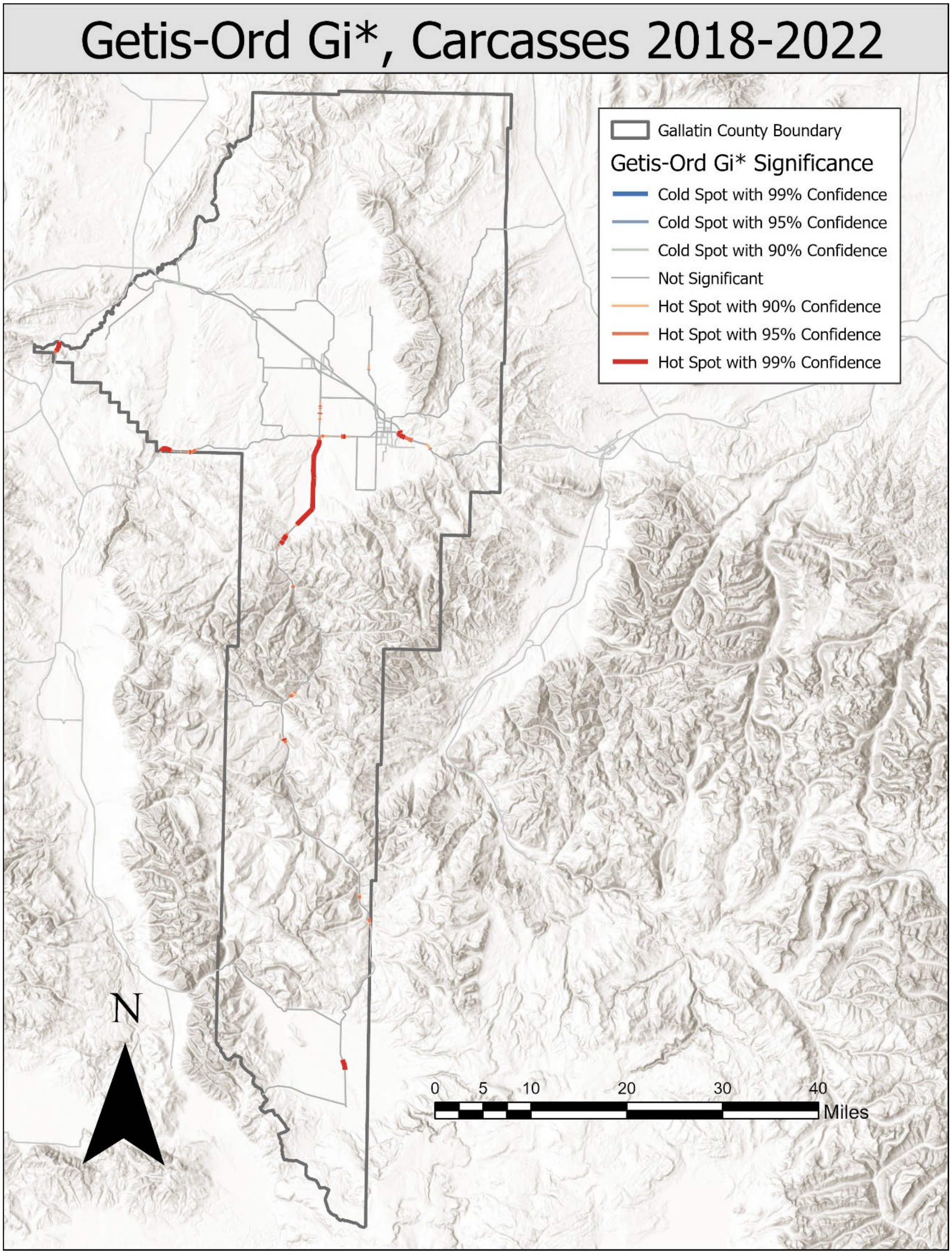

Figure 18: Significant hotspots and cold spots based on Getis-Ord Gi analysis for large wild mammal carcasses in Gallatin County, Montana (2018–2022).*

3.4 Discussion

There is great similarity between the hotspots identified through the KDE analyses for 2008-2022 and 2018-2022 for both the crash and carcass removal data. The same is true for the Getis-Ord Gi* analyses. Especially sections of I-90 and US Hwy 191 between I-90 through Four Corners to the mouth of Gallatin Canyon had the highest concentration of wild animal crashes and large wild animal carcasses. Based on the Getis-Ord Gi* analyses, these road sections generally had concentrations of crashes and carcasses that were significantly higher than expected should the crashes and carcasses have been randomly distributed. In other words, these road sections have not only the highest concentration of crashes and carcasses, but the identification of these road sections is not based on coincidence. These road sections have a concentration of crashes and carcasses that is beyond random.

From a human safety perspective, it would make sense to explore potential mitigation options first along the identified road sections. Note that from the perspective of biological conservation, the reduction of collisions for certain species (e.g., grizzly bear) would be of higher priority than other species (e.g., white-tailed deer) (Huijser et al., 2022b). This means that other road sections than the ones identified in this report may also require mitigation measures. In addition, from the perspective of biological conservation, reducing the barrier effect of roads and traffic may be required in yet other road sections (Huijser et al., 2022b).

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5 Appendix A: Salvage permits for roadkilled ungulates

In 2013, the Montana legislature passed a bill that allowed for the salvage of deer, elk, moose, and pronghorn killed by vehicles, which permits anyone (not just the driver involved) to take the animal, as long as a permit is obtained within 24 hours (Montana Fish, Wildlife & Parks, 2023; State of Montana, 2023). We obtained the salvage permit records from Montana Fish, Wildlife & Parks between 2013 (first record was 26 November 2013) and 31 December 2022. We then selected the records that related to Gallatin County. There were 920 salvage permits issued in total in Gallatin County (Figure 19). The average number of salvage permits per year between 2014 and 2022 in Gallatin County was 100.44 (SD=13.93) (Figure 19). Note that 2013 was excluded from the calculations as the 2013 data did not relate to a full calendar year.

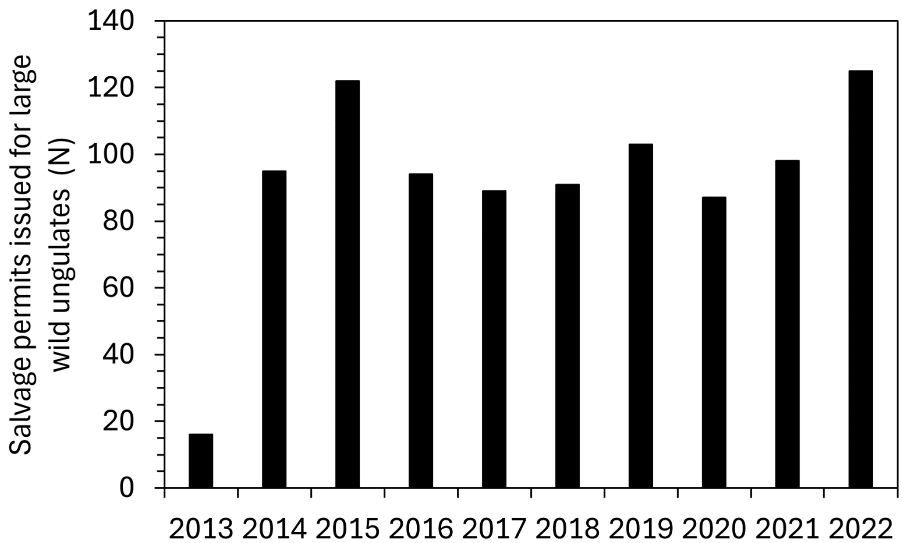

Figure 19: The number of salvage permits issued for roadkilled large ungulates in Gallatin County between 2013 and 2022.

6 Appendix B: I-90 Bozeman Pass

6.1 Data sources, data selection and data summary

This appendix relates to I-90 Bozeman Pass between Bozeman (junction with 7th Ave, mile-marker (MM) reference point 305) and Livingston (junction with US Hwy 89, MM 333).

The crash and carcass data sources, data selection procedure, and data analyses were similar to those described for Gallatin County. Note that there were no reported grizzly bear road mortalities in the USGS database for this road section.

The carcass removal data collected by MDT road maintenance personnel data was only recorded on the eastbound lanes, not on the westbound lanes. West and eastbound lanes are up to 0.21 mile apart on this road section, well within the search radius of 0.50 mile applied in the analyses.

Crash data

After data selection, 483 wildlife-vehicle crash records remained between 2008 and 2022.

Carcass data

After data selection, 666 large wild animal carcass records remained between 2008 and 2022 (Table 2). White-tailed deer (73.72%) and mule deer (20.12%) were the most frequently reported large wild animal carcasses.

Table 2: The species that were retained in the carcass database for Bozeman Pass (combination of MDT carcass removal data and grizzly bear road mortality data from USGS).

Species	Total (N)	Total (%)
Ungulates		
White-tailed deer	491	73.72
Mule deer	134	20.12
Unknown deer species	2	0.30
Elk	23	3.45
Moose	4	0.60
Carnivores		
Mountain lion	1	0.15
Black bear	11	1.65
Total	666	100.00

6.2 Hotspot maps

6.2.1 Kernell Density Estimation (KDE) analyses

The KDE hotspot maps for crashes are depicted in Figure 20 (2008-2022) and Figure 21 (2018-2022). The KDE hotspot maps for carcasses are depicted in Figure 22 (2008-2022) and Figure 23 (2018-2022).

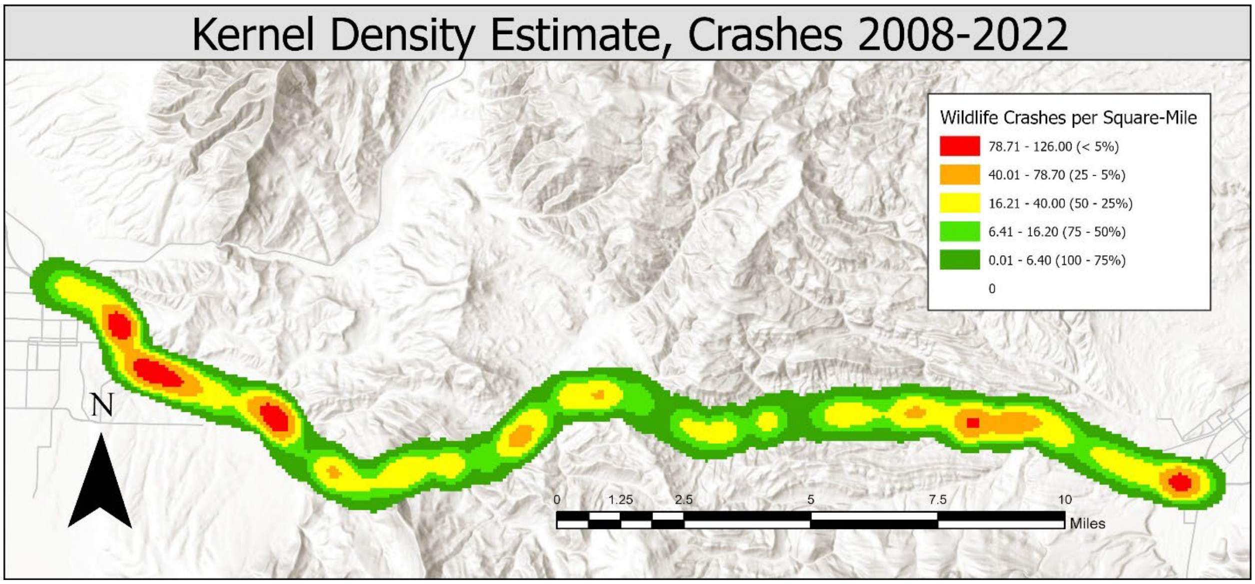

Figure 20: Kernel density hotspot map using percentiles for wildlife-vehicle crashes along I-90 between Bozeman and Livingston, Montana (2008–2022).

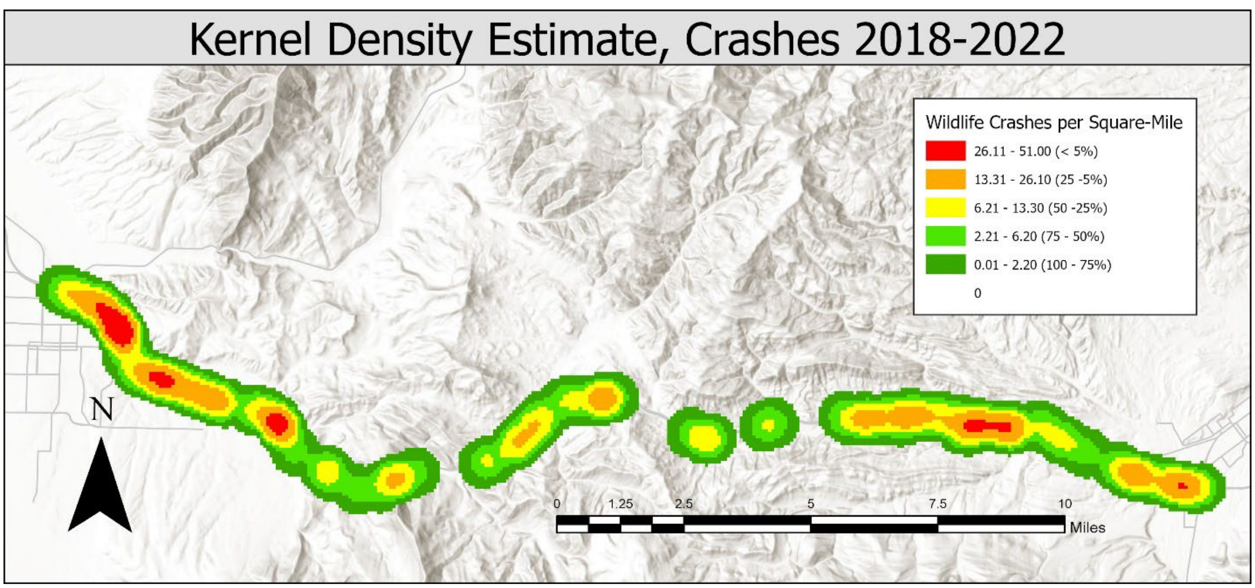

Figure 21: Kernel density hotspot map using percentiles for wildlife-vehicle crashes along I-90 between Bozeman and Livingston, Montana (2018–2022).

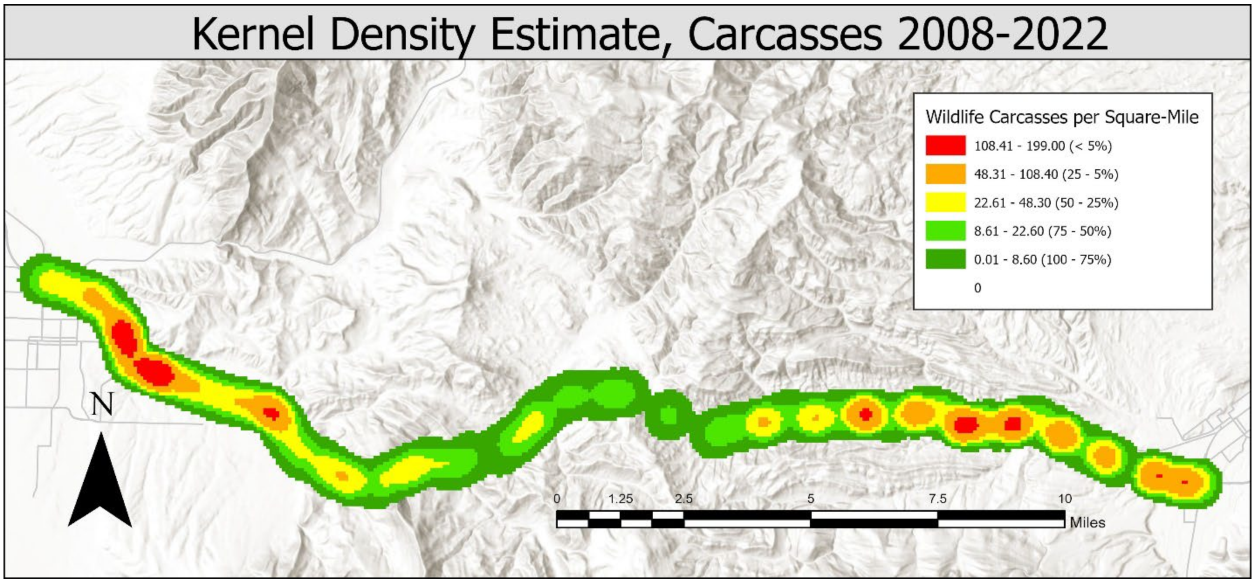

Figure 22: Kernel density hotspot map using percentiles for large wild mammal carcasses along I-90 between Bozeman and Livingston, Montana (2008–2022).

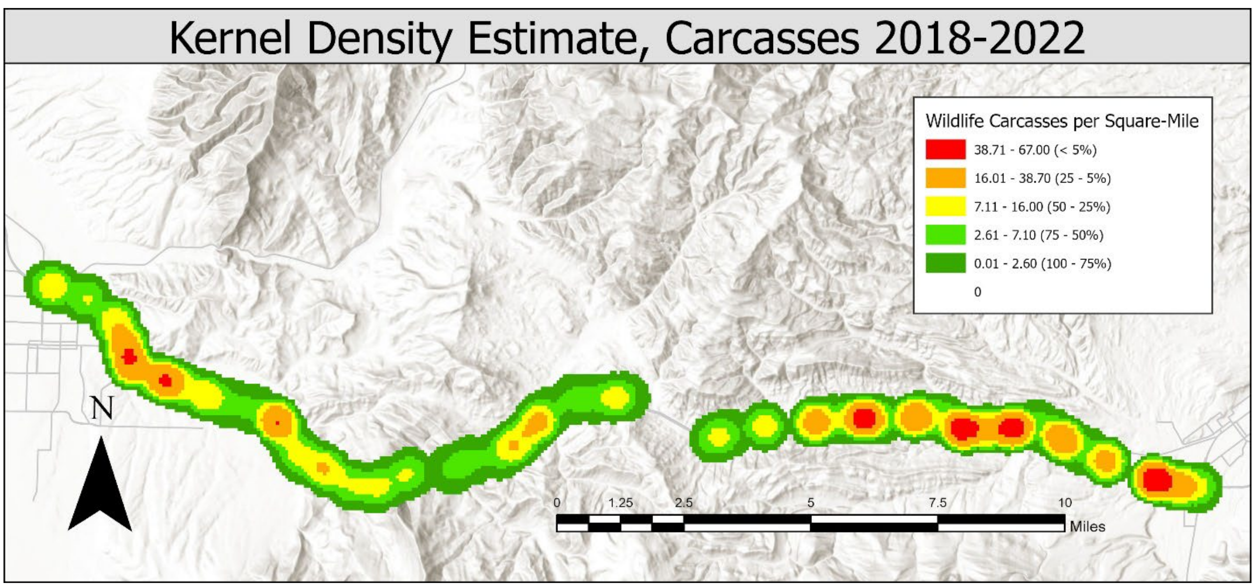

Figure 23: Kernel density hotspot map using percentiles for large wild mammal carcasses along I-90 between Bozeman and Livingston, Montana (2018–2022).

6.2.2 Getis-Ord Gi* analyses

The Getis-Ord Gi* hotspot maps for crashes are depicted in Figure 24 (2008-2022) and Figure 25 (2018-2022). The Getis-Ord Gi* hotspot maps for carcasses are depicted in Figure 26 (2008-2022) and Figure 27 (2018-2022).

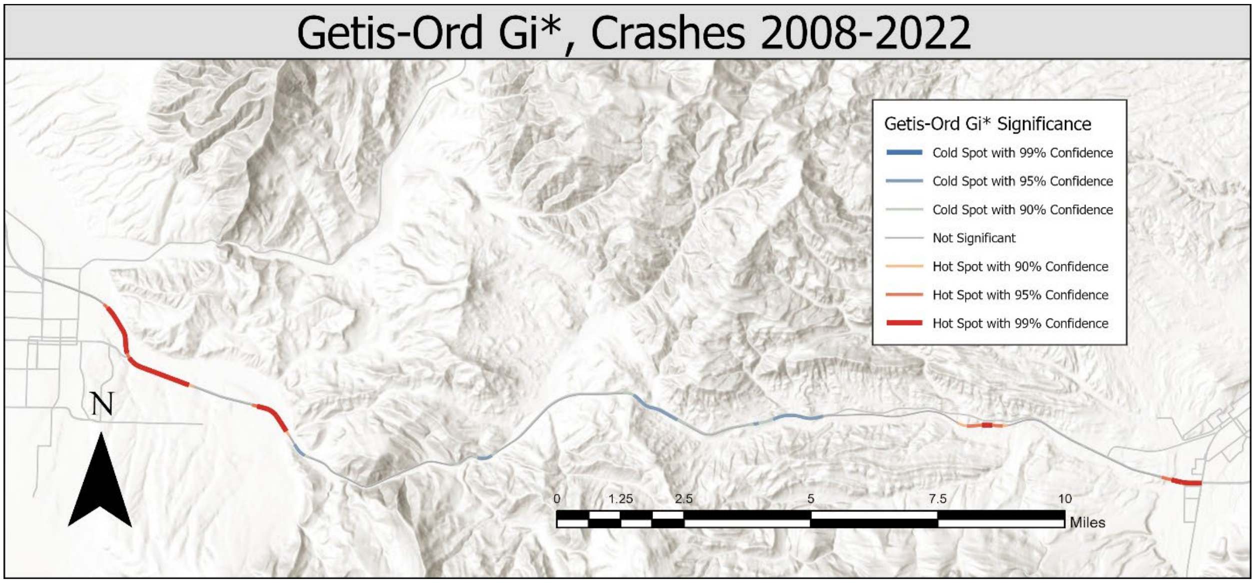

Figure 24: Significant hotspots and cold spots based on Getis-Ord Gi analysis for wildlife-vehicle crashes in Gallatin County, Montana (2008–2022).*

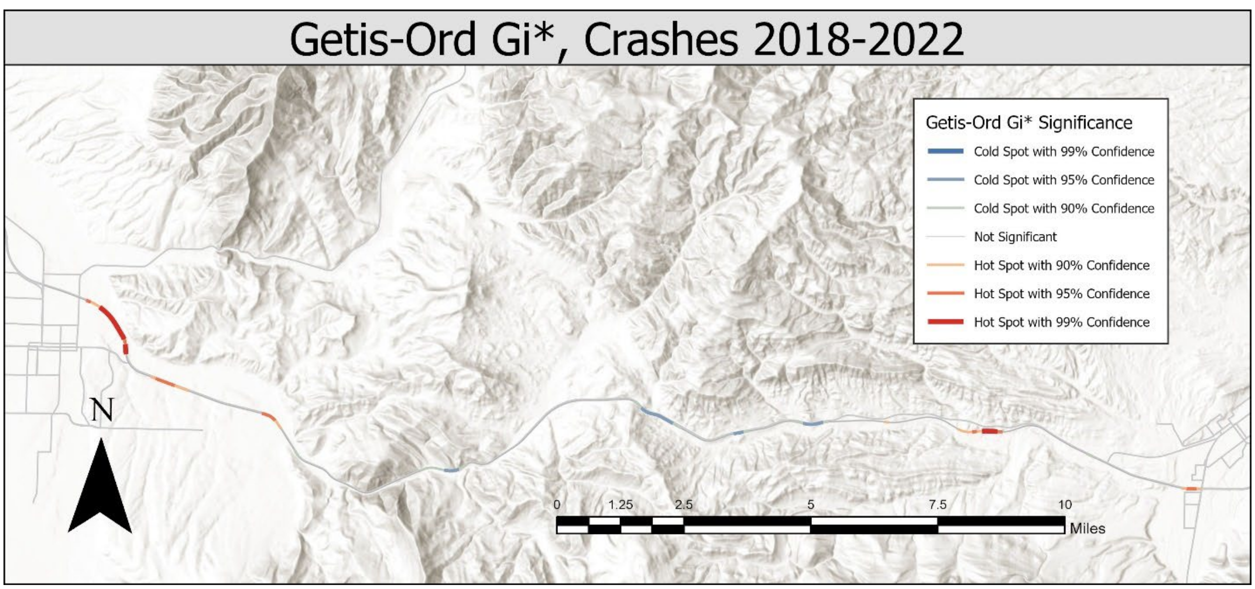

Figure 25: Significant hotspots and cold spots based on Getis-Ord Gi analysis for wildlife-vehicle crashes in Gallatin County, Montana (2018–2022).*

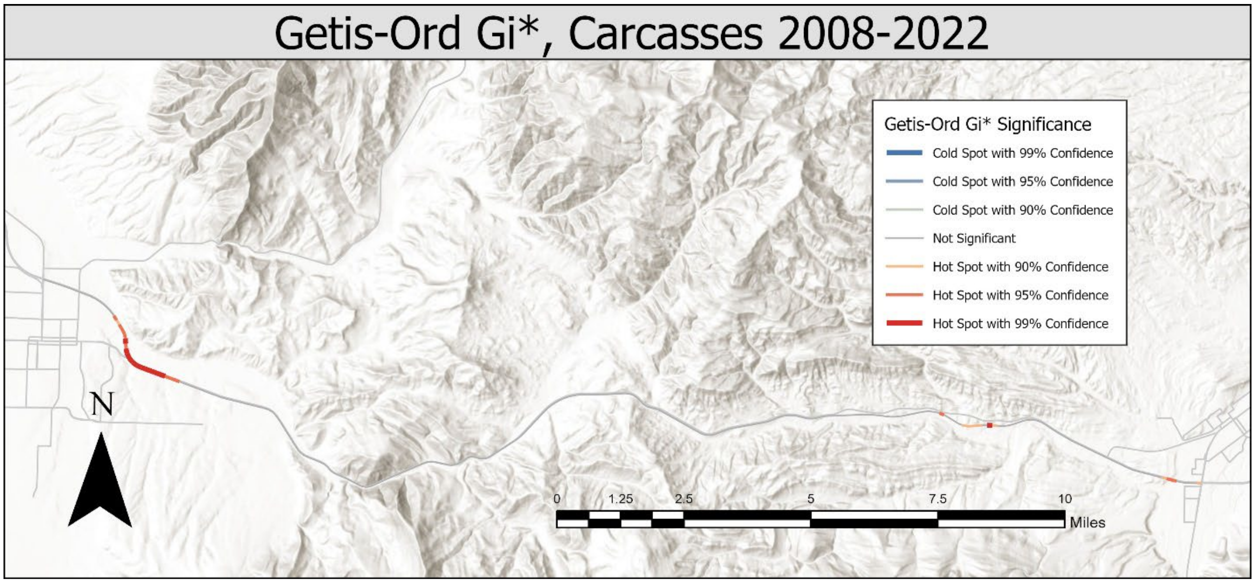

Figure 26: Significant hotspots and cold spots based on Getis-Ord Gi analysis for large wild mammal carcasses in Gallatin County, Montana (2008–2022).*

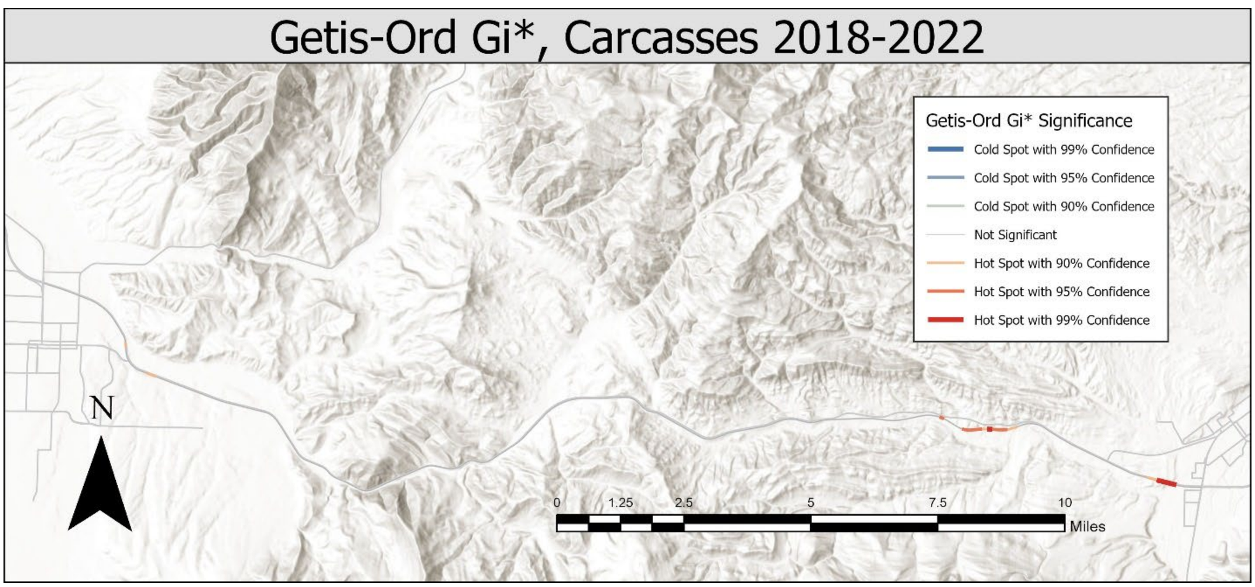

Figure 27: Significant hotspots and cold spots based on Getis-Ord Gi analysis for large wild mammal carcasses in Gallatin County, Montana (2018–2022).*