Patterns of Domestic Animal-Vehicle Collisions on Tribal Lands in Montana, U.S.

Final Report

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16. Abstract

Animal-vehicle collisions (AVCs) are a significant concern for motorist safety and pose a risk to both wildlife and domestic animals. This report analyzes spatial patterns of wildlife-vehicle collisions (WVCs) and domestic animal-vehicle collisions (DAVCs) on Montana's tribal lands to identify high-risk areas and inform mitigation strategies. Data from the Montana Department of Transportation (MDT) for large mammal carcasses (2008–2022) and reported crashes (2008–2020) were used to perform Kernel Density Estimation (KDE) and Getis-Ord Gi* (GOG) hotspot analyses for three tribal reservations with sufficient data: Blackfeet, Crow, and Flathead.

The KDE results show distinct spatial patterns for DAVCs and WVCs on each reservation, with DAVC hotspots concentrated near agricultural and grazing areas, while WVC hotspots were associated with natural habitats and wildlife corridors. The GOG analysis further revealed that DAVC hotspots tend to be more temporally stable, suggesting that collisions with domestic animals are influenced by consistent factors such as livestock access points and grazing practices. In contrast, WVC hotspots were more variable, likely driven by changes in wildlife movement patterns and seasonal behavior.

Overall, the findings indicate that the elevated rates of DAVCs on tribal lands, compared to non-tribal lands, are likely due to unique factors such as open range grazing practices and road infrastructure adjacent to grazing lands. This report emphasizes the need for targeted mitigation strategies on tribal roads, such as enhanced livestock fencing, road signage, and livestock underpasses in high-risk areas, to reduce collisions and improve safety for both motorists and animals. Understanding the distinct spatial and temporal patterns of DAVCs and WVCs is crucial for developing comprehensive mitigation approaches that enhance safety and connectivity on Montana's tribal lands.

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About the Western Transportation Institute

The Western Transportation Institute (WTI) was founded in 1994 by the Montana and California Departments of Transportation, in cooperation with Montana State University. WTI concentrates on rural transportation research; as stewards and champions of rural America, WTI also has a strong interest in sustainability. WTI research groups create solutions that work for clients, sponsors, and rural transportation research partners. WTI Research Centers include the Montana Local Technical Assistance Program, the National Center for Rural Road Safety, the Small Urban, Rural and Tribal Center on Mobility, the Federal-Public Lands Transportation Institute, and the West Region Transportation Workforce Center.

About the Small Urban, Rural and Tribal Center on Mobility

The mission of the Small Urban, Rural and Tribal Center on Mobility (SURTCOM) is to conduct research and provide leadership, education, workforce development and technology transfer in all transportation-related aspects of mobility for people and goods, focusing specifically on small urban, rural and tribal areas. Member institutions include the Western Transportation Institute at Montana State University, the Upper Great Plains Transportation Institute at North Dakota State University, and the Urban and Regional Planning program at Eastern Washington University.

Disclaimer

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1 Introduction

Animal-vehicle collisions (AVCs) have become an increasingly recognized issue among transportation planners and health and safety experts, with growing awareness of their significant risks to motorists (Sullivan, 2011). Most studies on AVCs have focused on wildlife-vehicle collisions (WVCs), particularly those involving large-bodied wildlife such as deer, moose, and elk. These animals are responsible for the majority of AVCs in North America, often causing substantial vehicle damage, human injury, and even fatalities (Huijser et al., 2008). As a result, WVCs have driven most mitigation efforts, such as the construction of wildlife crossing structures and exclusionary fencing aimed at reducing collisions with wildlife, improving motorist safety, and providing safe crossing opportunities for wildlife (Clevenger & Huijser, 2011). However, domestic animal-vehicle collisions (DAVCs), involving livestock such as cattle, horses, and sheep, have received far less attention despite their potential severity in some regions (Cramer & McGinty, 2018; Zaloshnja et al., 2003).

In many rural areas, particularly where open range grazing occurs, domestic animals can cross roadways without being impeded by fences, increasing the risk of collisions. These collisions, while less frequent than WVCs overall, can be locally significant. Research indicates that DAVCs not only result in substantial economic losses for ranchers but also pose considerable safety risks for motorists, with the potential for more severe crashes due to the large size and weight of livestock (Burton et al., 2014).

1.1 Background

The limited focus on DAVCs has been noted in several studies. Zaloshnja et al. (2003) highlighted the economic impact of livestock-related crashes, while Cramer and McGinty (2018) emphasized the higher likelihood of fatal injuries in collisions involving domestic animals. These findings are consistent with analyses conducted in other states like Utah, Nevada, and Texas, where DAVCs have been shown to result in a higher proportion of serious injuries and fatalities compared to WVCs (Wildlife Quality Improvement Team, 2005; Burton et al., 2014). While mitigation strategies for WVCs, such as underpasses and overpasses, have been widely studied (Clevenger & Huijser, 2011), relatively little research has explored measures to reduce DAVCs, especially on tribal lands where these collisions are disproportionately common.

A recent analysis for the state of Montana highlighted the unique challenges associated with DAVCs on tribal reservation roads. According to Creech et al. (2019), DAVCs on Montana's tribal lands occur at more than twice the expected rate based on geographic area or highway mileage. While DAVCs represent only 4.1% of all AVCs statewide, this fraction is substantially higher within tribal reservations. For instance, 50.6 percent of recorded AVCs on the Blackfeet Reservation involved domestic animals, underscoring the significant impact of these collisions on tribal communities.

Despite the clear risks posed by DAVCs, research on this issue has been limited. This research gap is particularly important because the safety of local residents and highway users, as well as the economic well-being of tribal ranchers, is at stake. In Montana, according to reported crash data from 2008-2020, DAVCs are estimated to be 8-times more likely to result in human fatalities compared to WVCs, and 1.6 times more likely to cause serious injuries. Additionally, the economic costs associated with DAVCs, including vehicle damage, livestock losses, and legal liabilities, are significant for tribal communities.

1.2 Research Objectives

This study aims to address the lack of research on DAVCs by investigating patterns and trends of AVCs on tribal lands in Montana. Specifically, it seeks to:

1. Compare the frequency and severity of DAVCs and WVCs on both tribal and non-tribal lands.
2. Identify road segments on tribal lands with disproportionately high rates of DAVCs, using both crash and carcass data.
3. Determine whether DAVC and WVC hotspots overlap or differ in terms of location and density.

This research contributes to a growing recognition of the unique challenges faced by tribal reservations in addressing AVCs. By identifying collision hotspots and performing kernel density estimation (KDE) and Getis-Ord Gi* hotspot analyses (GOG), this study highlights high-risk areas and provide insights into the spatial patterns of DAVCs and WVCs. The findings will inform the development of targeted mitigation strategies aimed at reducing both DAVCs and WVCs, thereby improving motorist safety and minimizing economic losses for tribal communities. In addition, the results may have broader implications for similar regions where livestock-related collisions are a significant concern, offering a model for addressing these challenges in other rural areas of North America.

2 Tribal Lands in Montana

Montana's tribal reservations span vast and diverse landscapes, ranging from the Great Plains to mountainous regions, each with unique environmental, cultural, and economic characteristics. These lands are home to significant agricultural activities, particularly cattle ranching, which is a cornerstone of the local economy. The open range policy, common across Montana, is also applied to most tribal lands. Under this policy, fencing is not required to contain livestock on grazing land, allowing them to freely wander onto roadways. This policy is particularly relevant on tribal lands, where the road infrastructure often intersects with areas used for livestock management. Despite similarities in land use and livestock management, each reservation has distinct geographic features, sizes, and transportation networks (Table 1), which influence the frequency and patterns of both WVCs and DAVCs.

Table 1: Geographic area and transportation network for tribal and non-tribal lands in Montana.

Geographic Area	Total Land Area (mi^2)	Total Road (mi)	Interstate (mi)	Principal Arterial (mi)	Minor Arterial (mi)	Major Collector (mi)
Blackfeet Reservation	2,396.9	227.7	0.0	49.1	75.1	103.6
Crow Reservation	3,840.3	284.7	123.9	22.2	12.7	126.0
Flathead Reservation	2,057.5	240.7	0.0	94.1	86.9	59.7
Fort Belknap Reservation	1,017.9	81.2	0.0	41.8	39.4	0.0
Fort Peck Reservation	3,295.4	309.0	0.0	89.0	52.1	168.0
Northern Cheyenne Reservation	701.4	55.8	0.0	39.1	4.2	12.4
Rocky Boy's Reservation	175.6	16.3	0.0	8.5	7.7	0.0
Montana (tribal lands)	13,484.9	1,217.1	123.9	344.2	270.4	478.6
Montana (non-tribal lands)	133,738.4	12,034.9	2,258.2	2,909.4	2,853.8	4,013.6
Montana (statewide)	147,223.3	13,252.0	2,382.1	3,253.6	3,124.1	4,492.2

2.1 Blackfeet Indian Reservation

The Blackfeet Indian Reservation is located in northwestern Montana, bordering Glacier National Park to the west. It spans 2,396.9 square miles, with a landscape characterized by a mix of grasslands, wetlands, and rolling foothills transitioning into the Rocky Mountains. The open range policy allows livestock, particularly cattle, to graze freely across the reservationn, illustrating the economic importance of cattle ranching in the region. The Blackfeet Reservation has 227.7 miles of Montana Department of Transportation (MDT) on-system routes, which intersect large areas of grazing land and natural habitats. The proximity to Glacier National Park also means that wildlife, such as deer, elk, and bears, frequently move through the reservation's open spaces.

2.2 Crow Indian Reservation

The Crow Indian Reservation, the largest in Montana, covers 3,840.3 square miles in the southern part of the state. The landscape varies from flat plains to the Bighorn Mountains, providing large areas of land for wildlife to roam. The Bighorn and Little Bighorn rivers provide vital water resources for agriculture. Cattle ranching is a dominant activity on the reservation, with large areas of open grazing

allowed under the open range policy. The Crow Reservation has 284.7 miles of MDT on-system routes. U.S. Route 212, a major route through the reservation, passes through extensive grazing areas and natural landscapes.

2.3 Flathead Indian Reservation

Located in western Montana, the Flathead Indian Reservation encompasses 2,057.5 square miles of diverse landscapes, including portions of the Mission Valley, lakes, rivers, and agricultural lands. The reservation's agricultural sector is strong, with cattle ranching and crop farming being major contributors to the economy. Although cattle ranching is less common compared to other tribal lands in Montana, the open range policy applies to large areas of farmland. The Flathead Reservation has 240.7 miles of MDT on-system routes, which pass through both agricultural areas and natural habitats rich with wildlife, including deer and elk.

2.4 Fort Belknap Indian Reservation

Fort Belknap Indian Reservation, situated in north-central Montana near the Canadian border, covers 1,017.9 square miles. The landscape is primarily semi-arid plains, with the Milk River providing irrigation for agricultural activities. Cattle ranching is a key economic activity, with large areas of the reservation dedicated to grazing under the open range policy. The reservation includes 81.2 miles of MDT on-system routes, which traverse open plains and grazing lands. Fort Belknap's expansive plains are also home to wildlife such as pronghorn and deer.

2.5 Fort Peck Indian Reservation

The Fort Peck Indian Reservation is located in northeastern Montana and spans 3,295.4 square miles, making it one of the largest reservations in the state. The Missouri River runs through the southern portion of the reservation, supporting both agriculture and natural habitats. Cattle ranching is widespread, with large areas dedicated to open grazing, a key component of the local economy. Fort Peck has 309.0 miles of MDT on-system routes, many of which cross open range areas and intersect wildlife corridors. The vast plains and riverine environments support a variety of species, contributing to the area's ecological diversity.

2.6 Northern Cheyenne Indian Reservation

The Northern Cheyenne Indian Reservation is located in southeastern Montana, covering 701.4 square miles of diverse terrain, including forested hills, grasslands, and riparian zones along the Tongue River. Cattle ranching is a significant activity, with much of the land used for grazing under the open range policy. The reservation is crossed by 55.8 miles of MDT on-system routes, which pass through areas of open grazing and natural landscapes. Forested areas and riparian zones are home to wildlife, further enriching the reservation's natural environment.

2.7 Rocky Boy's Indian Reservation

Rocky Boy's Indian Reservation, the smallest of Montana's reservations, covers 175.6 square miles in north-central Montana. Its landscape consists primarily of open grasslands with a semi-arid climate. Cattle ranching is an important activity, though on a smaller scale compared to other reservations, with grazing lands designated for livestock management under the open range policy. The reservation includes 16.3 miles of MDT on-system routes, which pass through open grasslands. Despite its small size,

Rocky Boy's Reservation supports both livestock and wildlife, contributing to its agricultural and ecological diversity.

3 Methods

This chapter focuses on the data and statistical analysis used to explore the patterns of DAVCs on tribal lands. All spatial data were projected using the NAD 1983 StatePlane Montana FIPS 2500 coordinate system, with meters as the unit of measurement. The data variables were processed using ArcGIS Pro 3.1.2 (ESRI, 2024), while statistical analyses were conducted using RStudio 4.4.1 (Posit Team, 2023).

3.1 Data Selection

This study utilized two datasets from the Montana Department of Transportation to analyze animal-vehicle collisions across the state: crash data from 2008 to 2020 and carcass removal data from 2008 to 2022. The crash data, reported by law enforcement personnel, typically includes more severe collisions that meet specific thresholds, such as a minimum estimated vehicle repair cost of US $1,000 or incidents involving human injuries or fatalities (Huijser et al., 2007). These crashes mostly involve large mammals, such as white-tailed deer, mule deer, and elk, although the species name is not always recorded. Carcass removal data, collected by MDT road maintenance crews, documents large mammals found within or near the roadway that pose a safety hazard (Huijser et al., 2007). Both datasets focus on large mammal species, as I excluded species smaller thane coyotes as they are less likely to have been consistently recorded and also pose lower risk to motorists.

Crash and carcass observations were selected within 25 meters of MDT on-system routes. The data were then divided into tribal and non-tribal groups to assess differences in trends and collision characteristics between these tribal and non-tribal lands. Small, isolated patches of tribal land—typically less than one square mile—were excluded from the analysis to ensure the data accurately represented the characteristics of the larger reservation areas. This approach allows for a more focused comparison of AVCs across Montana's tribal and non-tribal lands, using both crash and carcass data to identify trends and high-risk areas for large mammal collisions.

3.2 Hotspot Analysis

The hotspot analyses were conducted exclusively on Montana’s tribal lands to identify areas with high concentrations of domestic animal-vehicle collisions and wildlife-vehicle collisions. Due to the varying frequency of AVCs across different reservations, analyses were only performed for reservations that met our minimum criteria Specifically, a reservation was included in the hotspot analysis only if it had a minimum of 30 DAVCs and 30 WVCs recorded during the study period. This threshold ensured that the analyses would produce meaningful results and had the potential to identify statistically significant hotspots, should they indeed exist. Only the Blackfeet Reservation meets these criteria using carcass data, while the Blackfeet, Crow, and Flathead Reservations will have hotspot analyses conducted using reported crash data.

3.2.1 Kernel Density Estimation

Kernel Density Estimation was used to create density surfaces for both DAVCs and WVCs. The KDE analysis produces a smooth, continuous surface that visualizes the intensity of AVCs, highlighting areas with higher collision densities. Separate KDE analyses were performed for DAVCs and WVCs on each reservation that met the data threshold. The following parameters were used:

- **Bandwidth:** A bandwidth of 0.5 miles was selected to represent the area of influence for each collision. This distance is commonly used in AVC studies to reflect the scale at which collisions affect roadways and surrounding areas.
- **Output Cell Size:** The KDE analysis was performed using a 100-meter cell size, providing a detailed representation of collision densities.
- **Density Units:** The resulting density values are expressed as the number of collisions per square mile, making it easier to compare high-density areas across different regions.

This KDE analysis was used to visually assess and compare the spatial patterns of DAVCs and WVCs on the selected tribal reservations. Density surfaces for each reservation were reviewed to identify high-risk areas where collisions are most concentrated.

3.2.2 Getis-Ord Gi* Hotspot Analysis

The Getis-Ord Gi* spatial analysis was used to identify statistically significant clusters of DAVCs and WVCs on reservations with sufficient data. This method not only identifies collision clusters but also determines their statistical significance, providing a rigorous assessment of hotspot locations. Separate Getis-Ord Gi* analyses were conducted for DAVCs and WVCs, using the following parameters:

- **Input Field:** The "year" of each collision was used as the input field to put more weight on more recent collision events. This approach helps identify current hotspots and emphasizes trends that may be emerging in recent years.
- **Conceptualization of Spatial Relationships:** A fixed distance band conceptualization was applied to define the spatial relationship among points.
- **Distance Threshold:** The distance threshold for clustering was set to 0.5 miles, consistent with the KDE bandwidth. This ensures that both KDE and GOG analyses capture the same scale of spatial patterns.
- **Output Metrics:** The analysis produced z-scores and p-values for each collision location. High positive z-scores indicate statistically significant hotspots (areas with more collisions than expected), while low negative z-scores indicate cold spots (areas with fewer collisions than expected).

The GOG results were used to identify statistically significant hotspots for both DAVCs and WVCs. The output maps were then reviewed to understand where significant clusters of collisions occurred on each reservation.

3.2.3 Comparison of DAVC and WVC Hotspots

After generating KDE and GOG hotspots for each reservation, a comparison was made between the hotspots for DAVCs and WVCs to evaluate differences in spatial patterns and collision densities. This comparison helps identify whether domestic animal collisions and wildlife collisions share the same high-risk areas or if they occur in different locations. The results were summarized to highlight key similarities and differences in collision patterns, providing insights into the distinct factors driving DAVCs and WVCs on tribal lands.

4 Results

The results are presented in two sections: (1) DAVC Data in Montana and (2) Hotspot Analyses. The first section provides an overview of DAVC data on tribal lands in comparison to non-tribal lands in Montana, highlighting the frequency and distribution of these incidents. The second section presents the findings of spatial hotspot analyses for DAVCs and WVCs using Kernel Density Estimation and Getis-Ord Gi* analyses on eligible tribal reservations. The analyses focus on identifying areas with high densities of collisions and statistically significant clusters, providing insights into the spatial patterns of both DAVCs and WVCs across Montana's tribal lands.

4.1 Domestic Animal-Vehicle Collision Data in Montana

A comparison of crash and carcass data is shown in Table 2. Statewide, there are a total of 89,558 large mammal carcass locations from 2008 to 2022 and 32,586 reported crashes from 2008 to 2020. Of these, only 0.19% (*n* = 168) of carcass locations are associated with domestic livestock, whereas 4.13% (*n* = 1,345) of reported crashes involve domestic livestock. On Montana's tribal lands, 4,319 carcass locations and 2,612 reported crashes were documented, with 2.25% (*n* = 97) and 12.1% (*n* = 316) involving domestic livestock, respectively. These percentages are much higher compared to non-tribal lands, which have only 0.08% and 3.43% domestic livestock involvement for carcasses and reported crashes, respectively.

Table 2: Crash and carcass data summary comparing DAVC and WVC percentages for tribal lands in Montana.

Geographic Area	Total Carcasses	Domestic Carcasses	Wildlife Carcasses	% Domestic Carcasses	Total Crashes	Domestic Crashes	Wildlife Crashes	% Domestic Crashes
Blackfeet Reservation	211	67	144	31.75	320	162	158	50.63
Crow Reservation	24	2	22	8.33	155	30	125	19.35
Flathead Reservation	3,539	13	3,526	0.37	1,914	56	1,858	2.93
Fort Belknap Reservation	60	1	59	1.67	29	11	18	37.93
Fort Peck Reservation	429	13	416	3.03	126	22	104	17.46
Northern Cheyenne Reservation	10	0	10	0.00	34	26	8	76.47
Rocky Boy's Reservation	46	1	45	2.17	27	8	19	29.63
Montana (tribal lands)	4,319	97	4,222	2.25	2,612	316	2,296	12.10
Montana (non-tribal lands)	85,239	71	85,168	0.08	29,974	1,029	28,945	3.43
Montana (statewide)	89,558	168	89,390	0.19	32,586	1,345	31,241	4.13

Despite the higher number of carcass locations, large mammal domestic carcasses appear to be underreported on tribal lands compared to the number of reported crashes. Four reservations—Crow,

Fort Belknap, Northern Cheyenne, and Rocky Boy's—reported two or fewer domestic carcass locations over the 15-year period. The Blackfeet Reservation had the highest percentage of domestic animal carcasses (31.75%), while the Northern Cheyenne Reservation reported none (0%) (Table 2).

In contrast, the reported crash data show much higher percentages of domestic animal-vehicle collisions (DAVCs) on tribal lands, ranging from 2.93% on the Flathead Reservation to 76.47% on the Northern Cheyenne Reservation (Table 2). With the exception of the Flathead Reservation, all other tribal lands reported a higher percentage of DAVCs compared to the statewide average (4.13%). If the Flathead Reservation data were excluded, DAVCs would account for 37.48% of all animal-vehicle collisions on tribal lands in Montana.

4.2 Hotspot Analyses

Hotspot analyses were conducted on tribal reservations with sufficient data for both DAVCs and WVCs. Only reservations with at least 30 DAVCs and 30 WVCs were included in the analysis, which resulted in the identification of hotspots on the Blackfeet, Crow, and Flathead Reservations. No hotspot analyses were conducted for the Fort Belknap, Fort Peck, Northern Cheyenne, or Rocky Boy's Reservations due to the low number of collisions reported for these areas.

4.2.1 Kernel Density Estimates

The Kernel Density Estimation analysis was conducted to identify areas of high collision density for both WVCs and DAVCs on Montana's tribal lands. The KDE method creates a continuous surface that highlights the intensity of collision occurrences, allowing for the visualization of hotspot locations and the comparison of high-risk areas. This approach helps reveal spatial patterns in collision frequency and density across the study area, providing a foundation for identifying and prioritizing mitigation strategies.

4.2.1.1 Blackfeet Reservation

The Blackfoot Indian Reservation is the only tribal land area that passed the criteria for both carcass and crash data. The KDE for the Blackfeet Indian Reservation using carcass data can be seen in Figure 1. The highest 5% of estimated carcass WVCs per square-mile (WVC/mi^2) range from 9.61-24 WVC/mi^2. These highest risk areas are mainly located along US Highway-2 (US-2), east and west of Browning, Montana, and north-south along US Highway-89 (US-89) that runs along the border of Glacier National Park (Figure 1, left).

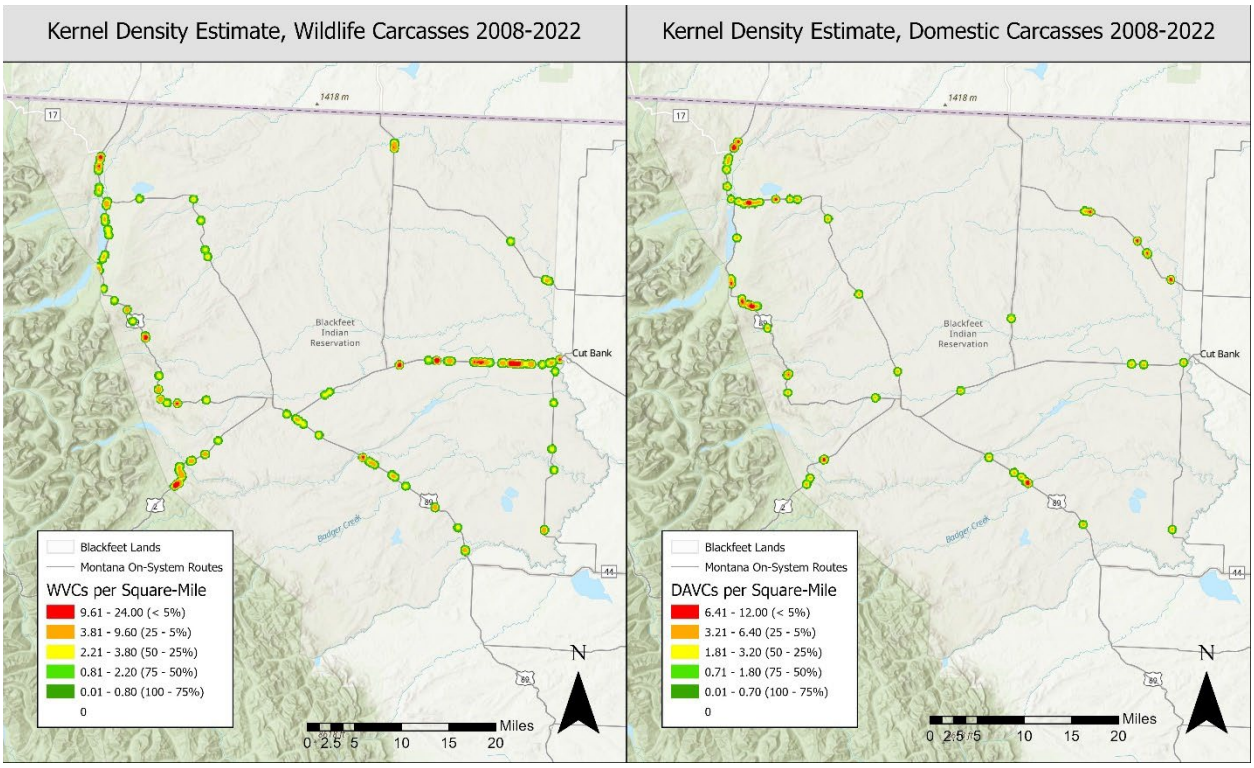

Figure 1: Kernel Density Estimates for the Blackfeet Indian Reservation wildlife (left) and domestic (right) carcasses 2008-2022.

The highest 5% of estimated carcass DAVCs per square-mile (DAVC/mi^2) range from 6.41-12 DAVC/mi^2. These are also located along US-89, but a wider hotspot is located just south of St. Mary's, Montana. The other DAVC/mi^2 hotspots are not located along US-2, but located along US-89 south of Browning, Montana, and along state highway-213 (Hwy-213) in the northeast corner of the Blackfeet Indian Reservation (Figure 1, right).

The KDE for the Blackfeet Indian Reservation using crash data can be seen in Figure 2. The highest 5% of identified wildlife hotspots range from 10.51-22 WVC/mi^2. These are located along US-89 north of St. Mary's, Montana, and along US-2 on both sides of Browning, Montana (Figure 2, left). There is a large WVC hotspot right on the western boarder of the Blackfeet Indian Reservation along US-2, right before the road enters National Forest land.

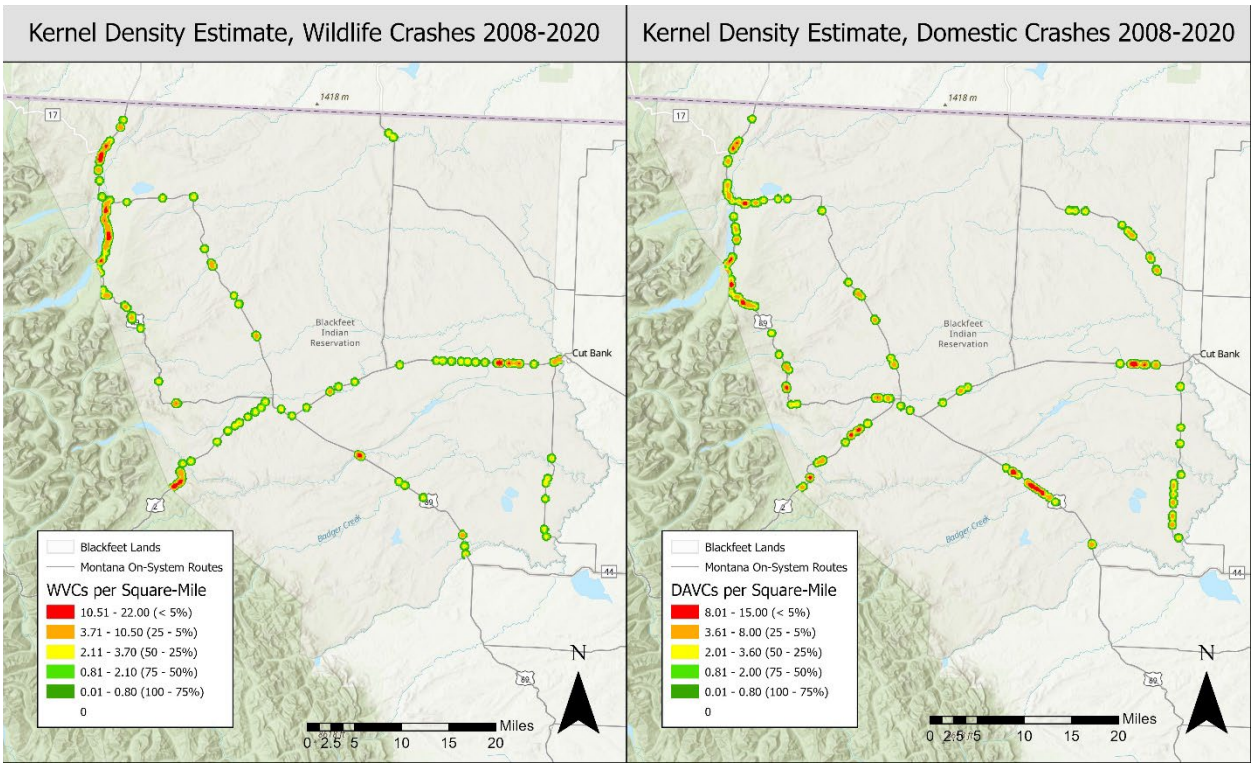

Figure 2: Kernel Density Estimates for the Blackfeet Indian Reservation wildlife (left) and domestic (right) reported crashes 2008-2020.

The highest 5% of identified domestic hotspots range from 8.01-15 DAVC/mi^2. These are in similar areas to the WVC hotspots, but the largest DAVC hotspot is located along US-89 south of Browning, Montana (Figure 2, right). This hotspot location is drastically different than any WVC hotspot location.

4.2.1.2 Crow Reservation

The KDE for the Crow Indian Reservation using crash data can be seen in Figure 3. The highest 5% of identified wildlife hotspots range from 8.21-18 WVC/mi^2. These are all located along Interstate-90 (I-90) that runs north-south through the tribal land (Figure 3, top). The highest 5% of identified domestic hotspots range from 4.21-8 DAVC/mi^2. These are located along state highway-384 (Hwy-384) just east of the I-90 intersection, along I-90 near Dunmore, Montana, along state highway-451 (Hwy-451) north of the Wyoming border, along state highway-313 (Hwy-313) at the entrance to Bighorn Canyon National Recreation Area, and along Pryor Road, just north of Pryor, Montana (Figure 3, bottom). There is no overlap between the top 5% of WVCs and DAVCs hotspot locations.

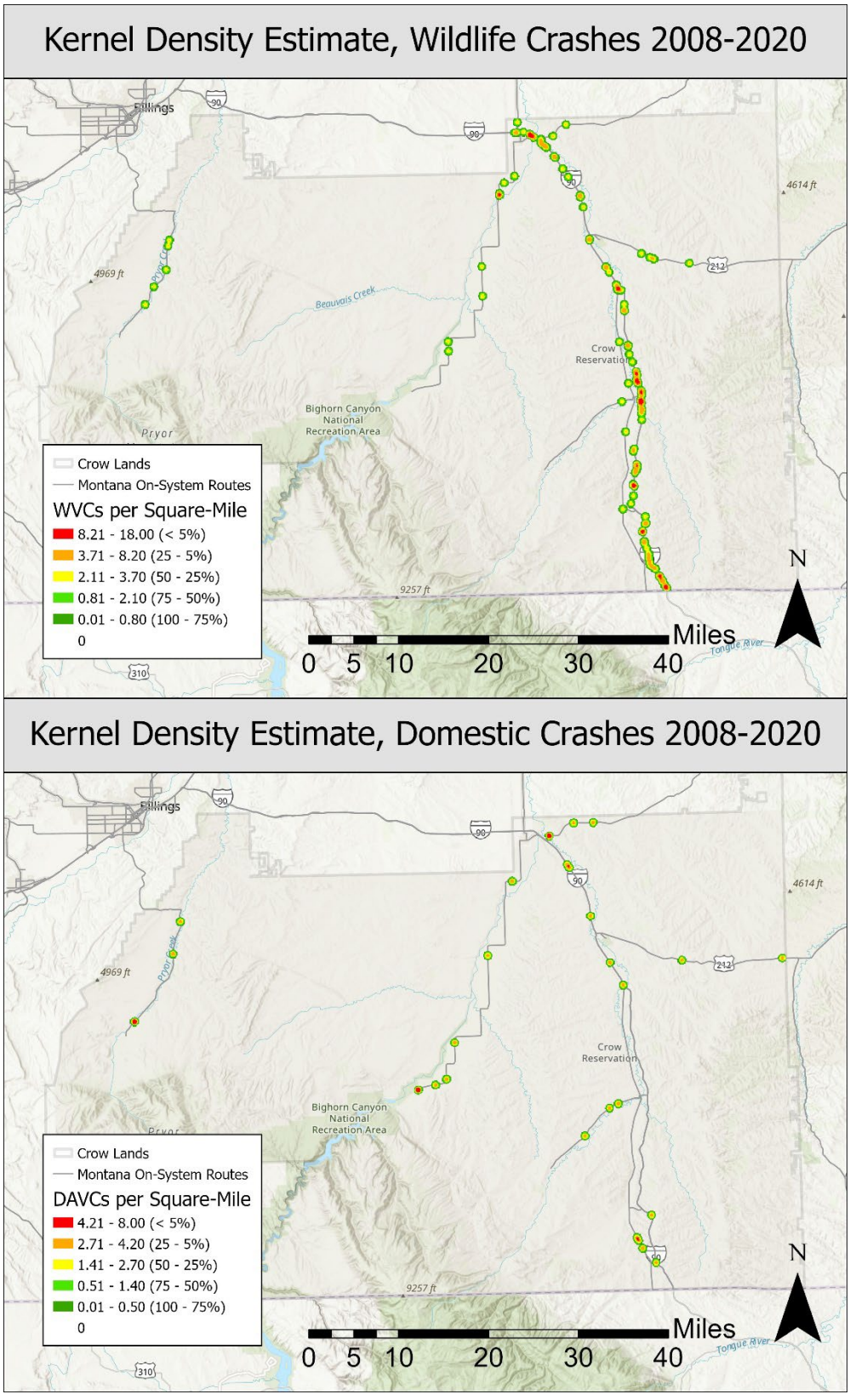

Figure 3: Kernel Density Estimates for the Crow Indian Reservation wildlife (top) and domestic (bottom) reported crashes 2008-2020.

4.2.1.3 Flathead Reservation

The KDE for the Flathead Indian Reservation using crash data can be seen in Figure 4. The highest 5% of identified wildlife hotspots range from 53.1-137 WVC/mi^2. These are all located along US Highway-93 (US-93), there are multiple locations south of Polson, Montana, and around Flathead Lake (Figure 4, left). The highest 5% of identified domestic hotspots range from 5.71-12 DAVC/mi^2. These are located along US-93 north of Evaro, Montana, and south of St. Ignatius, Montana, and along State Highway-28 (Hwy-28) (Figure 4, right). These DAVC hotspots along Hwy-28 are different than any highest risk WVC hotspot locations.

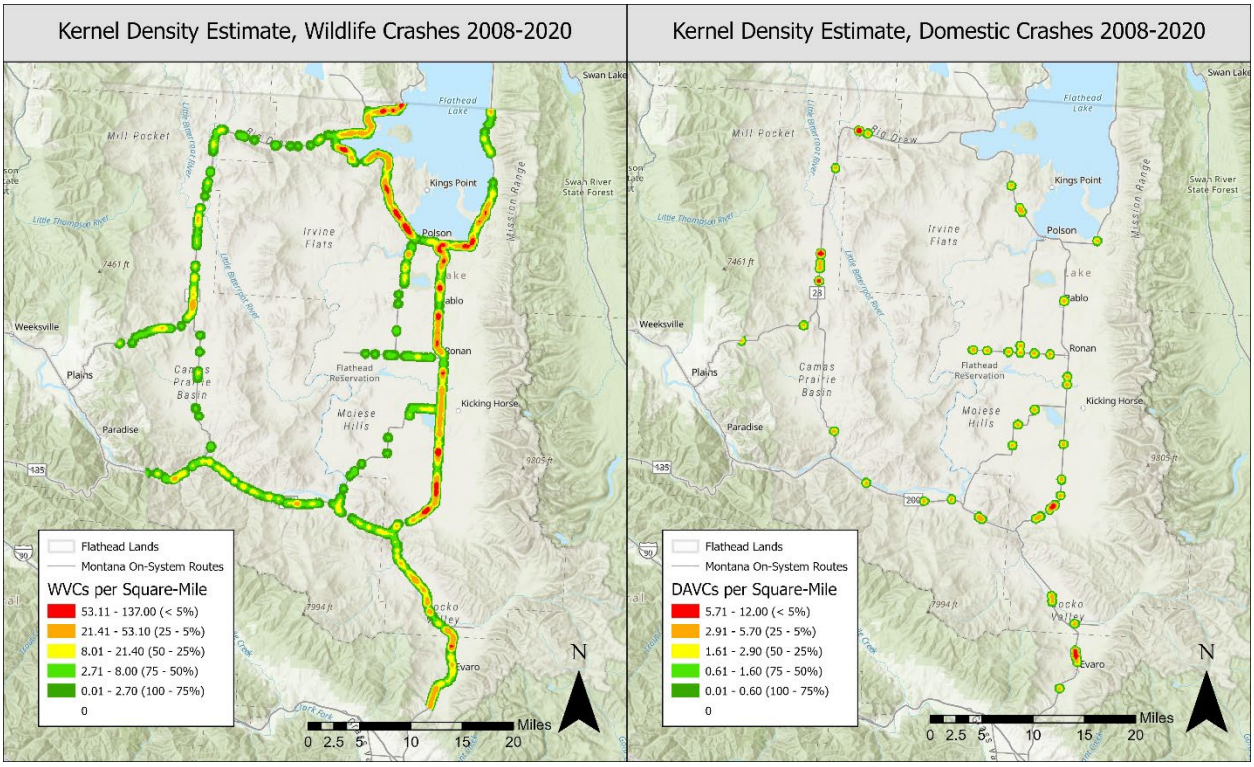

Figure 4: Kernel Density Estimates for the Flathead Indian Reservation wildlife (left) and domestic (right) reported crashes 2008-2020.

4.2.2 Getis-Ord Gi* Hotspot Analysis

The Getis-Ord Gi* analysis was used to identify statistically significant clusters of WVCs and DAVCs on Montana's tribal lands. This spatial analysis method determines whether high or low values are clustered in a given area, providing a measure of statistical significance for each hotspot or cold spot. By incorporating the temporal dimension of the data, the GOG analysis helps distinguish between persistent hotspots and areas where collision patterns have shifted over time, highlighting locations with recent spikes in collision activity. This approach complements the KDE analysis by adding a statistical framework to hotspot identification, ensuring that identified clusters are not due to random chance.

4.2.2.1 Blackfeet Reservation

The results of the Getis-Ord Gi* (GOG) carcass analysis for the Blackfeet Indian Reservation are shown in Figure 5. Wildlife-vehicle collision hotspots identified with 99% confidence were found in similar locations to those in the KDE analysis, specifically north and south of Browning, Montana, along US-89 (Figure 5, left). Another prominent hotspot is located on Hwy-213 in the northern part of the reservation, just south of the Milk River. The area east of Browning along US-2 was identified as a cold spot, indicating that while this location was a significant hotspot in the past, it has not been as active in recent years. The GOG analysis for DAVCs identified four hotspots with 99% confidence, all of which are located along Hwy-213 in the northeastern corner of the Blackfeet Reservation (Figure 5, right). Three additional hotspots were identified along US-89 with 95% confidence. Two other locations, one in the northwest corner along US-89 and another in the northeast corner along Hwy-213, were identified hotspots with 90% confidence.

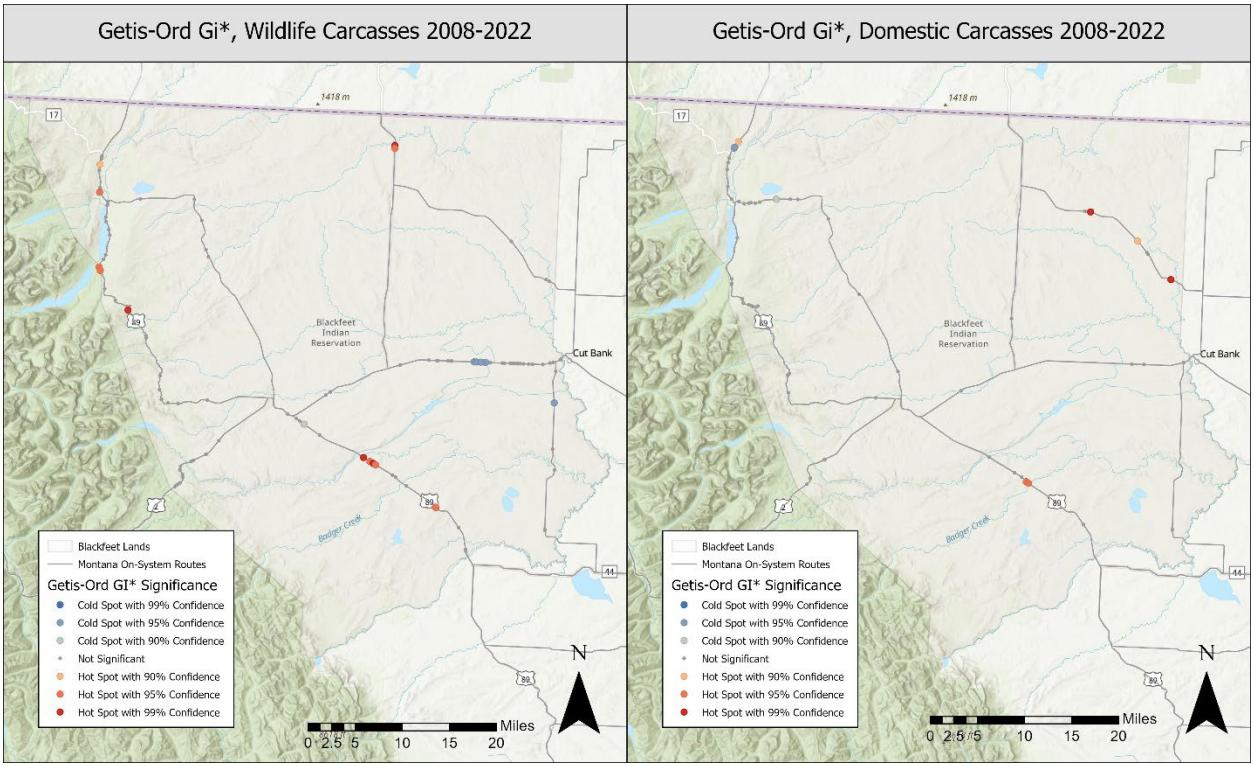

Figure 5: Getis-Ord Gi Hotspot Analysis for Blackfeet Indian Reservation wildlife (left) and domestic (right) carcasses 2008-2022.*

The crash data GOG analysis for the Blackfeet Reservation yielded results similar to previous analyses, but with lower confidence levels (Figure 6). Three WVC hotspots were identified with 90% confidence, located along US-2 on the eastern border of the reservation, along Hwy-464 north of Browning, and on northern US-89 near Camp Nine Mile Road (Figure 6, right). For DAVCs, hotspots were identified with 95% confidence along Hwy-213, US-2 at the eastern boundary, and US-89 south of St. Mary's, Montana (Figure 6, right).

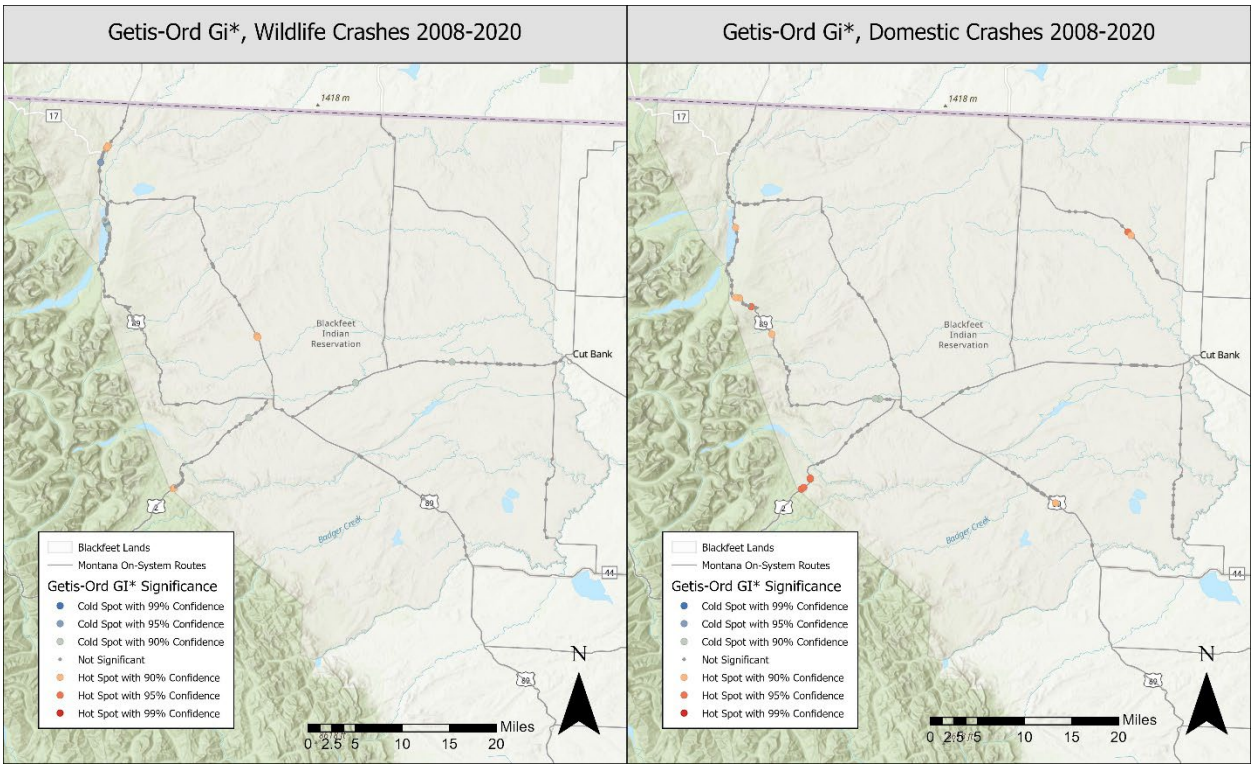

Figure 6: Getis-Ord Gi Hotspot Analysis for Blackfeet Indian Reservation wildlife (left) and domestic (right) reported crashes 2008-2020.*

4.2.2.2 Crow Reservation

The GOG analysis of reported crashes for the Crow Indian Reservation is shown in Figure 7. Four WVC hotspots were identified with 90% confidence or higher. All these hotspots are located along I-90, specifically between reference markers (RM) 501-502, RM 517-518, and near RM 537 (Figure 7, top). The DAVC GOG analysis also identified four hotspots with 90% confidence or higher, but none were located along I-90. Instead, these hotspots were found along Hwy-463 west of Lodge Grass, along Hwy-313 near Uffelman Loop, and along Pryor Road near RM 11.5 and RM 15 (Figure 7, bottom).

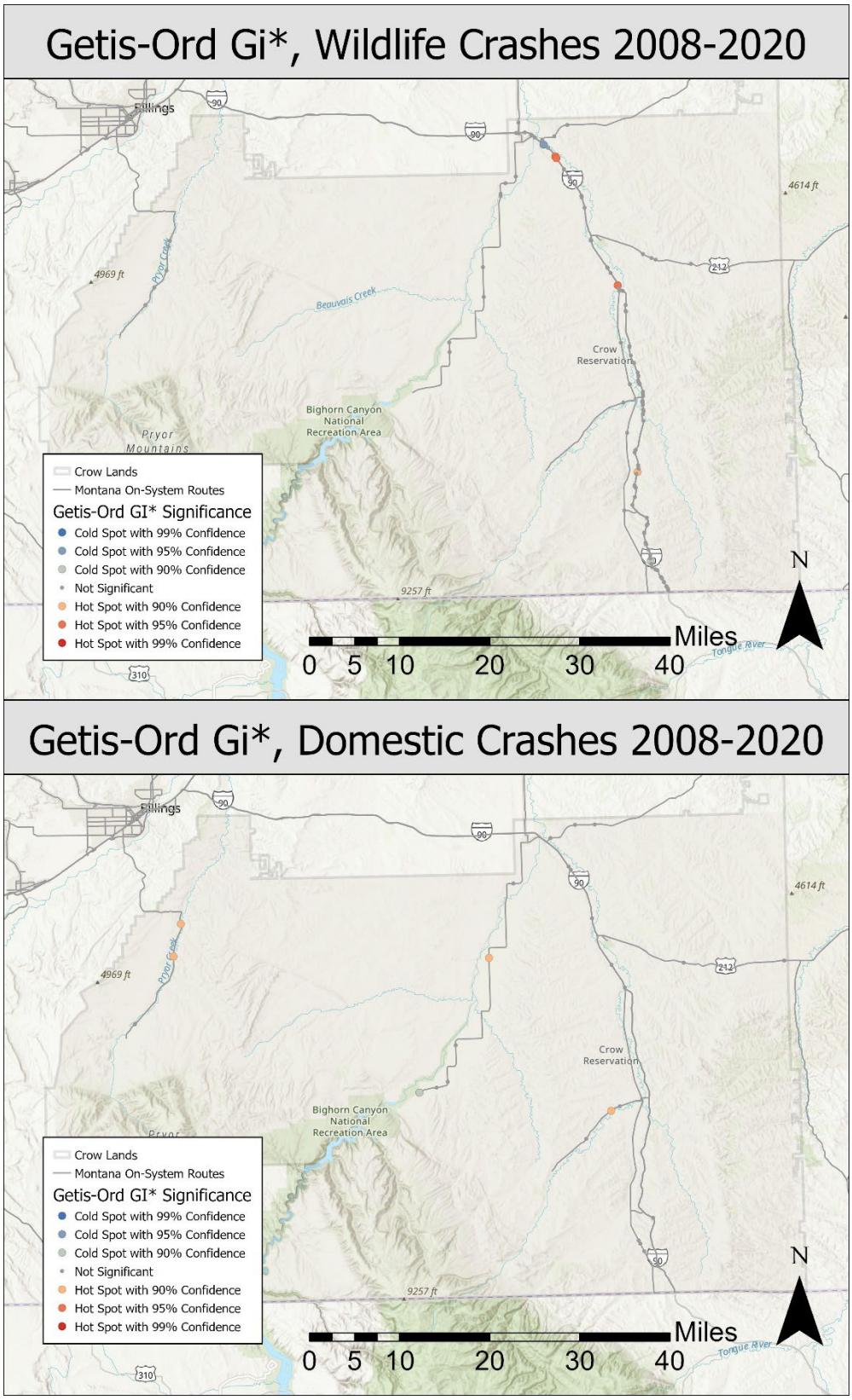

Figure 7: Getis-Ord Gi Hotspot Analysis for Crow Indian Reservation wildlife (top) and domestic (bottom) reported crashes 2008-2020.*

4.2.2.3 Flathead Reservation

The GOG analysis of reported crashes identified significantly more WVC hotspots on the Flathead Reservation compared to other tribal lands, influenced by the much larger dataset (Figure 8). Four main locations were identified as WVC hotspots with high confidence. The most significant hotspot is located along Hwy-28, from RM 16.5 to RM 18.5, near Hot Springs, Montana (Figure 8, left). Additional hotspots were found along US-93 just north of Ronan, between RM 49.5 and RM 50, from RM 63.5 to RM 64.5 north of Polson, and near RM 76 just south of Elmo, Montana (Figure 8, left). In contrast, DAVC hotspots are far less prominent on the Flathead Reservation, with only three locations identified at 90% confidence. These DAVC hotspots are located along US-93 south of Ronan at RM 45, along Hwy-28 at the western boundary of the reservation, and near RM 36 on Hwy-28 at the intersection of Browns Meadow Road (Figure 8, right).

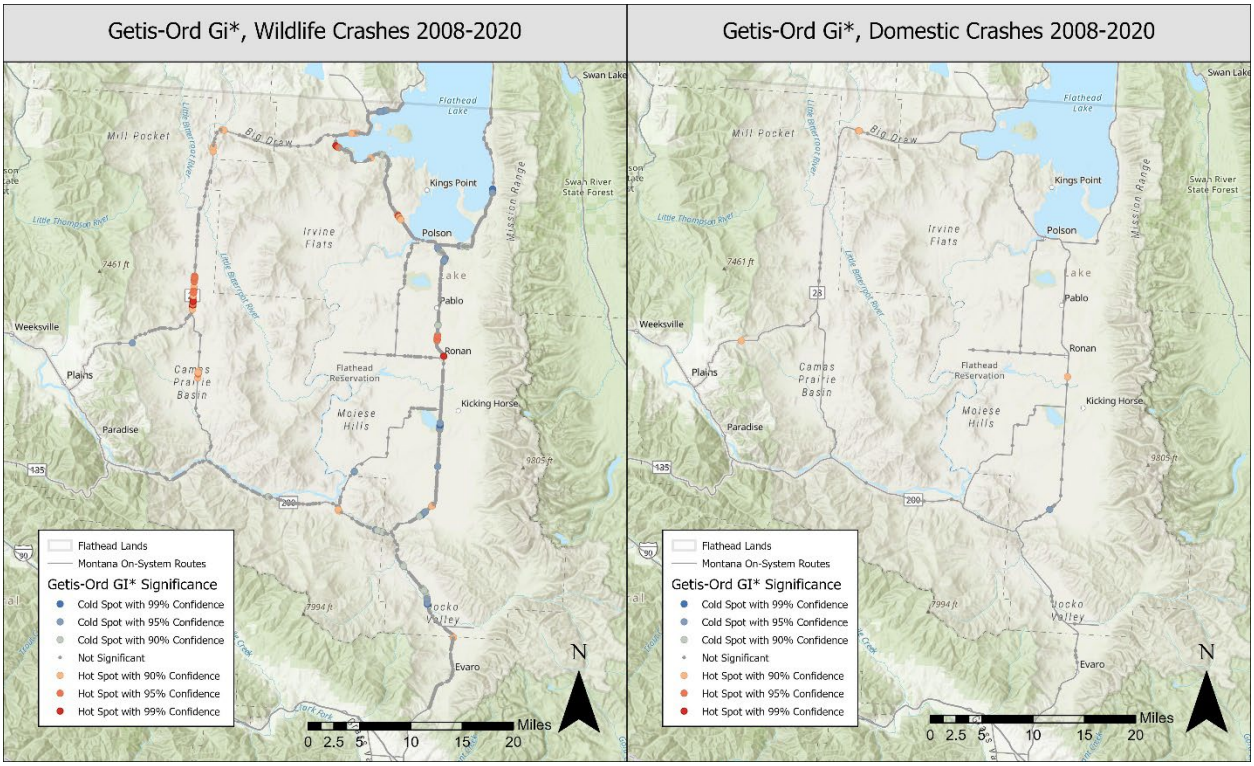

Figure 8: Getis-Ord Gi Hotspot Analysis for Flathead Indian Reservation wildlife (left) and domestic (right) reported crashes 2008-2020.*

5 Discussion and Conclusion

This section synthesizes the findings from the hotspot analyses and explores the implications of spatial patterns in domestic animal-vehicle collisions and wildlife-vehicle collisions on Montana's tribal lands. The discussion focuses on the distinct spatial distribution and stability of DAVC and WVC hotspots, emphasizing the need for targeted mitigation strategies tailored to the unique characteristics of each collision type. Additionally, the section addresses potential contributing factors to elevated DAVC rates on tribal lands, such as open range grazing practices and proximity to agricultural areas. The conclusion highlights key takeaways from the analyses and outlines recommendations for effective, location-specific mitigation measures aimed at reducing collision risks and enhancing roadway safety.

5.1 Domestic Animal-Vehicle Collision Data on Tribal Lands

The results clearly indicate that DAVCs are proportionally more common on tribal lands compared to non-tribal lands. Statewide, only 0.19% of large mammal carcasses and 4.13% of reported crashes involve domestic animals, whereas on tribal lands, these figures are 2.25% and 12.1%, respectively (Table 2). This suggests that livestock-related collisions are a more important issue on tribal lands than the rest of Montana, likely due to the prevalence of open range grazing practices and proximity to agricultural areas (Huijser et al., 2008).

5.1.1 Notable DAVC Rates on Specific Reservation

Blackfeet Reservation: The Blackfeet Reservation has the highest percentage of DAVCs in reported crash data, with 50.63% of reported animal-vehicle crashes involving domestic animals (Table 2). This is notably higher than other reservations and suggests that domestic animal collisions, particularly with cattle or horses, are a significant concern on Blackfeet roads.

Northern Cheyenne Reservation: An exceptionally high proportion of reported crashes (76.47%) on the Northern Cheyenne Reservation involve domestic animals (Table 2). However, the absence of domestic animal carcass data suggests that these collisions may be handled differently, or carcasses are not as frequently recorded or reported.

Fort Belknap Reservation: 37.93% of reported crashes on the Fort Belknap Reservation involve domestic animals, despite the fact that only one domestic carcass was recorded (Table 2). This discrepancy between crash data and carcass data may reflect underreporting of carcasses or a tendency for domestic animals to be removed before road maintenance crews can document them.

5.1.2 Low DAVC Presence on Some Reservations

Flathead Reservation: Despite having the highest overall number of large mammal collisions (both carcasses and crashes), the percentage of DAVCs on the Flathead Reservation is relatively low, with only 0.37% of carcasses and 2.93% of reported crashes involving domestic animals. This suggests that wildlife, particularly deer and elk, are the primary concern for animal-vehicle collisions in this area, with few incidents involving livestock.

Crow Reservation and Fort Peck Reservations: These reservations also show relatively low rates of DAVCs. On the Crow Reservation, 8.33% of carcasses and 19.35% of reported crashes involve domestic animals, while on the Fort Peck Reservation, 3.03% of carcasses and 17.46% of reported crashes involve domestic animals. These percentages are much lower than the Blackfeet and Northern Cheyenne reservations, indicating that domestic animal collisions are less frequent or reported differently here.

5.1.3 Carcass vs. Reported Crash Data

A key observation is the significant difference between the percentage of domestic animal involvement in reported crashes versus carcass data. For several reservations, the proportion of domestic animal involvement is much higher in crash data compared to carcass data. For instance, on the Blackfeet Reservation, 31.75% of carcasses involve domestic animals, but 50.63% of reported crashes do. On the Northern Cheyenne Reservation, 76.47% of reported crashes involve domestic animals, while no domestic animal carcasses were recorded. This suggests that domestic animals involved in collisions may be removed from the roadway more frequently or not recorded as carcasses by maintenance crews. In contrast, wildlife carcasses may remain on the road longer and are more likely to be documented.

5.2 Domestic Animal-Vehicle Collision Hotspots on Tribal Land

The KDE and Getis-Ord Gi* hotspot analyses indicate that the spatial distribution of DAVCs differs from that of WVCs, with few areas of overlap.

5.2.1 Blackfeet Reservation

The Blackfeet Reservation exhibited distinct patterns for DAVC and WVC hotspots. DAVC hotspots were primarily concentrated along US-89 south of Browning and along Hwy-213 in the northeastern corner of the reservation. In contrast, WVC hotspots were predominantly located along US-2, east and west of Browning, and in areas near Glacier National Park. The KDE and Getis-Ord Gi* analyses consistently identified these areas as high-risk for collisions, though the confidence levels varied, reflecting recent trends in collision frequency and severity. The spatial separation of DAVC and WVC hotspots suggests that different factors are influencing each collision type on this reservation.

5.2.2 Crow Reservation

On the Crow Reservation, DAVC hotspots were identified along secondary highways such as Hwy-463 and Hwy-313, rather than along the primary highway, I-90, where most WVC hotspots were located. This indicates that domestic animal collisions are more influenced by localized factors such as agricultural practices, livestock movement patterns, and road conditions, rather than overall traffic volumes. The results highlight the need for mitigation strategies tailored specifically to the agricultural nature of these roads, as WVC mitigation measures may not effectively address the underlying causes of DAVCs in this area.

5.2.3 Flathead Reservation

The Flathead Reservation showed a clear spatial separation between DAVC and WVC hotspots. DAVCs were concentrated along Hwy-28 and US-93 near agricultural areas, while WVCs were predominantly located along US-93 around Flathead Lake. This spatial distribution aligns with previous research, which suggests that the proximity of agricultural and grazing lands plays a significant role in the occurrence of DAVCs (Cramer & McGinty, 2018). The unique spatial patterns observed for each collision type reinforce the need for mitigation measures that consider local land use and road characteristics.

5.2.4 Temporal Stability of Hotspots

The GOG analyses of DAVCs revealed fewer cold spots compared to WVCs, suggesting that DAVC hotspots are more stable over time. Because the year of each collision was used as a temporal factor to determine statistical significance, the limited number of cold spots indicates that DAVC hotspots do not shift spatially as frequently as WVC hotspots. This stability is likely due to the consistent location of grazing areas, predictable livestock movement patterns, and the established presence of livestock

access points. In contrast, WVC hotspots are more dynamic, shifting in response to changes in wildlife movement patterns, habitat connectivity, and seasonal variations. This suggests that WVC mitigation measures may need to be more adaptable and responsive to changing conditions, whereas DAVC mitigation strategies can focus on long-term solutions for stable hotspot areas.

5.2.5 Implications for Mitigation Strategies

The separation of DAVC and WVC hotspots across all three reservations underscores the importance of implementing tailored mitigation strategies for each collision type (Sullivan, 2011). WVC hotspots, typically influenced by wildlife movement patterns and proximity to natural habitats, can be effectively managed through the installation of wildlife crossing structures, exclusionary fencing, and road signage that directs motorists' attention to wildlife crossings. In contrast, DAVC hotspots require different approaches, such as improved livestock fencing, enhanced signage warning of livestock presence, or modified livestock management practices in areas adjacent to roads. For example, restricting livestock grazing near high-risk road segments or installing underpasses specifically designed for livestock movement could reduce DAVC rates.

5.3 Conclusion

The analysis of DAVC and WVC hotspots on the Blackfeet, Crow, and Flathead Reservations reveals distinct spatial and temporal patterns, highlighting the need for tailored mitigation strategies to address each type of collision. The stability of DAVC hotspots suggests that long-term measures, such as fencing and localized road modifications, may be particularly effective in reducing collisions with domestic animals. In contrast, the more variable nature of WVC hotspots requires flexible management strategies that can adapt to changing wildlife movement patterns and environmental conditions.

The elevated proportion of DAVCs on tribal lands compared to non-tribal areas suggests that unique factors—such as open range grazing practices, road infrastructure, and livestock management—are contributing to the higher rates of livestock-related collisions on reservations. This study emphasizes the importance of implementing targeted mitigation strategies, such as improved livestock management practices, enhanced signage, or underpasses designed specifically for livestock crossings, to reduce DAVCs and improve safety on tribal roads.

Understanding the differing characteristics of DAVC and WVC hotspots is essential for developing comprehensive mitigation approaches that enhance motorist safety and support habitat connectivity on Montana's tribal lands. Future research should focus on further exploring the underlying factors influencing these patterns, such as livestock movement, traffic volumes, and seasonal variations, to refine these strategies and ensure effective collision reduction for both wildlife and domestic animals across all tribal reservations.

6 References

1. Burton, K. B., Taylor, D., & Gillingham, M. (2014). Domestic animal-vehicle collisions in rural Utah. Utah State University Press.
2. Burton, M., Prozzi, J., & Buddhavarapu, P. (2014). Predicting animal-vehicle collisions for mitigation in Texas. In Proceedings of the International Safer Roads Conference (Cheltenham, UK).
3. Clevenger, A. P., & Huijser, M. P. (2011). Wildlife crossing structure handbook: Design and evaluation in North America. Department of Transportation, Federal Highway Administration.
4. Cramer, P. C., & McGinty, M. A. (2018). Livestock-vehicle collisions in western states: A growing concern. Journal of Safety Research, 67, 56-63.
5. Cramer, P., & McGinty, C. (2018). Prioritization of wildlife-vehicle conflict in Nevada. Carson City, NV.
6. Cramer, P., & McGinty, K. (2018). Assessment of animal-vehicle collisions and their environmental impacts. Journal of Wildlife Management, 82(6), 1230-1240.
7. Creech, T. G., Fairbank, E., Clevenger, A., Callahan, A., & Ament, R. (2019). Differences in spatiotemporal patterns of vehicle collisions with wildlife and livestock. Environmental Management.
8. Creech, T. G., et al. (2019). Animal-vehicle collisions on Montana's tribal lands: Patterns and mitigation strategies. Montana Department of Transportation.
9. Creech, T., et al. (2019). Domestic animal-vehicle collisions on Montana tribal lands: Patterns, trends, and contributing factors. Montana Department of Transportation Report.
10. Esri. (2024). ArcGIS Pro (Version 3.1.2) [Software]. Environmental Systems Research Institute, Inc. Retrieved from https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview.
11. Fairbank, E., Callahan, R., Creech, T., Huijser, M., & Ament, R. (2019). Blackfeet animal-vehicle collision reduction master plan: Enhancing safety and connectivity for people and animals. Report prepared for Blackfeet Nation's Fish and Wildlife Department, Browning, MT.
12. Huijser, M. P., McGowen, P., Clevenger, A. P., & Ament, R. (2008). Wildlife-vehicle collision reduction study. Federal Highway Administration.
13. Huijser, M. P., McGowen, P., Fuller, J., Hardy, A., Kociolek, A., Clevenger, A., et al. (2008). Wildlife-vehicle collision reduction study: Report to Congress. Bozeman, MT.
14. Huijser, M. P., et al. (2008). Wildlife-vehicle collision reduction study: Best practices manual. Federal Highway Administration Report, Washington, D.C.
15. Posit Team. (2023). RStudio: Integrated development environment for R [Software]. Posit Software, PBC, Boston, MA. Retrieved from http://www.posit.co/.
16. Sullivan, J. M. (2011). Trends and characteristics of animal-vehicle collisions in the United States. Journal of Safety Research, 42, 9–16.
17. Sullivan, J. M. (2011). Trends and patterns in animal-vehicle collisions: Implications for mitigation. Accident Analysis & Prevention, 43(3), 646-653.
18. Sullivan, T. (2011). Factors affecting wildlife-vehicle collisions in North America. Transportation Research Board Report. Washington, D.C.
19. Wildlife Quality Improvement Team. (2005). Reducing livestock collisions on Nevada highways. Nevada Department of Wildlife.

20. Wildlife Quality Improvement Team. (2005). Wildlife and domestic animal-vehicle collisions. Taylorsville, Utah.
21. Zaloshnja, E., Miller, T. R., & Spicer, R. S. (2003). Costs of animal-vehicle collisions involving large wildlife in the United States. Accident Analysis & Prevention, 35(3), 451-462.
22. Zaloshnja, E., Miller, T., Galbraith, M., Lawrence, B., DeBruyn, L., Bill, N., et al. (2003). Reducing injuries among Native Americans: Five cost-outcome analyses. Accident Analysis & Prevention, 35, 631–639.