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Planning-Support for Mitigation of Wildlife-Vehicle Collisions and Highway Impacts on Migration Routes in Wyoming

By:

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Abstract Wyoming is home to abundant big game, including long-distance migratory species such as mule deer, elk, and pronghorn. Where these animals' movement patterns intersect with roads, vehicles often hit animals. This poses a threat both to highway safety and to wildlife populations. Here, we identified 27 deer-vehicle collision "hotspots" in the state. We then analyzed the ecological and road characteristics that are associated with these areas. High rates of deer-vehicle collision are most strongly associated with high traffic volumes, high speed limits, deer migration habitat, deer winter-use areas, irrigated agriculture, and wetlands. We then examined the spatial and temporal patterns of collisions for each hotspot in relation to known deer migration routes and winter-use areas. Using these results, we suggest mitigation measures that are most suitable for each of the 27 collision hotspots.			
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SI* (MODERN METRIC) CONVERSION FACTORS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised March 2003)

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LIST OF ABBREVIATIONS AND SYMBOLS

AADT – annual average daily traffic
AIC – Akaike's information criterion
BBMM – Brownian bridge movement model
CI – confidence interval
DF – degrees of freedom
DVC – deer-vehicle collision
ESRI – Environmental Systems Research Institute
FT – foot
GIS – geographic information system
GLM – generalized linear model
GPS – global positioning system
KM – kilometers
LRS – linear referencing system
M – meter
MI – miles
ML – main line
MP – mile post
MPH – miles per hour
NLCD – National Land Cover Database
SEM – standard error of the mean
TIN – Time-integrated Normalized Vegetation Difference Index
UD – utilization distribution
WGFD – Wyoming Game and Fish Department
WVC – wildlife-vehicle collision
WYDOT – Wyoming Department of Transportation
ΔAIC – Change in Akaike's information criterion

CHAPTER 1. EXECUTIVE SUMMARY

Wyoming is home to abundant big game, including long-distance migratory species such as mule deer, elk, and pronghorn. Where these animals' movement patterns intersect with roads, vehicles often hit animals. This poses a threat both to highway safety and to wildlife populations. In addition to causing direct wildlife mortality, wildlife-vehicle collisions also indicate that roads are posing a partial barrier to animal movements.

The Wyoming Department of Transportation continues to work to reduce wildlife-vehicle collisions and increase habitat connectivity in the state. Maximizing the effectiveness of these efforts requires an understanding of why, where, and when collisions occur. Such information helps to inform decisions about which mitigations are most suitable for a particular location. This is important because mitigation measures vary widely in cost and effectiveness

We used carcass and collision records from 2008 to 2013 to identify the areas in Wyoming with the highest rates of wildlife-vehicle collisions (focusing primarily on deer, which make up the majority of wildlife-related collisions). We identified 27 deer-vehicle collision "hotspots" in the state. These hotspots are stretches of road typically 5-20 miles long that have more than six deer-vehicle collisions (DVC) per mile per year. We first analyzed the location of 493 signs across the state intended to warn drivers about crossing wildlife. We identified locations currently lacking signs that should be considered for signage, and areas with signs where the collision rates do not warrant signage.

We then analyzed the ecological and road characteristics that are associated with areas of high DVC rates. Results showed that DVC spatial patterns are consistent across multiple years. High DVC rates are most strongly associated with high traffic volumes, high speed limits, deer migration habitat, deer winter-use areas, irrigated agriculture, and wetlands.

Next, we examined the spatial and temporal patterns of DVC for each hotspot in relation to known deer migration routes and winter-use areas. We used migration and winter-use data from six mule deer herds in Wyoming from which representative individuals have been fitted with GPS collars to track their movements. By comparing the spatial and temporal patterns of DVC with known deer movement routes, we were able to verify that DVC patterns in other parts of the state accurately reflect the seasonal movement patterns of deer. This analysis also highlighted places in known deer migration routes that suffer from high DVC rates and potential threats to habitat connectivity. Finally, from this analysis, we assessed where DVC hotspots are associated with migration times only, winter-use areas only, migration and winter-use, summer-use, or year-long deer presence.

Using these results, we suggest mitigation measures that are most suitable for each of the 27 collision hotspots. These recommendations take into account the seasonal patterns of deer movements across the road at that location, traffic volume, and the best current knowledge about the effectiveness of a variety of mitigation measures.

CHAPTER 2. INTRODUCTION

WILDLIFE-VEHICLE COLLISIONS IN WYOMING

Wildlife-vehicle collisions (WVCs) pose a serious threat both to highway safety and to wildlife populations.[1,2] In particular, collisions involving large ungulates, such as deer (*Odocoileus* spp.), moose (*Alces alces*), or elk (*Cervus elaphus*), often result in significant damage to the vehicle and injury to its occupants. Across the United States, an estimated 1-2 million wildlife-vehicle collisions (WVC) occur every year, and this number continues to climb as road networks expand and traffic volumes increase.[2]

Predicting and mitigating the occurrence of wildlife-vehicle collisions are high priorities both for the Federal Highway Administration (FHWA) and for State Departments of Transportation.[2] In Wyoming, an average of 2,228 WVCs were reported in the last three years, accounting for more than 15 percent of all reported collisions.[3-5] However, our analysis of Wyoming Department of Transportation (WYDOT) collision and carcass data (that latter of which is not included in collision statistics) shows that an average of more than 5,000 wildlife-vehicle collisions have occurred annually over the last three years. This number further underestimates actual collisions, as many animals leave the road right-of-way before dying.[6] The overwhelming majority (>85 percent) of collisions in Wyoming involve mule deer.

These collisions pose a safety hazard and are costly; in addition to causing significant damage to vehicles and injury to their occupants, they are almost always lethal to the animal. The Wyoming Department of Transportation's estimated costs per reported collision are $11,600 in injury and property damage costs and $4,000 in the unclaimed restitution value of each mule deer that is killed. Taken together, deer-vehicle collisions total approximately $24-29 million per year in Wyoming in injury and damage costs and an additional $20-23 million per year in wildlife costs.

Highways and vehicle collisions also have a significant negative impact on wildlife populations – reducing their numbers through impacts and mortalities, reducing habitat quality, and impeding their movements through their seasonal ranges and along their migratory corridors.[7-9] Where highways create a partial or complete barrier to wildlife movements, they threaten populations by impairing their ability to access the resources they need.[9] Wyoming supports one of the largest populations of ungulates in North America. However, mule deer populations in Wyoming are in decline, as they are across most of the West,[10] and conserving their populations is an extremely high priority for the Wyoming Game and Fish Department (WGFD).[11] Roads have been identified as posing a significant threat to mule deer populations in Wyoming and across their range. [12]

Most of Wyoming's ungulates are migratory. Ungulates depend on migration to avoid the high elevation deep snows in winter but, conversely, to benefit from the higher quality forage available at high elevations in summer. Wyoming is home to an extensive network of mule deer migration routes, including the recently-discovered 150-mile Red Desert to Hoback migration — the longest known terrestrial migration in the lower 48 states.[13] Mule deer movements and migrations in Wyoming and across the West are imperiled due to a variety of anthropogenic habitat modifications, including energy and housing developments, fences, and roads.[11-20]

The Wyoming Department of Transportation continues to work extensively to mitigate wildlife-vehicle collisions; doing so is important to achieving WYDOT's strategic goals of keeping people safe on the state transportation system, and exercising good stewardship of our resources.[21] These are particularly important as the human population of Wyoming continues to grow, with corresponding increases in residential and road development as well as vehicle traffic.[22]

Understanding where and why wildlife-vehicle collisions occur is an important step in mitigating the problems of wildlife-vehicle collisions and habitat fragmentation for wildlife. Data on the spatial and temporal patterns of vehicle collisions with wildlife can be related to habitat and road features, as well as information about wildlife movement patterns, to gain insights into where and why collisions are occurring.[20,23-26] By understanding the spatial and temporal patterns of WVCs, transportation managers can make informed decisions about how to prioritize the location and type of mitigation measures and thus maximize the cost-effectiveness of mitigations.[23,27-29] This is important because there are many potential mitigation measures available, and these range widely in costs and effectiveness under different circumstances.[27-31] Common mitigation measures include wildlife warning signs (e.g., static icon of a jumping deer), temporary (movable) wildlife warning signs, highway under- and over-passes in conjunction with funnel fencing to guide animals towards crossing structures, wildlife cross-walks (designated locations for crossing, often accompanied by funnel fencing and signage to alert drivers), and animal detection systems. These range in effectiveness from un-detectible effects to >80 percent reductions in WVC and in cost from hundreds to millions of dollars.[27,30-31]

In this study, we set out to:

1. *Identify the locations of highest wildlife- and deer-vehicle collision (DVC) rates in Wyoming.*
2. *Evaluate the location of existing wildlife warning signs in relation to areas with high collision rates.*
3. *Relate patterns of deer-vehicle collisions to ecological and road factors in order to understand the drivers of high DVC rates in Wyoming.*
4. *Relate information about known deer migration routes to DVC patterns in order to identify where migration routes are most impacted by roads.*
5. *Recommend possible mitigations for areas with high DVC rates, given new insights into the temporal patterns and causes of high DVC rates in these areas.*

CHAPTER 3. LOCATIONS OF WILDLIFE WARNING SIGNS IN WYOMING

INTRODUCTION

Wildlife warning signs (e.g. jumping deer symbol) are one of the most commonly-used methods aimed at reducing wildlife-vehicle collisions because they are relatively inexpensive and require little maintenance.[32] The Wyoming Department of Transportation has records of nearly 500 wildlife warning signs that have been installed around the state. Several Highway Safety and Maintenance personnel have indicated that it would be valuable to evaluate the location of these signs in relation to spatial patterns of WVC, in order to ensure optimal placement of signs.

We utilized WYDOT's maintenance district sign inventories, Linear Referencing System (LRS) of Wyoming roads, and wildlife-vehicle collision and carcass data to analyze the relationships between wildlife warning sign placement and vehicle collisions. In this analysis, we included all non-livestock ungulate records available in the wildlife-vehicle collision database. Our objectives were to identify areas with high WVC rates and no signs, as well as areas with signs but low WVC rates, in order to guide decisions about future sign placement.

METHODS

Data Acquisition and Preparation

All data preparation and analyses were conducted using ArcGIS versions 9.3, 10.0 and 10.3.[33]

The sign database was created from WYDOT's maintenance district sign inventory, which contains all types of signs across the state. We focused on signs pertaining to wildlife warnings or animal crossings and left out signs pertaining exclusively to stock animals. The sign types used for this analysis were:

- Attention Deer Crossing (6).
- Caution Watch For Animals On Road (9).
- Deer Crossing (4).
- Deer Crossing Area Reduce Speed (2).
- Elk Crossing (8).
- Game Crossing (451).
- Migratory Deer Crossing (1).
- Moose Crossing (1).
- Watch For Wildlife On Road (11).

This created a subset of 493 signs across Wyoming.

Road attribute data were derived from WYDOT's LRS. In order to prepare roads data for analysis, we removed:

- Roads that were not main line (ML) Routes.
- Roads with no carcass or crash data.

- Roads that were shorter than two miles long.

For divided roadways represented by two different lines, one line was removed and collision data were assigned to the remaining line. The final road network used in our analyses was made up of 161 different roads and 6,692 mi (10,769 km) of roadway.

We acquired WYDOT's state-wide carcass location data ("carcass" data) and reported wild animal-vehicle crash data ("crash" data) records for the years 1990-2013. We then merged the digital records into a master "collisions" database and converted this tabular data into a spatially explicit geo-database. This was a multi-step process involving substantial data cleanup and removal of duplicate records. Records coded as "mule deer", "white-tailed deer", "elk", "moose", "mule deer", "pronghorn", or simply "deer" were used. For the purposes of analysis, we further restricted our data to the years 2008-2013. According to WYDOT personnel, carcass data collection protocols were improved and standardized across the state starting in 2008. All records were snapped to nearest LRS route and cleaned for mismatched ML Routes. This created a subset of 36,366 WVC records.

For this analysis, we set out to examine patterns of WVC in the several miles around wildlife crossing signs. We segmented WYDOT's LRS routes network into 1 mi (1.6 km) road sections and quantified the number of collisions along each segment. This was the finest spatial scale at which we could examine total WVC counts since many carcass observations are assigned to the nearest mile marker (MP). For this reason, we centered the 1 mi (1.6 km) road segments on WYDOT's mile markers and calculated the number of WVC in 0.5 mi (0.8 km) in either direction from the mile marker to create 6,305 complete 1 mi (1.6 km) -long segments.

Counts of WVC per mile over all years (2008-2013) ranged from 0 to 110, or 0-18.3 per mile per year (0-11.4 per km per year). Data were log-transformed to achieve normality and divided into five equal bins, which we categorized as:

- Zero: 0 WVC per mile per year (0 per km per year).
- Low: > 0 but < 2 WVC per mile per year (> 0 but < 1.25 per km per year).
- Medium: ≥ 2 but < 6 WVC per mile per year (≥ 1.25 but < 3.75 per km per year).
- High: ≥ 6 but <10 WVC per mile per year (≥ 3.75 but < 6.25 per km per year).
- Very High: ≥ 10 WVC per mile per year (≥ 6.25 per km per year).

Data Analysis

For all analyses of sign location, we assumed that sign warnings applied to the 5 mi (8 km) after the sign along the road. The distance over which wildlife warning signs influence driver behavior is not known, but may be significantly shorter than 5 miles. [32] We used 5 miles in order to identify places that were most clearly "far" from any wildlife warning sign and thus highest priority for new signage.

We first identified areas with high WVC rates but no sign nearby. We ran a "Near" analysis in ArcGIS using each 1 mi (1.6 km) road segment and the location of each wildlife warning sign. This allowed us to determine whether there is a wildlife warning sign within each 1 mi (1.6 km) segment and if not, what is the distance to the nearest sign. We used this analysis to locate all of the road segments with "High" or "Very High" WVC classification that were more than 5 mi (8 km) from the nearest wildlife warning sign.

We then identified signs that had low WVC rates in the 5 mi (8 km) stretch of road directly following the sign's location. The maintenance district sign inventory includes information about the cardinal direction in which the sign is facing. We created a Zone of Influence shape file to make sure we only tallied the WVC records after the sign. For example, if a sign faces East (toward West-bound traffic), the 5 mi (8 km) stretch of road West of the sign was extracted. Several signs (n=20 records out of 493) did not have usable information about their cardinal direction and were excluded from this analysis. Signs located within 2.5 mi (4 km) from the end of a road were also not used (n=27 records). We then extracted the total number of WVC for each sign's 5 mi (8 km) zone of influence using the methods detailed above. Signs for which the entire 5 mi (8 km) zone of influence had only "Zero" and "Low" WVC were identified.

Lastly, we compared WVC rates before and after sign installation. Out of 493 possible signs in the database, only 227 records had installation dates, and of these only 63 had at least one year of data before and after installation. Wherever possible, we averaged the number of WVC per year for the three years before installation and the three years after installation; where this was not possible, only one or two years of data were used to generate an average annual number of WVCs. We excluded the year in which the sign was installed since the precise date of installation was unknown. Rates of WVC before and after sign installation were compared using a paired *t*-test.

RESULTS

Location of Areas with Very High WVC Rates

Rates of WVC's were logarithmically distributed and ranged from 0 to 18.3 per mi per year (0 to 11.4 per km per year) (table 1).

Table 1. Number of 1 mi (1.6 km) road segments in each of five categories of WVC rate.

Category	WVC per mile per year	Number of road segments
Zero	0	1603
Low	> 0 and < 2	3818
Medium	≥ 2 and < 6	737
High	≥ 6 but <10	92
Very High	≥ 10	22

We present the location of 1 mi (1.6 km) road segments with high WVC rates in several ways. The rank order of the 22 miles classified as "Very High" is given in table 2, while spatial clusters of these miles are indicated in table 3. The most dangerous 1 mi (1.6 km) stretch of road for ungulates was just north of Thermopolis, with 110 records over the six-year period (18.3 WVC per year). Four stretches in the "Very High" category were located between Daniel Junction and Pinedale; however, this area had an extensive mitigation project completed in 2012 that is already proving highly successful.[34]

Table 2. Road segments (1 mi or 1.6 km) with the highest ungulate WVC rates in Wyoming, in rank order.

Rank	Route	ML Route	MP	WVC Count	Average Per Year
1	US20	ML34	137	110	18.33
2	WY89	ML50	3	107	17.83
3	WY89	ML50	6	98	16.33
4	US191	ML13	106	91	15.17 (2)
5	WY89	ML50	5	86	14.33
6	WY89	ML50	4	82	13.67
7	US14	ML29	4	82	13.67
8	US20	ML34	139	78	13.00
9	US20	ML34	136	77	12.83
10	US30	ML12	6	76	12.67
11	I80	ML80	3	76	12.67
12	US191	ML13	96	73	12.17 (12)
13	US20	ML34	138	71	11.83
14	WY89	ML50	7	70	11.67
15	US191	ML13	97	70	11.67 (7)
16	US20	ML34	130	69	11.50
17	US14	ML29	3	65	10.83
18	US14	ML29	6	65	10.83
19	US14	ML29	10	65	10.83
20	US14	ML29	16	64	10.67
21	US20	ML34	131	60	10.00
22	US191	ML13	90	60	10.00 (5)

For Pinedale locations, we present number of WVC from 2013 (after crossing structures completed) in parentheses.

Table 3. Road segments (1 mi or 1.6 km) with the highest ungulate WVC rates in Wyoming, grouped by location. The rank WVC rate is given in parentheses.

Area	Route Name	MP and Rank
Evanston	I80 [ML80]	MP 3 (11th)
	WY89 [ML50]	MP 3 (2nd)
		MP 4 (6th)
		MP 5 (5th)
		MP 6 (3rd)

		MP 7 (14th)
Thermopolis	US20 [ML34]	MP 130 (16th)
		MP 131 (21st)
		MP 136 (9th)
		MP 137 (1st)
		MP 138 (13th)
		MP 139 (8th)
Cody	US Alt14 [ML29]	MP 3 (17th)
		MP 4 (7th)
		MP 6 (18h)
		MP 10 (19th)
		MP 16 (20th)
Pinedale	US191 [ML13]	MP 90 (22nd)
		MP 96 (12th)
		MP 97 (15th)
		MP 106 (4th)
Cokeville	US30 [ML12]	MP 6 (10th)

Areas With High and Very High WVC Rates But No Sign

We identified 23 1 mi (1.6 km) road segments that have an average of six or more WVCs per year (High and Very High categories) and are located more than 5 mi (8 km) from the nearest wildlife warning sign.These include three segments from the Very High category and 20 from the High category (table 4). These are clustered in seven general areas around the state (figure 1).

Table 4. Areas with High and Very High WVC rates but no sign.

Area	**Route Name**	**MP**
Road segments > 5 mi (8 km) from a wildlife warning sign and averaging ≥ 10 WVC per year:		
Cody	US Alt 14 [ML29]	MP 6
		MP 10
		MP 16
Road segments > 5 mi (8 km) from a wildlife warning sign and averaging 6-10 WVC pear year:		
Cody	US Alt 14 [ML29]	MP 7
		MP 9
		MP 11
		MP 12
		MP 13
		MP 17
Worland and Thermopolis	US20 [ML34B]	MP 154
		MP 155
		MP 158
		MP 159

		MP 162
		MP 163
		MP 164
		MP 168
		MP 169
Garland	US Alt14 [ML29]	MP 40
Between Riverton and Lander	WY 789 [ML20]	MP 99
Chugwater	I25 [ML25]	MP 57
Elk Mountain	I80 [ML80]	MP 252
Between Evanston and Kemmerer	US 189 [ML11]	MP 10

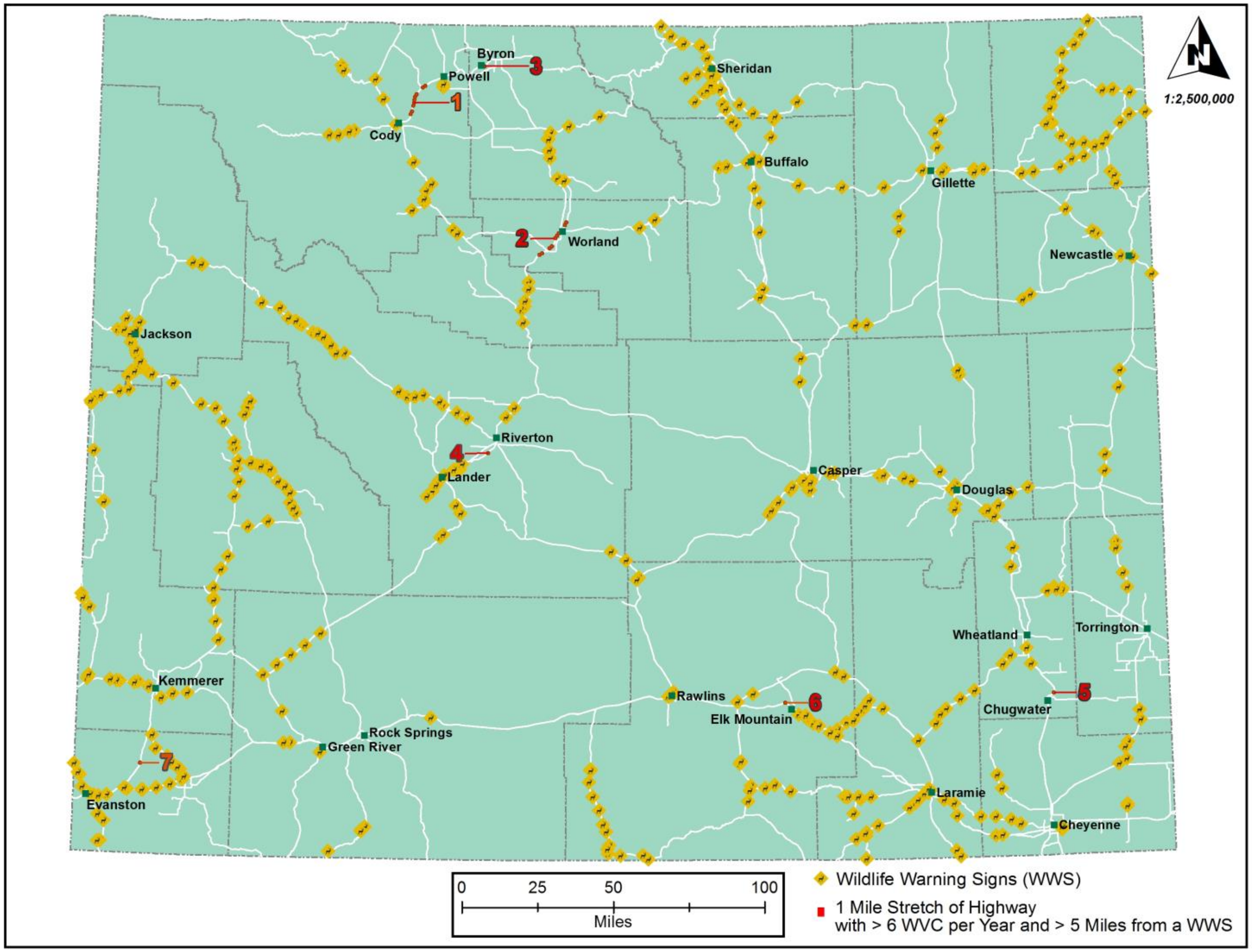


Figure 1. Locations of the 23 road segments (in seven general locations) that experienced more than six WVC per year and are located more than 5 mi (8 km) from the closest wildlife warning sign.

Areas With Signs But Zero and Low WVC Rates

We identified five signs that had zero WVCs in the 5 mi (8 km) after the sign (in the direction of traffic flow) over six years (table 5; figure 2). Two of these signs say “Caution Watch for Animals on Road”. It is possible that these refer to livestock and open range conditions rather than the wildlife species for which we examined WVC rates (elk, moose, pronghorn, mule deer, and white tail deer).

Table 5. Sign locations with zero WVCs recorded between 2008 – 2013.

Sign	Legend	WYRoute	MLRoute	MP
267886	GAME CROSSING SYMBOL	WY 10	ML101	8.98
280762	CAUTION WATCH FOR ANIMALS ON ROAD NEXT 6 MILES	WY 28	ML1912	117.73
280767	CAUTION WATCH FOR ANIMALS ON ROAD NEXT 24 MILES	WY 28	ML1912	124.5
301046	GAME CROSSING SYMBOL	WY 296	ML1507	20.1
301063	GAME CROSSING SYMBOL	WY 296	ML1507	22.3

We identified 64 signs for which all of the 5 mi (8 km) after the sign had <2 WVCs per year (table 6; figure 2). As above, six of these signs say “Caution Watch for Animals on Road” and may be referring primarily to livestock rather than wildlife.

Table 6. Sign locations with <2 WVCs per mile per year (<1.25 per km per year) recorded between 2008 – 2013.

Sign	Legend	WYRoute	MLRoute	MP
252462	GAME CROSSING SYMBOL	US287/WY789	ML21	42.81
254820	GAME CROSSING SYMBOL	US287/WY789	ML20	7.05
261333	GAME CROSSING SYMBOL	WY252	ML1302	0.69
266104	GAME CROSSING SYMBOL	WY11	ML102	1
266120	GAME CROSSING SYMBOL	WY11	ML102	7.1
266332	WATCH FOR WILDLIFE ON ROAD (FOLDING)	WY34	ML109	1
266334	WATCH FOR WILDLIFE ON ROAD (FOLDING)	WY34	ML109	9.06
272492	GAME CROSSING SYMBOL	WY211	ML211	20
272505	GAME CROSSING SYMBOL	WY211	ML211	25
272723	GAME CROSSING SYMBOL	WY212	ML212	5.19
272745	GAME CROSSING SYMBOL	WY212	ML212	6.11
280718	CAUTION WATCH FOR ANIMALS ON ROAD NEXT 24 MILES	WY28	ML1912	100.01

280739	CAUTION WATCH FOR ANIMALS ON ROAD NEXT 6 MILES	WY28	ML1912	106
280740	CAUTION WATCH FOR ANIMALS ON ROAD NEXT 18 MILES	WY28	ML1912	106
280745	CAUTION WATCH FOR ANIMALS ON ROAD NEXT 12 MILES	WY28	ML1912	112
280746	CAUTION WATCH FOR ANIMALS ON ROAD NEXT 12 MILES	WY28	ML1912	112
280761	CAUTION WATCH FOR ANIMALS ON ROAD NEXT 18 MILES	WY28	ML1912	117.73
282955	GAME CROSSING SYMBOL	WY150	ML2100	17.9
283280	GAME CROSSING SYMBOL	WY412	ML2103	22.4
284963	GAME CROSSING SYMBOL	WY59	ML43	134.18
285278	GAME CROSSING SYMBOL	WY50	ML300	19.96
285288	GAME CROSSING SYMBOL	WY50	ML300	25
286539	GAME CROSSING SYMBOL	US14	ML607	179.46
286540	GAME CROSSING SYMBOL	US14	ML607	179.97
286566	GAME CROSSING SYMBOL	US14	ML607	181.4
286606	GAME CROSSING SYMBOL	US14	ML607	187
286629	GAME CROSSING SYMBOL	US14	ML607	192
286637	GAME CROSSING SYMBOL	US14	ML607	196.35
286966	GAME CROSSING SYMBOL	WY585	ML2303	26.66
287126	GAME CROSSING SYMBOL	WY24	ML601	0.61
287170	GAME CROSSING SYMBOL	WY24	ML601	5.42
287208	GAME CROSSING SYMBOL	WY24	ML601	6.52
287214	GAME CROSSING SYMBOL	WY24	ML601	9.61
287490	GAME CROSSING SYMBOL	WY24	ML601	35.64
287610	GAME CROSSING SYMBOL	WY112	ML604	2.02
287625	GAME CROSSING SYMBOL	WY112	ML604	7.05
287630	GAME CROSSING SYMBOL	WY112	ML604	13.31
287635	GAME CROSSING SYMBOL	WY112	ML604	18.68
287636	GAME CROSSING SYMBOL	WY112	ML604	18.78
287646	GAME CROSSING SYMBOL	WY112	ML604	23.45
287647	GAME CROSSING SYMBOL	WY112	ML604	23.45
287656	GAME CROSSING SYMBOL	WY112	ML604	28.65

290436	GAME CROSSING SYMBOL	US14	ML302	14.36
292952	GAME CROSSING SYMBOL	WY450	ML2300	34.04
292956	GAME CROSSING SYMBOL	WY450	ML2300	37.07
297690	GAME CROSSING SYMBOL	WY131	ML701	6.11
300438	GAME CROSSING SYMBOL	WY290	ML1500	5.92
300878	GAME CROSSING SYMBOL	WY295	ML1505	10.04
301061	GAME CROSSING SYMBOL	WY296	ML1507	22.29
301424	WATCH FOR WILDLIFE ON ROAD	US 26/287	ML30	9.22
362235	GAME CROSSING SYMBOL	WY332	ML332	2.67
391890	GAME CROSSING SYMBOL	WY150	ML2100	11
402548	GAME CROSSING	WY412	ML2103	7.5
402553	GAME CROSSING SYMBOL	WY412	ML2103	10
402554	GAME CROSSING NEXT 5 MILES	WY412	ML2103	12.5
402556	GAME CROSSING NEXT 5 MILES	WY412	ML2103	17.4
402558	GAME CROSSING NEXT 5 MILES	WY412	ML2103	17.4
406440	GAME CROSSING	WY412	ML2103	6.5
413654	ELK CROSSING SYMBOL	WY585	ML2303	16.5
417387	GAME CROSSING SYMBOL	WY352	ML352	16.94
417389	GAME CROSSING SYMBOL	WY352	ML352	21.86
417867	CAUTION WATCH FOR ANIMALS ON ROAD	WY372	ML1906	12.7
422041	GAME CROSSING SYMBOL	WY59	ML43	129.17
426809	WATCH FOR WILDLIFE ON ROAD	WY130	ML103	52.44

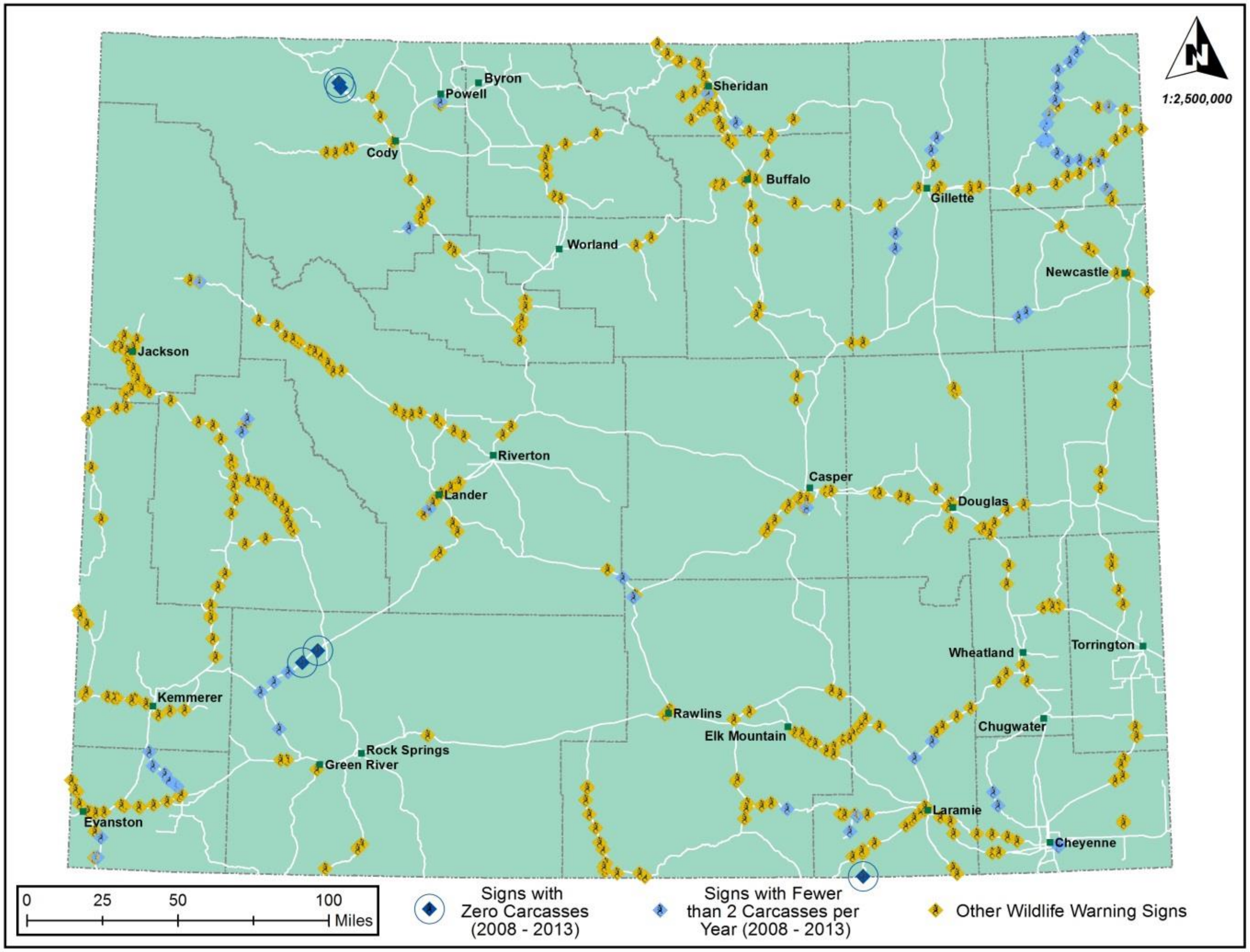


Figure 2. Existing wildlife warning signs with zero or fewer than two WVC records per mi per year (1.25 per km per year) in the 5 mi (8 km) after the sign (in the direction of traffic flow) between 2008 and 2013.

Effectiveness of Signs

Of the 63 5 mi (8 km) "zone of sign influence" segments that could be analyzed, 12 had the exact same WVC average before and after the sign was installed, 28 had fewer WVC after the sign was installed, and 23 records had more WVC after the sign was installed. There was no significant difference in WVC per year before and after sign installation (mean before = 8.92 ± 1.82 SEM, mean after = 9.71 ± 1.99 SEM, t = -0.29, n=64, p=0.77).

DISCUSSION

The results of this analysis highlight opportunities to remove some signs that are located in low WVC areas and to install signs in several high and very high WVC areas that appear not to have any wildlife warning signs. Installing signs in these high WVC areas is one of the simplest and least costly ways to try to reduce WVC rates. However, it is important to note that the general consensus in the scientific literature is that permanent wildlife warning signs — even "enhanced" ones (e.g. ones with flashing lights, graphic images, or variable messages) — are ineffective.[30,32] This may be because of "sign fatigue" -- drivers see so many signs that they stop paying attention to them, particularly if drivers do not perceive there to be a large presence of wildlife in the roadways.[32] With at least 493 signs in Wyoming, it is very possible that drivers pay little attention to these signs.

Removing signs from zero, low, and even moderate WVC areas could reduce the phenomenon of sign fatigue. (Note: although it might be argued that the low WVC rates are evidence of the signs' effectiveness, this seems unlikely given that numerous studies have shown signs to have minimal effectiveness). Alternatively, permanent signs could be replaced with seasonal signs, which have been shown to reduce WVCs by 9-50 percent.[32] Most areas with high WVC rates have seasonal peaks, and movable or temporary signs could be used during these times (see Chapters 5 and 6 for specific recommendations). Temporary night-time reductions in speed limit could help to further reduce WVC rates in these areas. In general, however, it is important to consider that signs are considered among the least cost-effective mitigation methods because of their low effectiveness; wherever possible, other mitigation methods should be used.

CHAPTER 4. PATTERNS OF DEER-VEHICLE COLLISIONS ACROSS WYOMING

INTRODUCTION

We made use of WYDOT's wildlife-vehicle collision records to analyze patterns of deer-vehicle collisions across the state. We focus on deer because they make up the vast majority (>85 percent) of wildlife-vehicle collisions. Our purpose here was to understand broad-scale drivers of high versus low DVC.

METHODS

Data Acquisition and Preparation

We acquired WYDOT's state-wide carcass location data ("carcass" data) and reported wild animal-vehicle crash data ("crash" data) records for the years 2008-2013, then merged the digital records into a master "collisions" geo-database following the protocols outlined in Chapter 3. Records coded as "mule deer", "white-tailed deer", and "deer" were retained. Because of the ambiguity of the latter designation, we combined all three types of record into a master data set of "all deer". Given the distribution of mule deer versus white-tailed deer in Wyoming, these data likely represent >90 percent mule deer records.

Collision records varied substantially in their degree of spatial precision. While many crash records have GPS coordinates associated with them, carcass locations are estimated by highway maintenance crews in reference to the nearest mile. For the purpose of analysis, we therefore assigned all carcass or crash records to the nearest whole-mile marker.

Road attribute data were derived from WYDOT's Linear Referencing System (LRS) of Wyoming roads. In order to prepare roads data for analysis, we removed:

- Roads that were not ML Routes.
- Roads with no traffic data.
- Roads with no carcass or crash data.
- Roads that were less than two miles long.

For divided roadways represented by two different lines, one line was removed and road attribute and collision data were assigned to the remaining line. The final road network used in our analyses was made up of 161 different roads and 6,692 mi (10,769 km) of roadway.

We analyzed collision and habitat patterns at the scale of 3.2 mi (5.15 km). This scale enabled us to obtain meaningful habitat data within an ecological relevant radius. Collision and habitat data were obtained on a scale of 3.2 mi (5.15 km) rather than 3 mi (4.8 km) because the distance between whole-mile markers is not always precisely 1 mi (1.6 km); by extending to 3.2 mi (5.15 km), we ensured that each road segment included three mile markers and their associated collision records. Segments were centered on every fourth mile marker and extended 1.6 mi (2.6 km) in each direction. Segment-centers started at mile marker 2 of each ML route to avoid sampling road intersections twice. Collision data were extracted for a total of 1,518 unique road segments.

For each road segment, we extracted data on total traffic volume, truck traffic volume, and speed limit as road characteristics potentially related to DVC patterns. Traffic volume and truck traffic volume were derived from WYDOT's Annual Average Daily Traffic (AADT) estimates, which are maintained for 2,142 road segments across the state.[22] Within each of our 3.2 mi (5.15 km) road segments, total vehicle and truck traffic AADT were averaged for the years spanning 2008-2013. Speed limit data were extracted from WYDOT Traffic Program data.[35] If speed limit or traffic estimates varied within the road segment, we extracted the maximum value within that segment. Total traffic and truck traffic volumes were log-transformed to achieve normality. In order to facilitate analysis, speed limit data were collapsed into three levels: ≤55 mph, 65 mph, and 75 mph.

We considered two possible definitions of deer winter-use areas based on designations made by the Wyoming Game and Fish Department (WGFD). We defined "winter-use" as a composite of several seasonal designations identified and maintained in GIS by the WGFD: winter range (WIN), winter and year-long range (WYL), crucial winter range (CRUWIN), crucial winter and year-long range (CRUWYL), and severe winter range (SWR). These were combined for both mule deer and white-tailed deer, although white-tailed deer range made up only 1 percent of our resulting "winter range" composite shapefile. Our "crucial winter-use" composite was similarly defined using WGFD's crucial winter (CRUWIN) and crucial winter and year-long (CRUWYL) range designations. We categorized each road segment based on whether it intersected winter-use areas or not, and whether it intersected crucial winter-use areas or not.

We also considered two possible definitions of deer migration routes: "expert migration" and "modeled migration". We defined "expert migration" using linear routes of deer migration patterns that are maintained by WGFD. [36] These were developed from expert knowledge and limited telemetry data. We buffered these linear features by 1 km (0.6 mi) on either side to accommodate for the fact that precise animal movement patterns vary from individual to individual. We categorized each road segment based on whether it intersected this buffered area or not. For the alternative "modeled migration," we used a probability surface of migratory mule deer habitat in Wyoming created by applying a machine learning model to existing GPS collar-derived migration routes to create a migration habitat value that ranged from 0-1 (1 being the highest probability of a migration route occurring).[37] For each road segment, we calculated the average migration habitat value within a circle 3.2 mi (5.15 km) in diameter and centered on the linear road segment.

In addition, we considered a variety of other variables that could influence deer habitat use and therefore DVC patterns. These included: terrain ruggedness, primary productivity, land cover class, and proximity to bridges where water bodies intersect roads. Terrain ruggedness was defined as the standard deviation of DEM (30 m [98.4 ft] resolution) within the circle. Primary productivity was defined using the time-integrated Normalized Difference Vegetation Index (TIN), a measure of primary production (plant growth) across the entire growing season. This was obtained from the U.S. Geological Survey, which creates TIN layers from the 250 m (820.2 ft) resolution MODIS (Moderate Resolution Imaging Spectroradiometer) sensor for each year.[38]

For each habitat circle, we averaged the TIN values over the six years of the study. Land cover classes were derived from the National Land Cover Database 2011[39] (NLCD), with cover classes collapsed into a smaller number of cover classes to facilitate analysis (table 7). Land cover data were defined as the percent of the circle that was covered by each land cover type, log-transformed where necessary to meet assumptions of normality. Because assumptions of normality could not be met for percent crop cover, we categorized each habitat circle based on whether it contained any cropland or not. Bridge presence or absence for each habitat circle was determined using data from the WYDOT Planning Section;[40] since we were only interested in bridges that spanned water bodies, we only considered bridges that were within 50 m (164 ft) of a stream or river (using ESRI's River_ln_24k layer).

Table 7. Sixteen cover classes from the National Land Cover Database collapsed into six cover classes for the purposes of data analysis.

NLCD Cover Class	Cover Class for Analysis
Open Water	Wetland
Perennial Snow/Ice	Other
Developed, Open Space	Developed
Developed, Low Intensity	Developed
Developed, Medium Intensity	Developed
Developed, High Intensity	Developed
Barren Land	Other
Deciduous Forest	Forest
Evergreen Forest	Forest
Mixed Forest	Forest
Shrub/Scrub	Sagebrush
Herbaceous	Cropland
Hay/Pasture	Cropland
Cultivated Crops	Cropland
Woody Wetlands	Wetland
Emergent Herbaceous Wetlands	Wetland

Data Analysis

In order to facilitate visualization of deer-vehicle collision patterns and hotspots across Wyoming, we conducted a kernel density analysis of all collisions from 2008-2013. We used the ArcGIS Kernel Density tool from the Spatial Analyst Tools Density toolbox. The cell size was set to 895.5 m (0.55 mi) with a search radius of 4.83 km (3 mi).

We used a two-step hurdle model approach[41] to model the effects of habitat and road variables on DVC patterns across all six years. All analyses were conducted using the "MASS" and "nlme" packages in the R statistical software.[42] In the first step, we used a logistic regression to model the effects of predictor variables on a binomial response variable: DVC absent versus DVC present (any non-zero value). In the second step, we used a linear model to model the effects of predictor variables on the count (number) of DVCs for road segments that had positive (non-zero) DVC count values. The number of DVCs response variable was log-transformed to achieve normality. We used this two-step approach to accommodate very high zero-inflation in the full data set (many road segments with zero DVCs). In the first step, we effectively ask: "what are the variables that predict presence of DVCs versus absence of any DVCs?" In the second step, we effectively ask: "what are the variables that predict the number of DVCs, in places where DVCs occur?"

For both response variables, we used the same modeling process. Candidate variables that were correlated with each other (correlation coefficient >0.4) were excluded or treated as alternatives. Sage steppe cover was negatively correlated with almost all other cover variables and was not an informative variable since almost all of the state has high sage steppe cover; consequently this variable was not considered in any models. Total traffic volume and truck traffic volume were correlated with one another and were considered as alternatives to each other. Similarly, the two possible definitions of deer winter-use areas and the two possible definitions of deer migration areas were considered alternatives to each other. As a preliminary step, we made a simple comparison of the full model with each of these three pairs of alternative variables for each of the two response variables, then chose the alternative variable that provided the best model fit. We then used a forward-backward model selection process to identify the variables that best explained DVC patterns. Model fit was evaluated using Akaike's Information Criterion (AIC).

Additionally, because we were interested in whether results were consistent across all six years of data, and all four seasons (defined as fall=Sept-Nov, winter=Dec-Feb, spring=Mar-May, summer=June-Aug), we ran the best model for each year and for each season separately. We did this for count data only (number of DVC), since count and presence-absence models yielded similar results and the count data are more meaningful from a management perspective. Since yearly data for time-integrated NDVI were available, we used data from that year (e.g. for 2009 DVC data, we used 2009 TIN data).

RESULTS

A total of 36,366 DVC were recorded in Wyoming between 2008-2013, for an average of 6,061 per year. These DVC were clumped into noticeable hotspots (figure 3) that were very consistent across years (figure 4) and generally consistent (with some key exceptions) across seasons (figure 5).

Preliminary modeling revealed that all traffic was a better fit than truck traffic for both the presence-absence and count models (presence-absence: $\Delta AIC = 21.4$; count: $\Delta AIC = 70.8$); that modeled migration was a better fit than expert migration for both models (presence-absence: $\Delta AIC = 10.2$; count: $\Delta AIC = 43.1$; and that winter-use was a better fit for the presence-absence model ($\Delta AIC = 7.5$) but crucial winter-use was a better fit for the count model ($\Delta AIC = 17.8$).

The best models for both response variables were very similar (figure 6, figure 7); for both presence of DVC and the number of DVC, the greatest amount of variation was explained by traffic volume, and large amounts of variation were also explained by modeled migration habitat value, presence of cropland, and winter-use / crucial winter-use area presence (figure 6). The presence of DVC was also strongly related to primary production (TIN) and bridge presence, whereas these variables were less important in explaining the total number of DVC. Variation in the total number of DVC was strongly related to wetland cover and speed limit, both of which were less important (but still significant) in explaining presence of DVC. These variables all had parameter estimates that were significantly different from zero, further underscoring their importance in explaining DVC patterns (figure 7).

Traffic volume — the most important predictor of DVC — had a logarithmic relationship with number of DVC. Model results indicate that a 100 percent increase (doubling) of traffic volume was associated with a 40 percent increase in the number of DVC. This relationship appears to be accurate for most of the range of traffic volumes found in Wyoming, but not at very high traffic volumes. The majority of road segments with very high DVC rates fell between about 2,000 and 15,000 vehicles per day, and DVC rates dropped off above 15,000 vehicles per day (figure 8). Traffic volume patterns across Wyoming show that high traffic volumes exist on I-80 and outside of major towns (figure 9).

Speed limit was also an important predictor of DVC. Model results show that DVC were 92 percent higher in places with a speed limit of 75 mph, compared to places with a speed limit of 55 mph or less, and 61 percent higher in places with a speed limit of 65 mph compared to places with a speed limit of 55 mph or less.

Both crucial winter-use area and migration habitat value were important predictors of DVC. Deer-vehicle collisions were 55 percent higher inside crucial winter-use areas compared to outside crucial winter-use areas; the relationship between crucial winter range and DVC hotspots can be seen in figure 10. The relationship between migration habitat value and DVC hotspots is also apparent when these two variables are mapped (figure 11). Interpreting the exact relationship of migration habitat value with DVC is complicated since migration habitat value is unitless, but in general an increase of 0.10 in migration habitat value (which ranged from 0 to 0.99) led to a 19 percent increased in DVC. The presence of cropland was another key habitat variable; DVC rates were 44 percent higher where cropland was present compared to where there was no cropland present (figure 12).

These results were quite consistent across years. The effects of traffic volume, migration habitat value, crucial winter-use area, presence of cropland, and wetland cover were all significant (parameter estimates significantly different from zero) in all six years (figure 13). Speed limit and bridge presence were significant in most years. Developed cover, forest cover, and primary production were not significant predictors of DVC for most years, indicating that these variables are not reliable predictors of DVC patterns.

Results were also quite consistent across seasons, with several notable exceptions (figure 14). Traffic volume, migration habitat value, and wetland cover were significant in all four seasons, though migration habitat value had much less predictive power in winter than other seasons. Crucial winter range and cropland were significant predictors in all seasons but summer. Developed cover, forest cover, and primary production were not consistently significant across seasons.

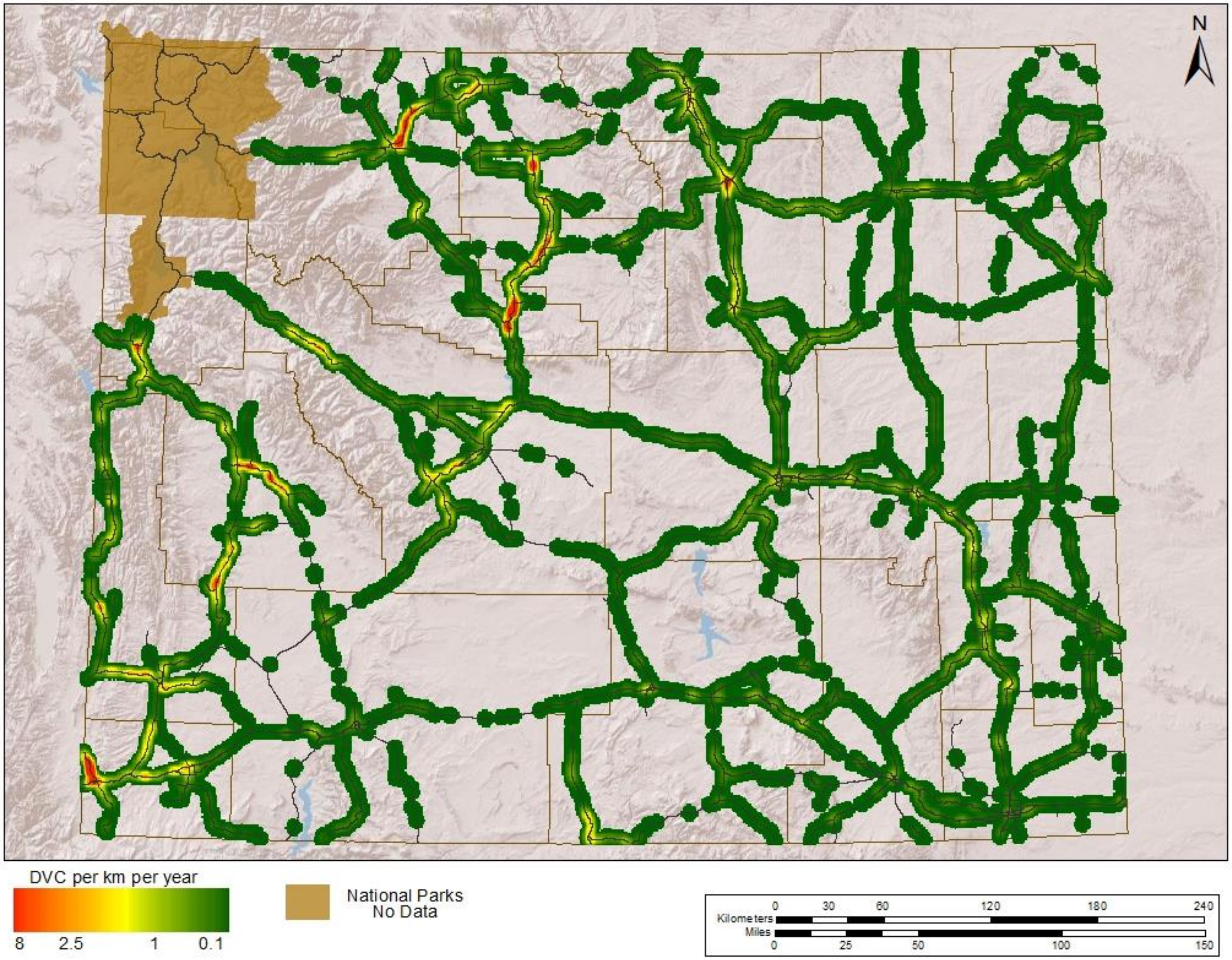


Figure 3. Deer-vehicle collision distribution across Wyoming, using a kernel density estimation of carcass and crash records, 2008-2013.

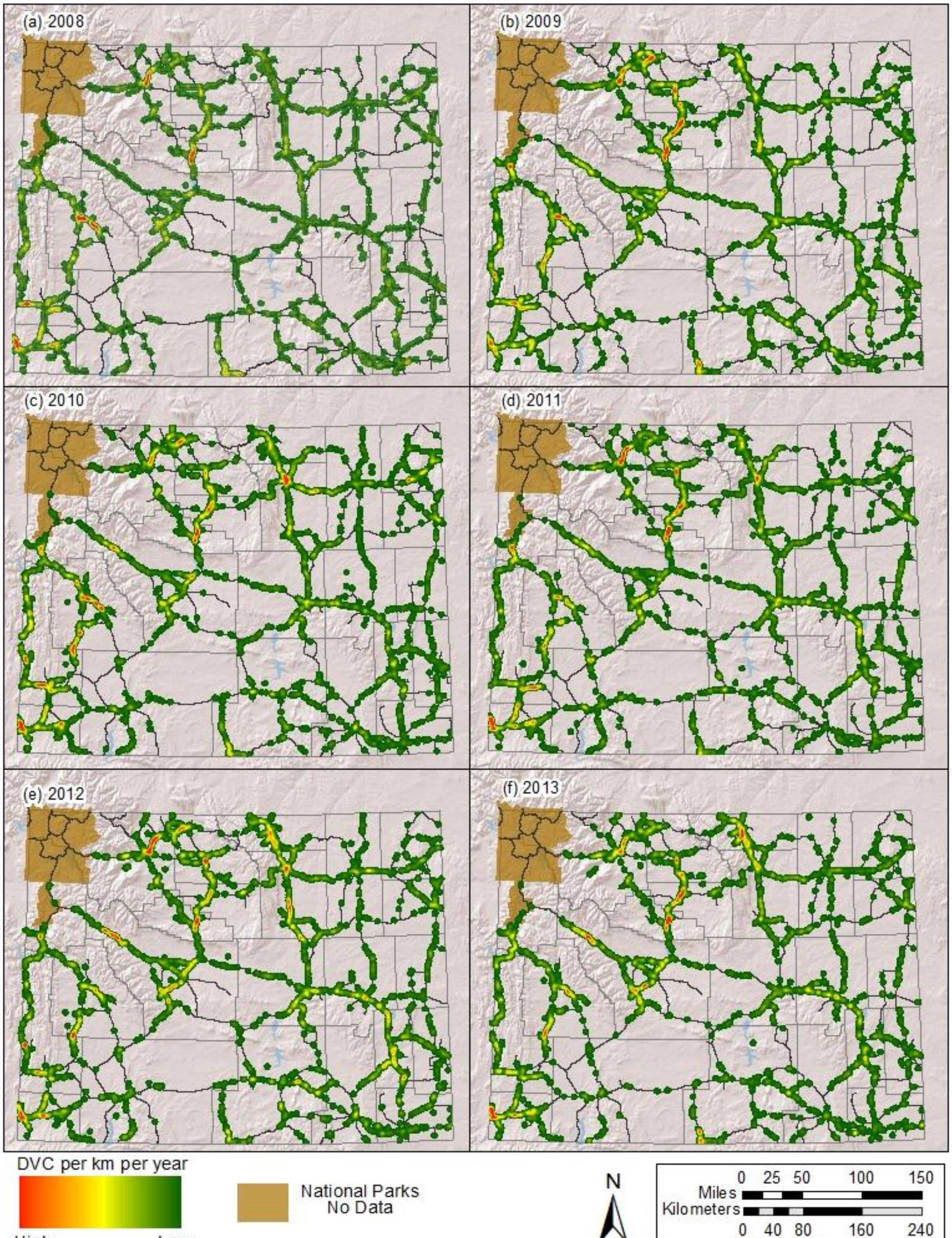


Figure 4. Deer-vehicle collision distribution across Wyoming, by year.

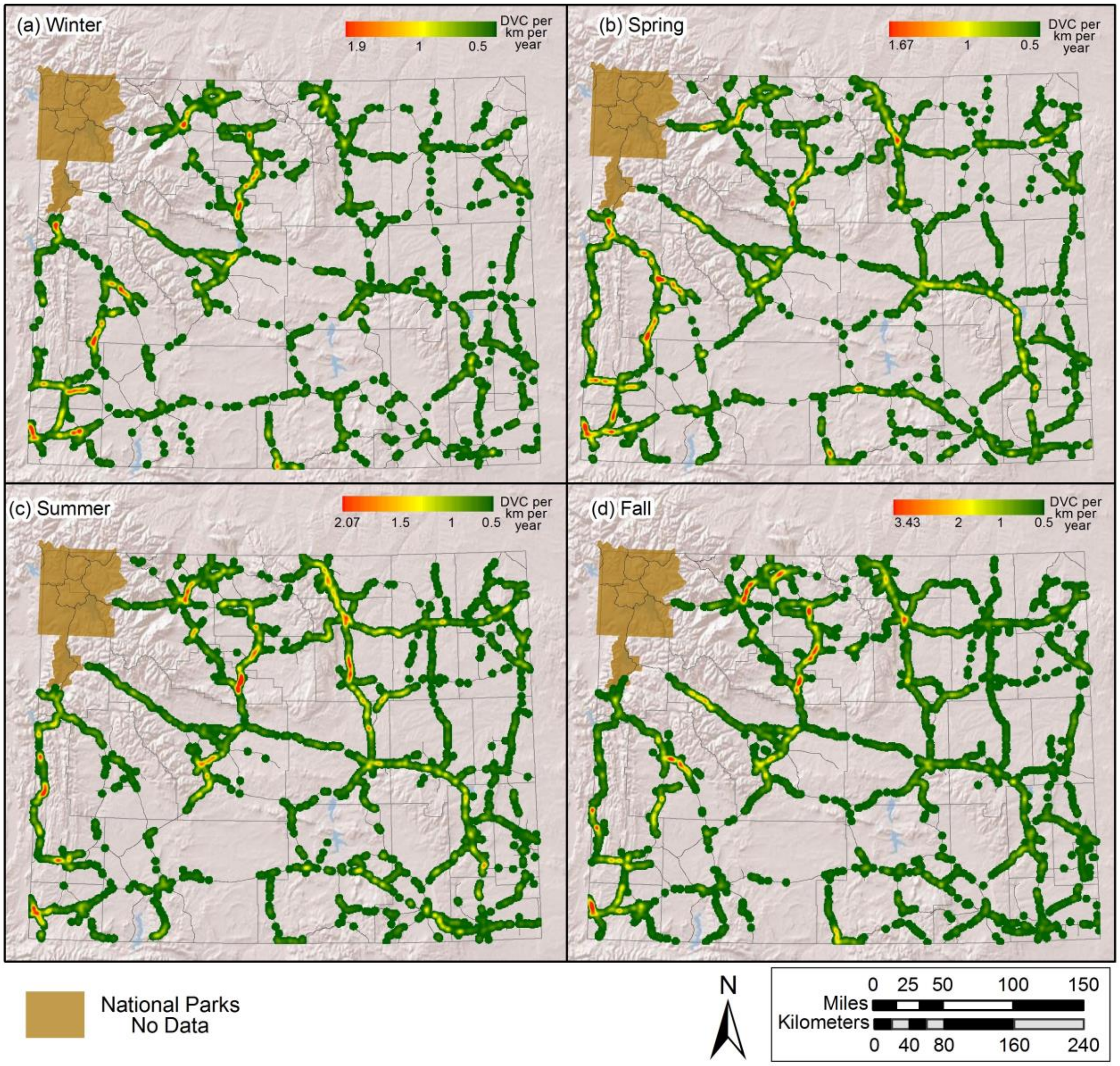
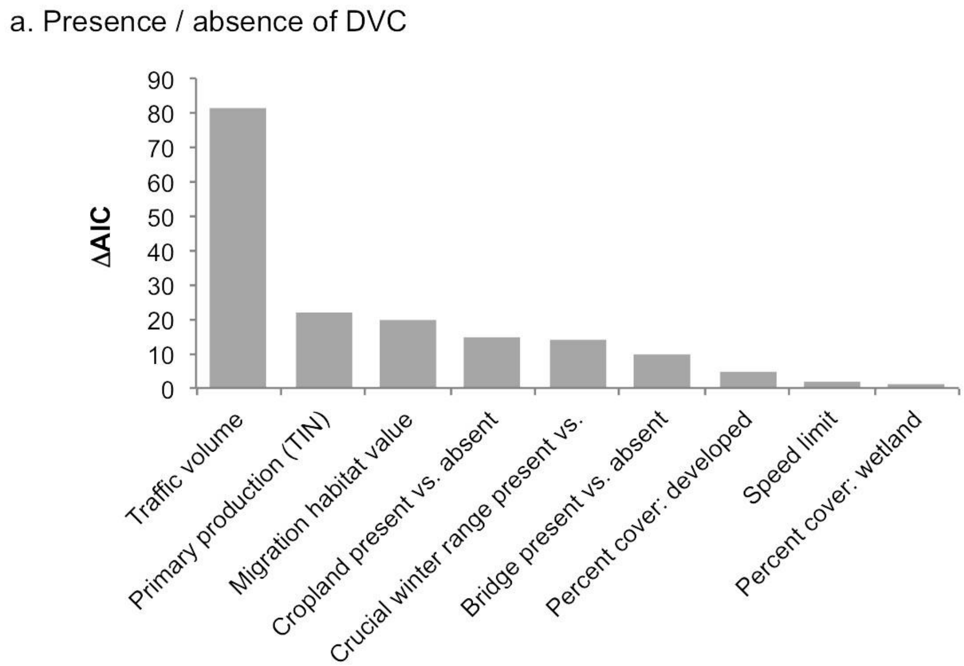


Figure 5. Deer-vehicle collision distribution across Wyoming, by season.



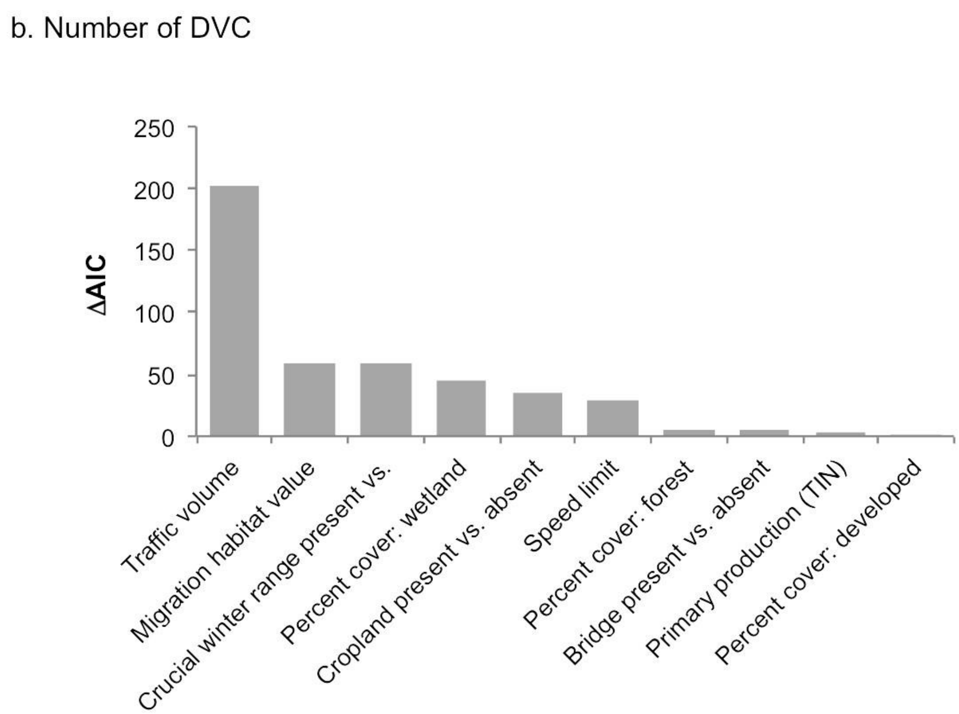


Figure 6. The contribution of each predictor variable to explaining variation in (a) likelihood of deer-vehicle collisions occurring; and (b) number of deer-vehicle collisions, in places where they occur. Only predictor variables that were retained in the best models are shown. The contribution of each predictor variable to explaining variation is given as the difference in AIC between the best-fit model and the nested models where that variable is omitted.

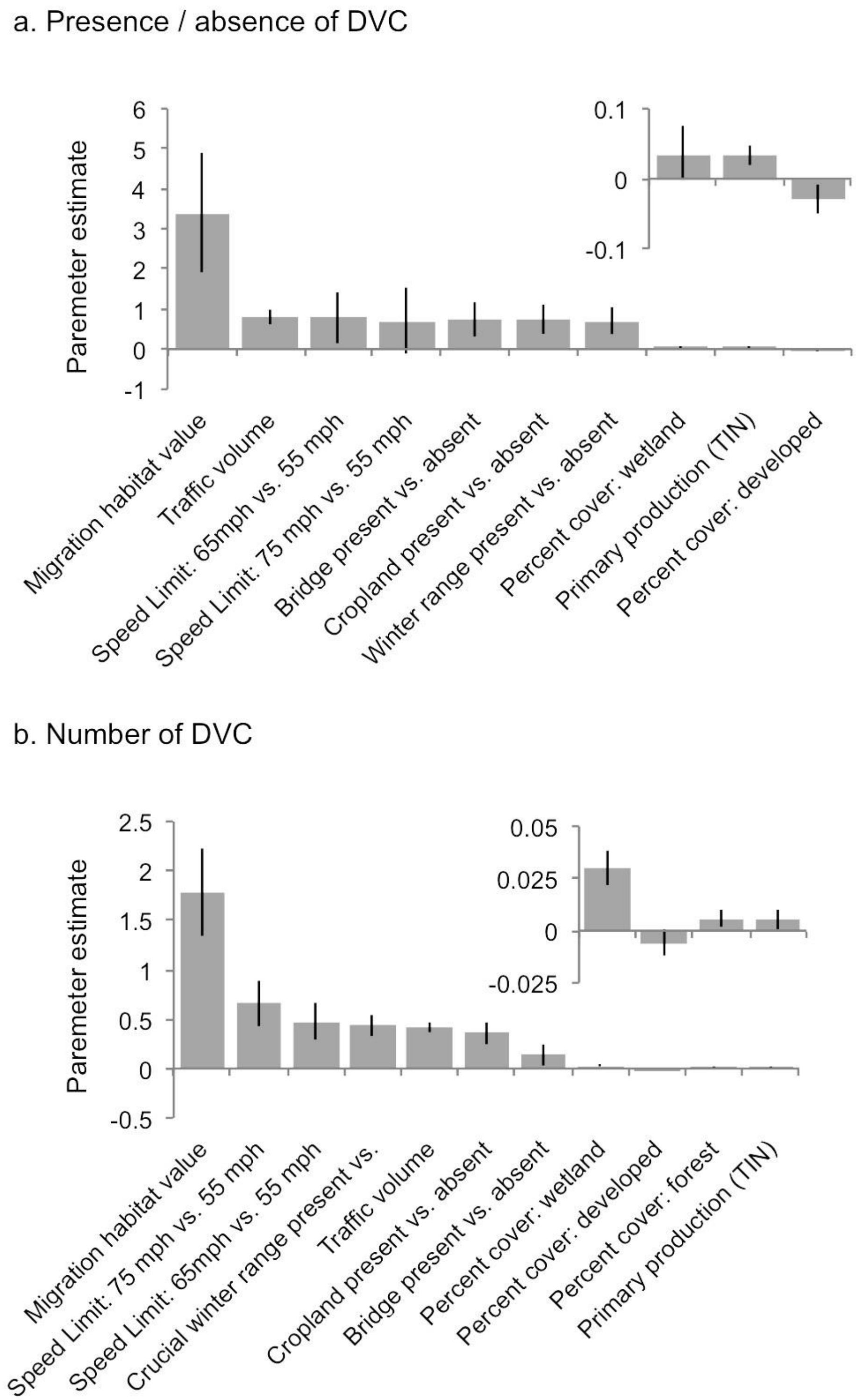


Figure 7. Parameter estimates and 95 percent confidence intervals for variables associated with (a) high likelihood of deer-vehicle collisions occurring; and (b) a high number of deer-vehicle collisions, in places where they occur. Only variables that were retained in the best models are shown. Insets show parameter estimates for variables with very small values.

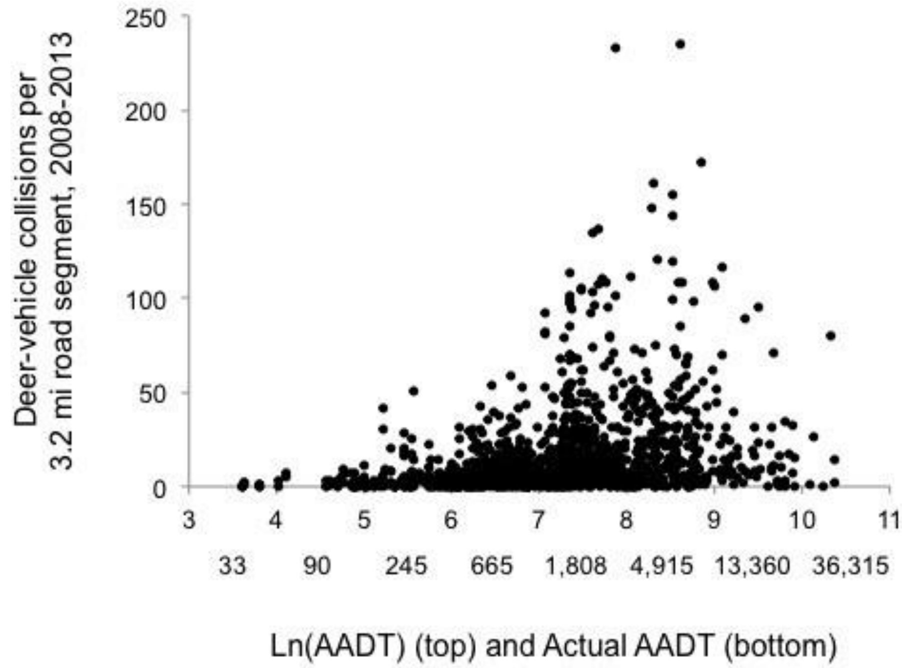


Figure 8. Scatter plot of DVC as a function of the natural log of traffic volume (AADT). Untransformed AADT values are given for ease of interpretation.

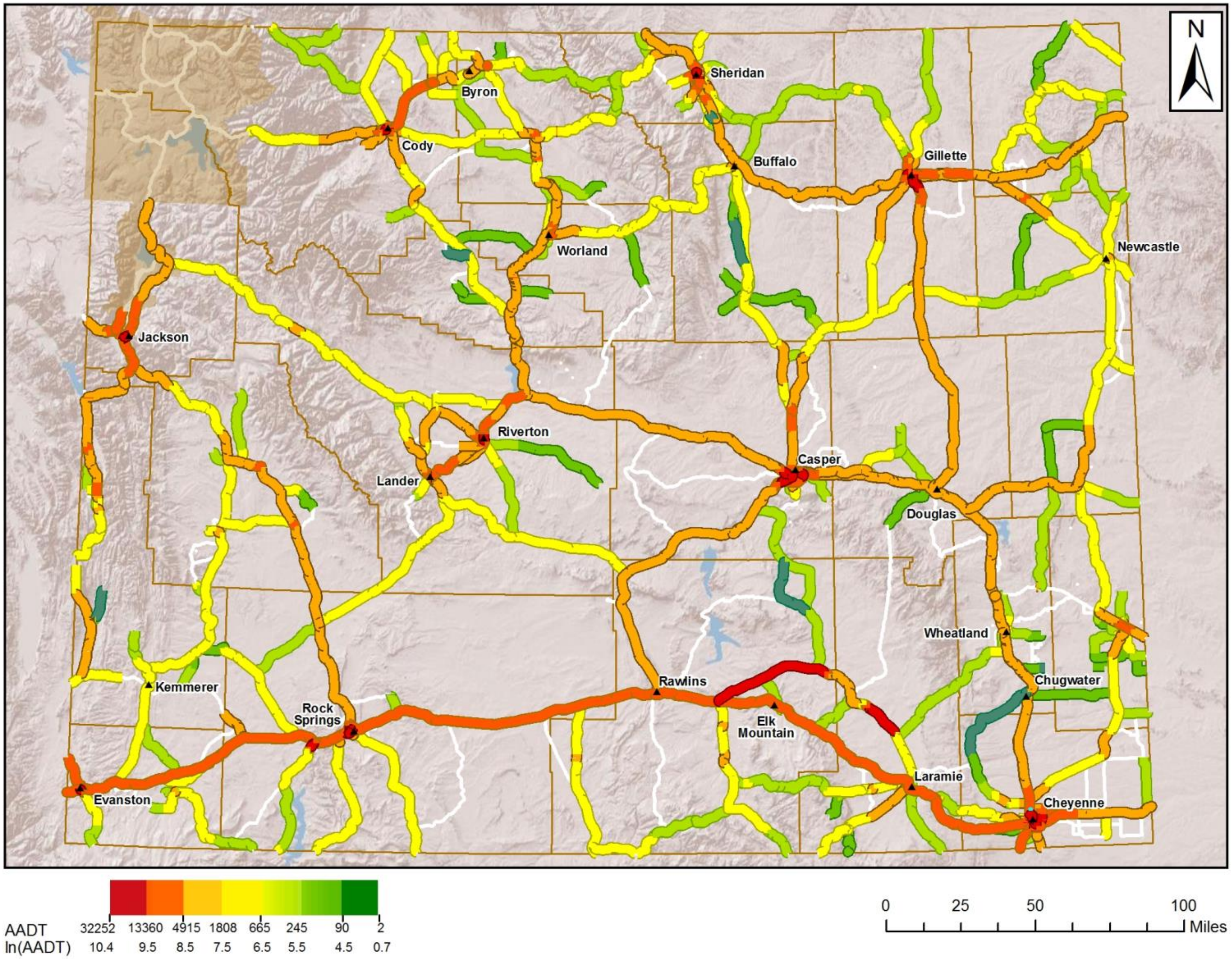


Figure 9. Traffic volumes (AADT) on Wyoming's road network. Traffic values are given as AADT and ln(AADT), since DVC patterns are strongly related to ln(AADT).

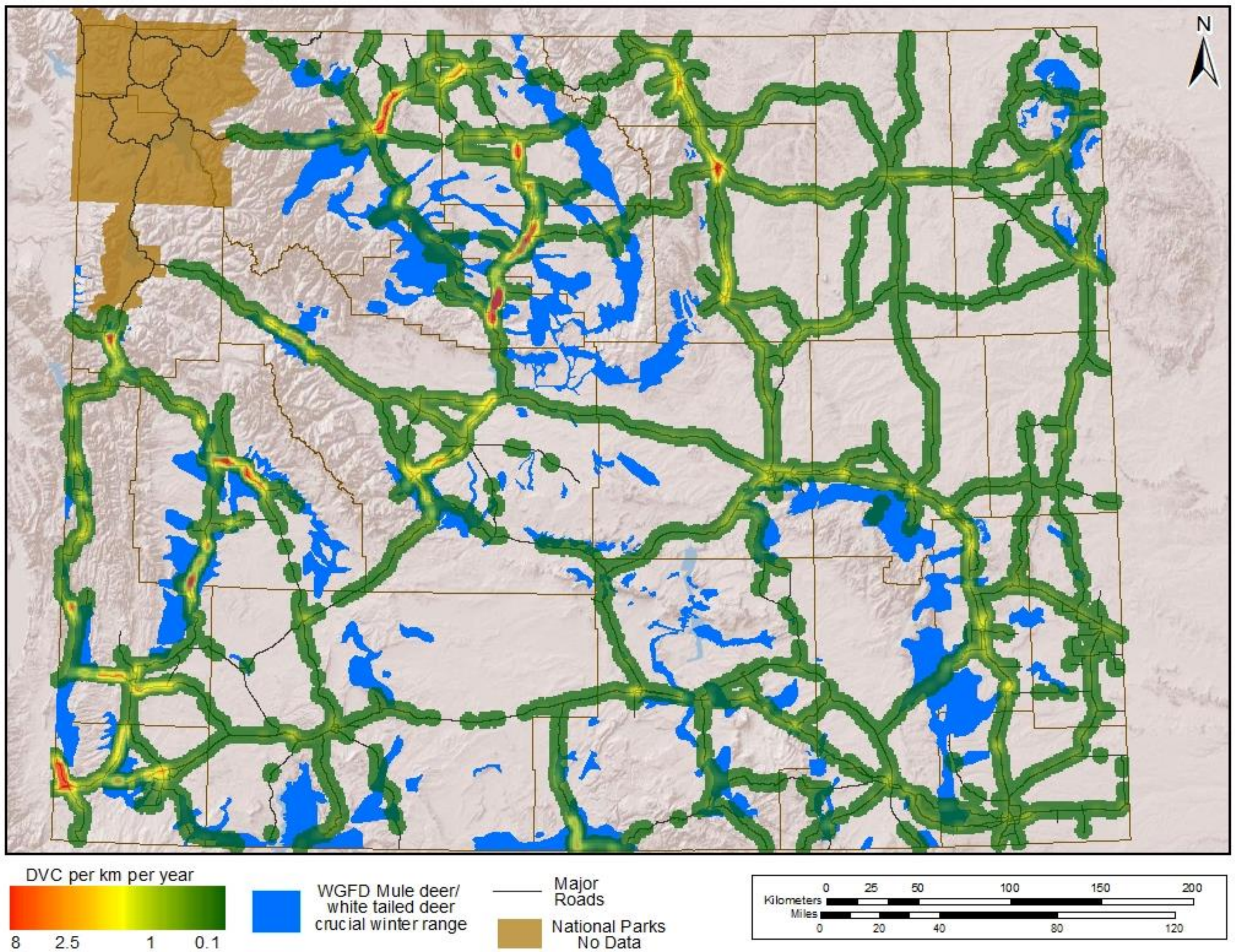


Figure 10. Deer-vehicle collision distribution across Wyoming overlain with deer winter-use and crucial winter-use areas.

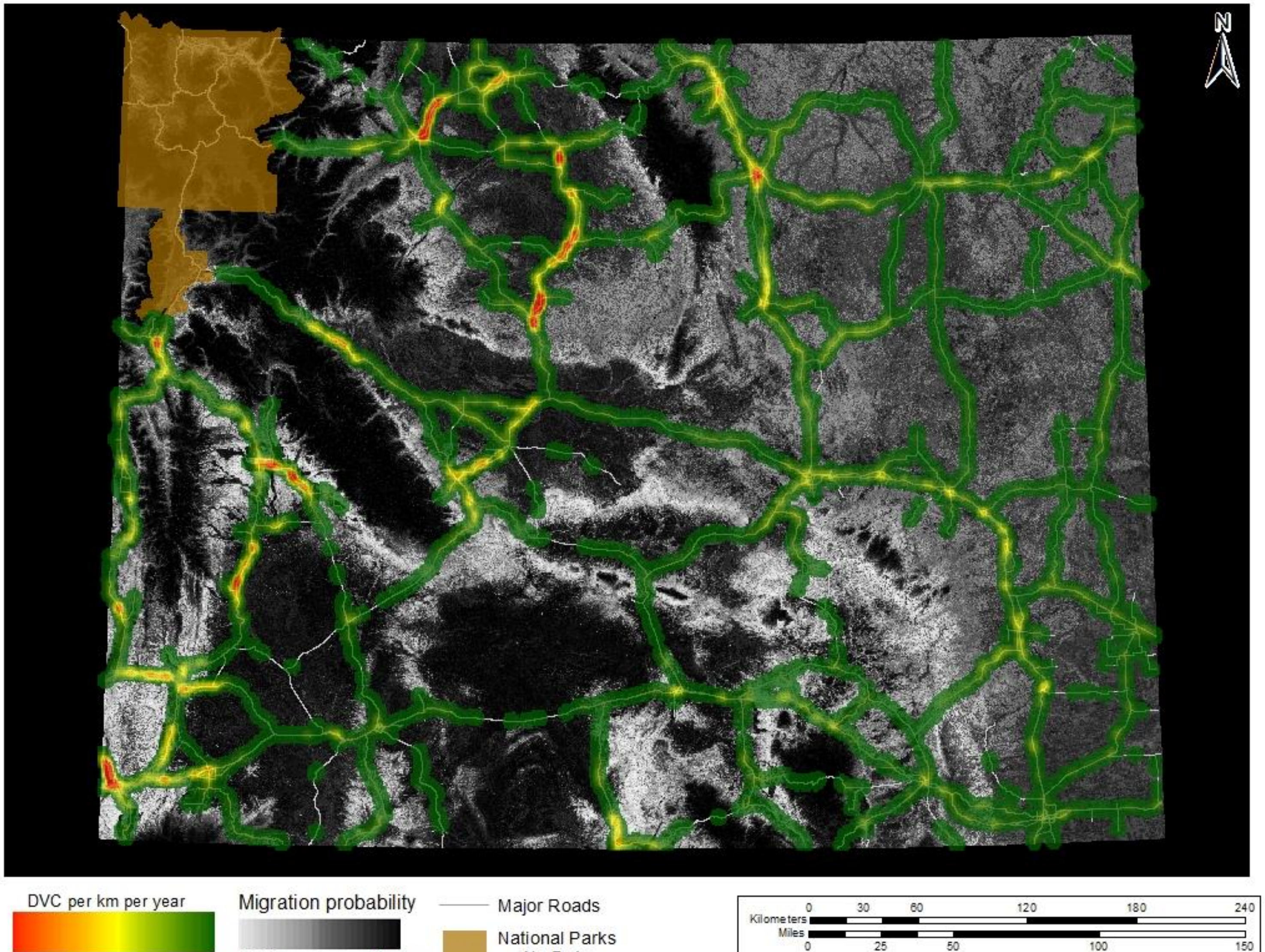


Figure 11. Deer-vehicle collision distribution across Wyoming overlain with modeled migration habitat value.

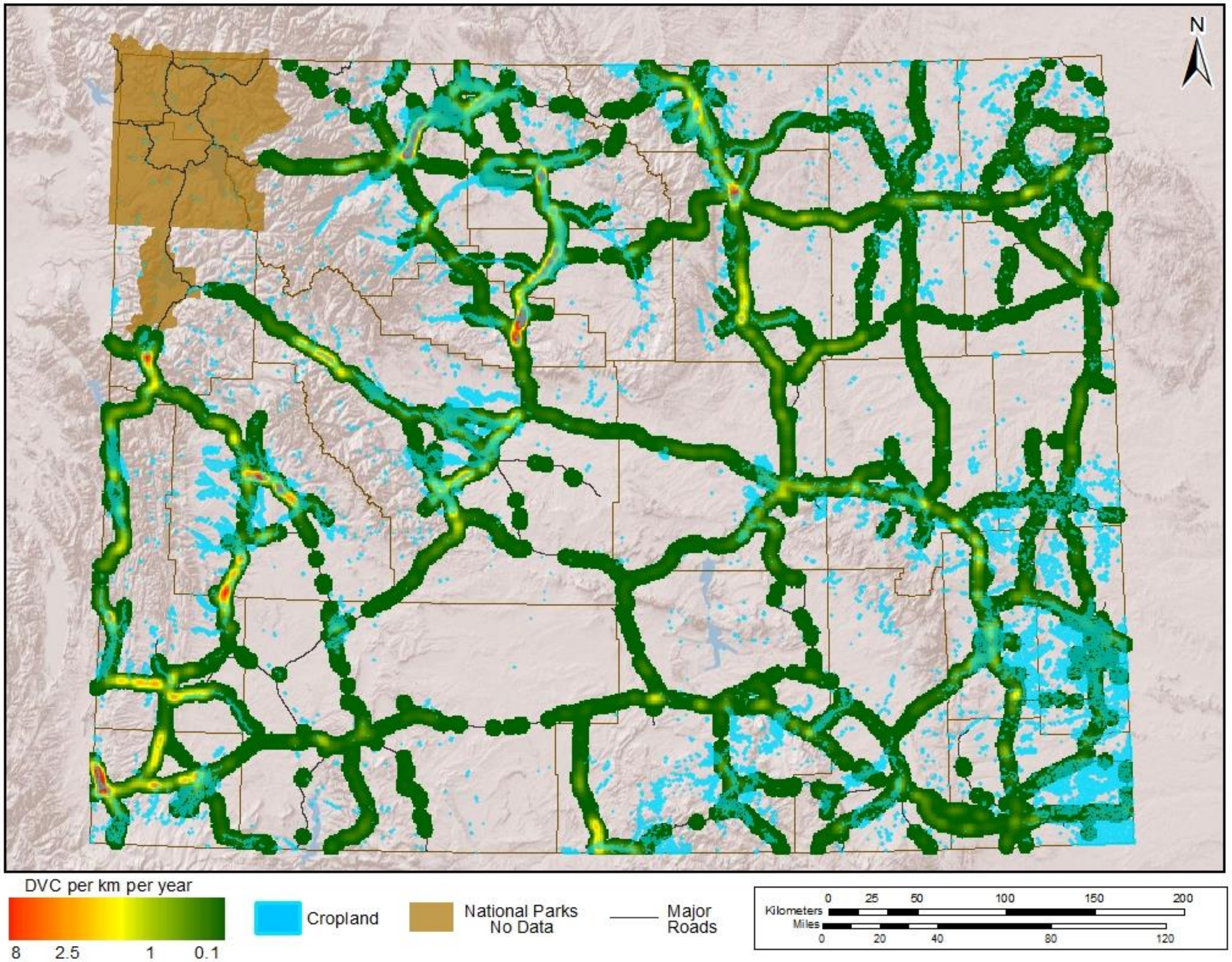


Figure 12. Deer-vehicle collision distribution across Wyoming overlain with cropland.

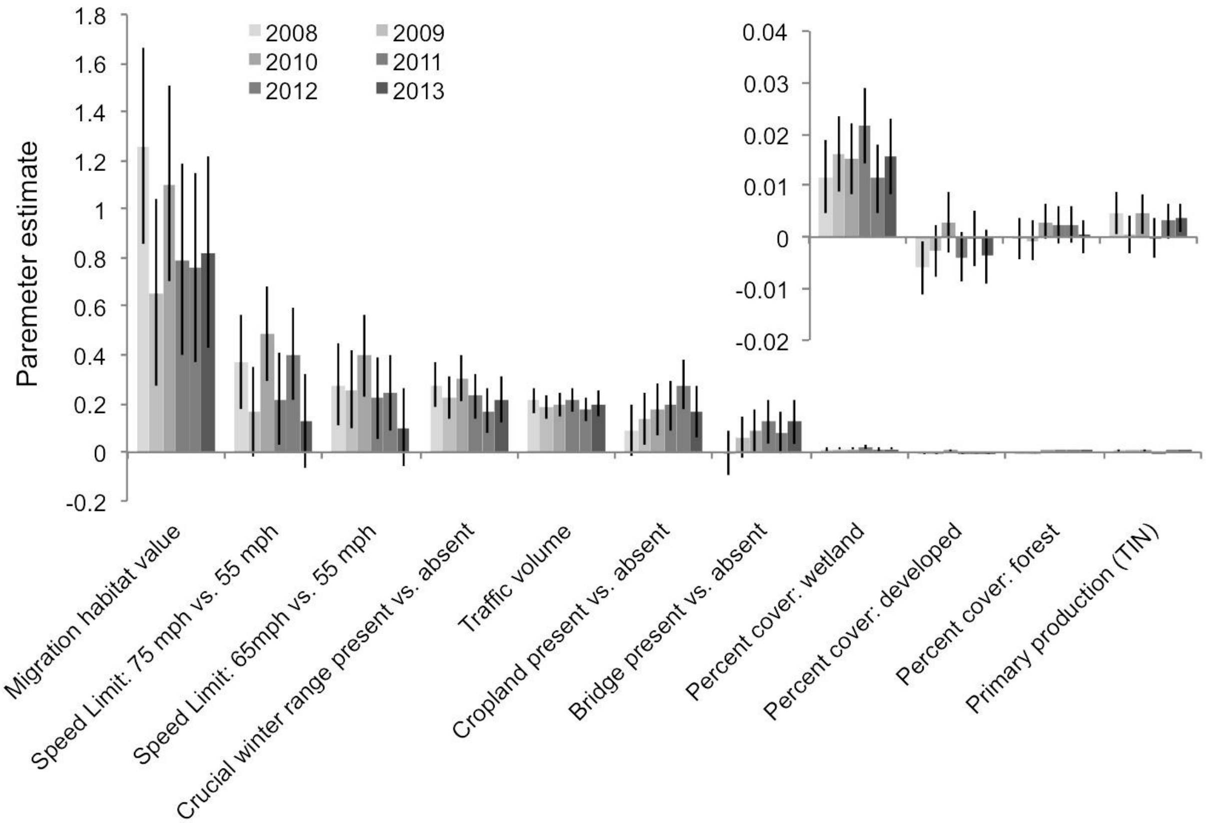


Figure 13. Parameter estimates and 95 percent confidence intervals for total number of deer-vehicle collisions, by year. Insets show parameter estimates for variables with very small values.

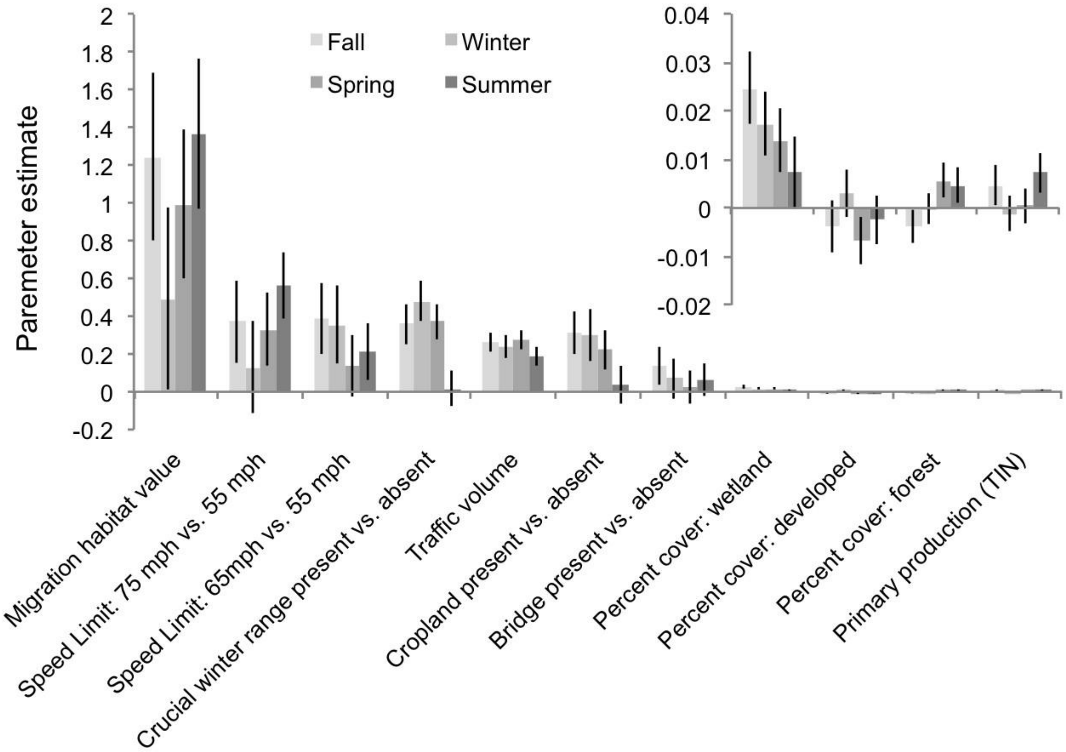


Figure 14. Parameter estimates and 95 percent confidence intervals for total number of deer-vehicle collisions, by season (all years 2008-2013). Insets show parameter estimates for variables with very small values.

Future DVC predictions

One of the original objectives of this project was to verify the model and use it to make predictions about future DVC patterns under several future traffic scenarios for key areas of interest or concern. Our proposed approach to model verification was to "back-cast" DVC based on past traffic volumes on several stretches of road that have seen significant traffic volume increases, and compare predicted (back-cast) DVC to actual past DVC data. We selected Farson to Daniel (US 191), La Barge to Daniel (US 189) and Baggs to I-80 (WY 789) as stretches of road where traffic volume approximately doubled between 1997 and 2007.

There were several challenges with doing this. First, owing to the extreme zero-inflation of the data (many 3.2 mi, 5.15 km, stretches with zero DVC), we had to run two separate models of DVC patterns across the state. However, we could only use one of those models (the count model) to make predictions about the number of DVC. This is not ideal, since the model was not parameterized for places with no DVC, but each of the focal stretches of road include places with no DVC. Despite this, the model predictions (output as ln(DVC)) were strongly and linearly correlated with ln(actual DVC) (e.g. for 2007, R^2=0.54, p<0.0001), indicating that the model was performing reasonably well. However, when predicted DVC were back-transformed (e^DVC), the resulting prediction of DVC significantly under-predicted actual DVC in hotspot areas and over-predicted DVC in all other areas. This led us to conclude that the model was not accurately predicting the number of DVC across the entire focal stretches of road. This under- and over-prediction is likely a result of three things: first, the "compressing" effect of working with log-transformed data — by definition reducing the tail of the distribution (e.g. areas with very high DVC rates); second, using the count model, which always results in a non-zero number, to predict DVC in places that have zero DVC; and third, the inability of the model to fully account for the fact that deer are present and use certain areas but not others (in other words, a place could have all of the factors that contribute to a DVC hotspot, but if there are no deer there, there will be no DVC).

Given these limitations of the model, we suggest a different approach to predicting future DVC patterns in response to potential increases in traffic volume. First, since the location of DVC hotspots appears to be highly stable from year to year, we focus predictions on those hotspots, rather than the entire road network. Specifically, we focus on the 27 hotspots used in chapters 5 and 6 of this report (figure 15). Second, we apply the count model's relationship between traffic volume and DVC to these hotspots (100 percent increase in traffic volume results in a 40 percent increase in DVC). Third, we apply two future scenarios: a "low" estimate of 1 percent increase in AADT per year and a "high" estimate of 2 percent increase in AADT per year. Over 20 years, these translate to a 20 percent and 40 percent increase in traffic volume, respectively — or an 8 percent and 16 percent increase in DVC, respectively. Using this approach, we predict DVC for 2030 for each hotspot (table 8).

A significant advantage to this approach is that it uses WYDOT's own best estimates of low and high future traffic conditions.[43] However, there are two important caveats to this approach. First, it does not account for possible decreases in DVC if traffic volume becomes so high as to create a barrier to deer movements. Second, it does not account for the fact that traffic volumes may increase disproportionately quickly in some places. For example, during periods of intense energy development, traffic volumes have risen by 3-4 percent per year in some parts of Wyoming. However, over a 20 year period, an average growth of 2 percent is reasonable for these areas.[43]

Table 8. Current and predicted 2030 DVC rates, given scenarios of a 1 percent and 2 percent increased in AADT (total 20 percent and 40 percent increase, respectively).

Hotspot	DVC/yr: Current	DVC/mi/yr: Current	DVC/yr: 20 percent traffic increase	DVC/mi/yr: 20 percent traffic increase	DVC/yr: 40 percent traffic increase	DVC/mi/yr: 40 percent traffic increase
Baggs	21.5	1.64	23.2	1.8	24.9	1.9
Baggs North	10.16	2.03	11.0	2.2	11.8	2.4
Glendo Reservoir	48.17	3.68	52.0	4.0	55.9	4.3
Jackson	76	4.33	82.1	4.7	88.2	5.0
Warren Bridge	19.5	3.25	21.1	3.5	22.6	3.8
Pinedale	103.17	3.91	111.4	4.2	119.7	4.5
La Barge	118.33	5.19	127.8	5.6	137.3	6.0
Kemmerer North	22.17	2.02	23.9	2.2	25.7	2.3
Kemmerer	109.5	3.08	118.3	3.3	127.0	3.6
Cokeville	25.5	6.54	27.5	7.1	29.6	7.6
Smoot	32.33	2.49	34.9	2.7	37.5	2.9
Evanston North	99.67	9.23	107.6	10.0	115.6	10.7
Evanston West	22.5	7.5	24.3	8.1	26.1	8.7
189 South	67.33	4.06	72.7	4.4	78.1	4.7
Leroy	38.83	3.88	41.9	4.2	45.0	4.5
Sheridan	35	2.78	37.8	3.0	40.6	3.2
Buffalo	66	3.04	71.3	3.3	76.6	3.5
Dubois	66.17	3.94	71.5	4.3	76.8	4.6
Meeteetse	22.33	3.72	24.1	4.0	25.9	4.3
Cody	128.83	7.08	139.1	7.6	149.4	8.2
Byron	30.67	4.38	33.1	4.7	35.6	5.1
Basin	49.83	5.79	53.8	6.3	57.8	6.7
Worland	76.33	5.02	82.4	5.4	88.5	5.8
Thermopolis	164.67	5.76	177.8	6.2	191.0	6.7
Riverton-Shoshoni	52.33	3.06	56.5	3.3	60.7	3.5
Lander-Riverton	37.83	1.99	40.9	2.1	43.9	2.3
Lander South	51.83	2.88	56.0	3.1	60.1	3.3

DISCUSSION

Deer-vehicle collisions in Wyoming are highly clustered in space. Across the state, there are clear "hotspots" with high DVC rates, whereas most locations have very few DVC (figure 3). This kind of clustering has been observed in most studies of WVC patterns, although the scale of clustering varies widely depending on the species in question and its body size and range requirements.[23,26,29,44] At the state-wide scale, DVC hotspots were also highly consistent in time; the same hotspots occurred across six years and across all four seasons. Within each hotspot, there are certain seasons that are more "hot" than others (see Chapter 5); however, almost all hotspots were somewhat hot at all times of year (figure 5).

Both the occurrence and number of DVC were most strongly related to total traffic volume. Total traffic was a much stronger predictor of DVC than truck traffic, contrary to common wisdom that truck traffic has a disproportionately strong effect on WVC. In Wyoming, truck traffic is highest on I-80, which has relatively low DVC rates, probably because the highway creates a barrier to deer movements — because of high traffic volume, high speed limit, four-lane width, or some combination of these factors. It is likely that total traffic is a better predictor of DVC state-wide because truck traffic is not equally distributed across the state.

The effect of total traffic volume on the number of DVC was logarithmic. This means that the same absolute increase in traffic volume is associated with a much bigger effect at lower traffic volumes than at high traffic volumes. In general terms, a doubling in traffic volume was associated with a 40 percent increase in DVC. Traffic volume in the study area ranged from a six-year mean AADT of 37 to 31,673 vehicles per day. Deer-vehicle collisions occurred over the full range of AADT but were much less likely to occur in places with low traffic volume. Although the relationship between log of traffic volume and log of DVC was linear (not quadratic), a graphical depiction of DVC patterns in relation to traffic volume showed that DVC rates declined above about 15,000 AADT (figure 10). This supports a general observation that large mammals find it difficult to cross roads with AADT rates above 10,000-20,000.[24,32] However, whether or not a road creates a total movement barrier likely depends on additional factors such as speed limit, number of lanes, and whether there are guard rails, fences, or other barriers along the road or between divided sections of highway. In the network of roads considered here, many of the areas of highest traffic volume were associated with towns and did not necessarily have high speed limits or number of lanes — perhaps making these places somewhat permeable to deer.

Speed limit was also an important variable associated with number of DVC; areas with a 75 mph speed limit had nearly twice as many DVC as areas with a speed limit of 55 mph or less. In a similar analysis for moose collisions in Sweden, collision rates were found to peak at intermediate speed limits, and the authors concluded that high speed limits made it difficult for moose to cross roads, resulting in lower collision rates.[24] For Wyoming, there was no evidence that DVC rates dropped off at high speed limits; however, further exploration of the data showed that DVC rates are lower under the combination of high traffic volume and 75 mph speed limits — again suggesting that several factors combine to create an effective barrier effect for deer movements (e.g. on I-80). Additionally, the recent increase in speed limit to 70 mph on select roads in Wyoming can be expected to lead to higher DVC rates in hotspots along those roads.

Our results predict a 16 percent increase in DVC (approximately) where speed limits have been raised from 65mph to 70 mph.

Variables that relate to the presence of deer were also strongly related to DVC patterns. We found that a modeled migration habitat value surface was a much stronger predictor of DVC patterns than migration routes derived from expert opinion. This modeled migration habitat value surface was derived from GPS collar data — which was used to make predictions for places where no GPS collar data are available. The strong relationship between modeled migration habitat value and DVC patterns suggests that the migration habitat model is working well to predict places where migration routes cross roads.

In addition to migration, deer winter range and crucial winter range areas were also strongly related to DVC (the former being a slightly better fit for DVC occurrence and the latter a slightly better fit for number of DVC). Across Wyoming, mule deer tend to winter in lower-elevation areas, which coincide with where most roads are located; there are few roads in the higher-elevation deer summer range areas. Most deer herds include both a migratory and non-migratory component, with the non-migratory component remaining in "winter range" throughout the year. This may explain why DVC rates in three of four seasons were significantly higher (about 55 percent higher) inside deer winter range areas (figure 10).

Other deer habitat variables that were important in predicting both the occurrence and number of DVC were wetland cover and the presence of cropland. Both wetlands and irrigated fields are areas with relatively high plant productivity and likely attract deer due to the higher abundance and quality of forage available to them in those areas.

These results include elements that are both similar to and different from findings of similar studies that have been carried out elsewhere. In terms of road conditions, our findings are generally very similar to others'. In a review of studies of WVC patterns, Gunson[23] found that increased traffic volume was a strong predictor of WVC rates for many species, including several species of ungulates; this has also been found elsewhere,[24,26,45] though at least one study found no effect of traffic volume on DVC rates.[46] Gunson's review and several other studies[23,24,26,45,46](with one contrary finding[47]) have also shown that increased speed limit is associated with increased ungulate WVC rates.

In terms of the effects of habitat variables on DVC patterns, there appears to be less agreement across studies. Among the studies reviewed by Gunson,[23] most found that ungulate WVC rates were lower in developed (urban) areas and near agricultural land, and higher near forested and open habitat. This is contrary to our findings that DVC rates are highest near cropland and only weakly associated with forest cover. Preference for forested versus open cover is highly species-dependent, and Gunson's review was mostly based on studies of moose and white-tailed deer, which prefer forested habitat. In contrast, mule deer are generally found in open habitat (e.g. sagebrush steppe habitat) in winter, when the majority of DVC in Wyoming occur.

The effects of cropland or agriculture appear to be somewhat context-dependent. Contrary to the studies summarized in Gunson's review, several other studies on white-tailed deer found higher collision rates near agricultural land.[45,48] Whether agricultural land serves as an attractant or deterrent to deer may depend on the types of crops and extent of agriculture involved. Croplands in Wyoming are limited to areas close to water and are often interspersed with more typical mule deer winter habitat (e.g. sagebrush steppe), which may allow deer greater access to this land than in other places where agriculture has displaced ungulate habitat over large areas. Further, in Wyoming, fallow fields in winter offer higher-quality forage than native vegetation and are highly attractive to deer – as they appear to be for white-tailed deer in some other areas.

Development also appears to have a variety of effects on WVC rates, depending on the extent and type of development. While large urban areas are likely a deterrent to ungulates (leading to fewer WVCs in those areas), smaller, low-density developed areas – such as are found in Wyoming – may actually attract deer and other ungulates (for example, to eat high quality forage in lawns and gardens). In rural Sweden, there was a positive effect of development on moose-vehicle collisions,[49] similar to our results. Further, in our analysis, developed cover was correlated with traffic volume, making it difficult to assess whether development itself or traffic volume associated with development is the cause of higher DVC rates in developed areas. Given the strength of the effect of traffic volume in relation to DVC rates, it seems likely that traffic volume, rather than development itself, is the cause of high DVC rates in more developed areas.

Although the specific habitat variables associated with high WVC rates may vary from geographic location to location, a general finding across this and other studies like it is that high quality habitat (whether natural or anthropogenically modified) is a strong predictor of where high WVC rates occur. High quality habitat in combination with high traffic volumes and/or speed limits appears to be the combination of elements that leads to the very highest WVC rates.

With these analyses, we conducted a broad-scale analysis of the patterns and variables correlated with deer-vehicle collisions across a large geographic area. There are many finer-scale factors that have been found to be strongly associated with high ungulate WVC rates in other studies.[23] These include factors such as road curvature and visibility, roadside fencing, roadside vegetation (e.g. plants that are highly palatable and attractive to ungulates[50-52]), and roadside micro-topography (e.g. ditches or steep embankments). We did not consider these variables because it was impossible to do so at a state-wide scale and because our objective was to identify general patterns. In order to fully understand the causes of high DVC rates in a specific area, it would be valuable to consider both the coarse- and fine-grain variables that are operating in that area.

Understanding the variables that are associated with high DVC rates provides valuable insights into why DVC rates might be high in a particular area and what might be done to manage or mitigate them. Many of the most prominent hotspots of DVC – for example, the areas just north and south of Thermopolis and the area northeast of Cody – appear to be a near “perfect storm” of factors that create high DVC rates: deer winter range with high crop cover, access to water, near a developed area with moderately high traffic volume, and high speed limit.

Although land cover is difficult or impossible to manage, speed limits can be managed. Keeping speed limits low (especially at night) may be a particularly important in areas that have high traffic volume, abundant cropland, or where deer seasonal or daily movement routes cross major roadways. Traffic volume is more challenging to manage, but understanding its role is important for long-term planning. Predicted increases in DVC rates (table 8), for example, may be useful for planning and justifying mitigation measures (e.g. future crossing structures). Understanding the scale at which DVCs are clustered is also valuable because any mitigation will have to be applied at the scale of the cluster; if a mitigation is applied at too fine a spatial scale (e.g. one underpass with only a short length of fencing in either direction), it may just shift the center of collisions to another, nearby area.

These results also show that the spatial patterns of DVC are very stable over time. From a management perspective, this is valuable information since it suggests that there are a few, key places upon which to focus mitigations. In chapter 5, we further identify and discuss the ecological factors causing the major DVC hotspots in Wyoming.

CHAPTER 5. KEY COLLISION HOTSPOTS AND VULNERABLE MIGRATION ROUTES

INTRODUCTION

It is clear that deer-vehicle collisions in Wyoming are clustered into hotspots that are associated with deer migrations, winter habitat use, or in some cases year-round habitat use. In this chapter, we take a deeper look at the timing and ecological context of deer-vehicle collisions in 27 focal hotspots around Wyoming (table 9; figure 15). To the extent possible, we aim to understand whether deer-vehicle collisions are a seasonal or perennial problem in each of these hotspots and relate collision patterns to deer habitat connectivity and possible mitigations. The majority of these hotspots are obvious areas with high DVC rates; several others are included because of their ecological importance (e.g. where a major migration corridor crosses a highway).

Table 9. Locations of 27 focal hotspots of deer-vehicle collisions.

District	Hotspot Name	ML Route	MP Start	MP End	Route Name
1	Baggs	ML18	40.10	53.20	WY 789
1	Baggs North	ML18	25.8	30.6	WY 789
2	Glendo Reservoir	ML25	104.40	117.50	I 25
3	Jackson	ML10	141.00	158.57	US 26/89/189/191
3	Warren Bridge	ML13	122.00	129.50	US 191/189
3	Pinedale	ML13	84.30	110.70	US 191/189
3	La Barge	ML11	80.20	103.00	US 189
3	Kemmerer North	ML11	36.70	50.00	US 189
3	Kemmerer	ML12	33.60	69.20	US 30
3	Cokeville	ML12	4.50	8.4	US 30
3	Smoot	ML10	64.00	76.50	US 89
3	Evanston North	ML50	0.70	11.50	WY 89
3	Evanston West	ML80	0.40	3.60	I 80
3	189 South	ML11	3.80	20.40	US 189
3	Leroy Interchange	ML80	18.65	27.90	I 80
4	Sheridan	ML90	17.6	30.21	I 90
4	Buffalo	ML90	41.5	63.2	I 90
5	Dubois	ML30	55.70	72.50	US 26/US 287
5	Meeteetse	ML33	54.40	57.80	WY 120
5	Cody	ML29	1.30	19.50	US 14A/WY 114/WY 120
5	Byron	ML29	36	43.5	US 14
5	Basin	ML34	197.20	203.50	US 16/20/WY 789
5	Basin	ML37	1	3.3	US 14
5	Worland	ML34	156.30	171.50	US 16/20
5	Thermopolis	ML34	127.00	155.60	US 20/WY 789
5	Riverton-Shoshoni	ML20	106.40	123.50	US 26/287/WY 789

5	Lander-Riverton	ML20	82.30	100.30	US 26/287/WY 789
5	Lander South	ML14	57.50	72.90	WY 28
5	Lander South	ML20	72.90	76.50	US 26/287/WY 789

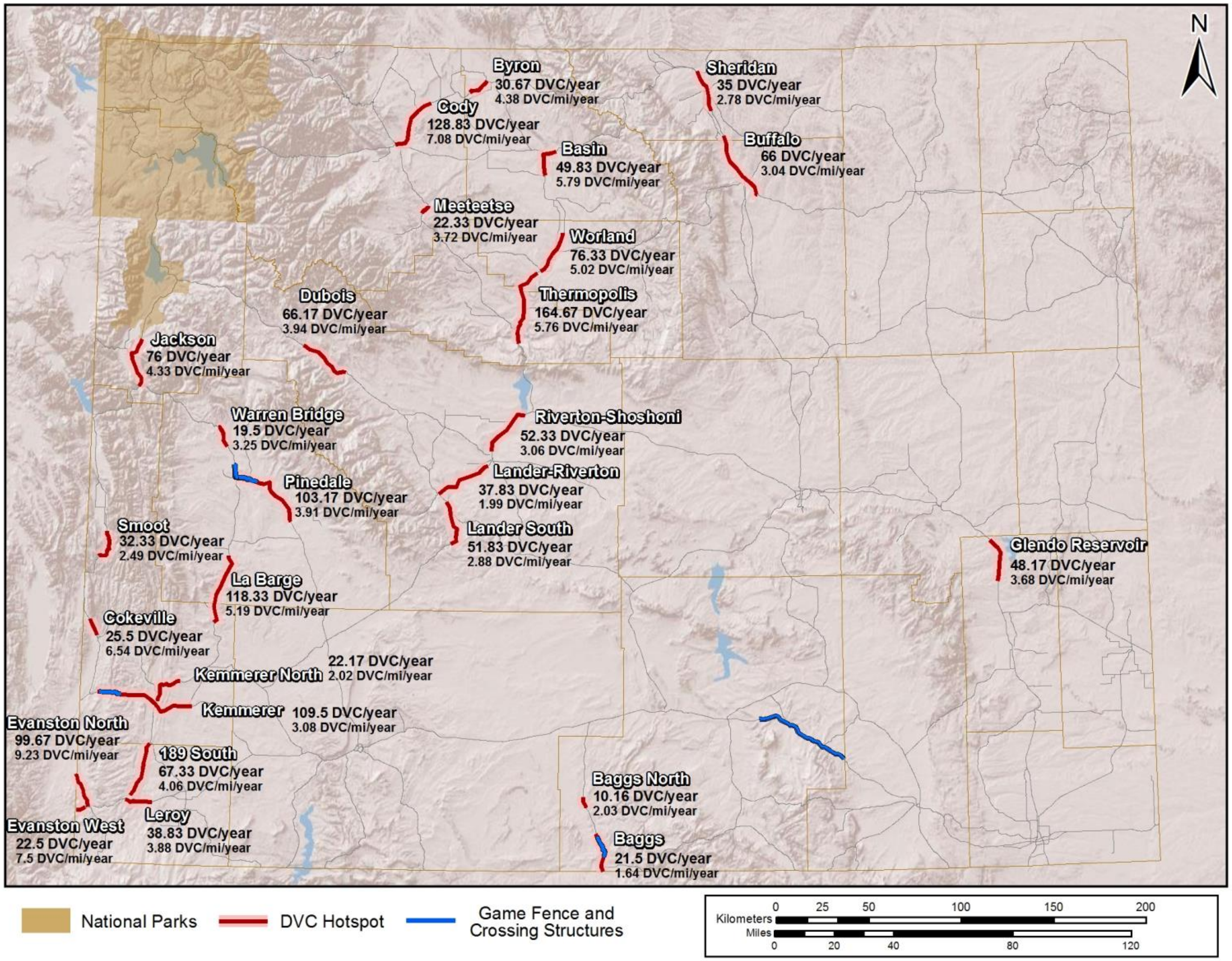


Figure 15. Twenty-seven focal hotspots of DVC in Wyoming. Total DVC per year and DVC per mi per year are given, excluding any part of the hotspot that has game fence and crossing structures.

METHODS

Migration Routes

We used GPS-collar data collected on mule deer from six herds in Wyoming to define key mule deer migration corridors for those herds. These included:

- Pinedale herd - Mesa section: 141 migrations, 70 animals, 2005-2013.
- Pinedale herd - Ryegrass section: 67 migrations, 27 animals, 2007-2013.
- Atlantic Rim herd - north section: 44 migrations, 25 animals, 2005-2010.
- Atlantic Rim herd - south section: 125 migrations, 56 animals, 2005-2010.
- Red Desert herd: 110 migrations, 34 animals, 2011-2013.
- Platte Valley herd: 125 migrations, 43 animals, 2011-2013.
- Wyoming Range herd: 52 migrations, 35 animals, 2013-2014.
- Jackson herd: 52 migrations, 20 animals, 2010-2012.

In most cases, collars were set to record GPS locations every 2 hours. For the Atlantic Rim herds, GPS locations were recorded every 2.5-3 hours, and for the Jackson herd they were recorded every 1.5-2 hours.

We used the Brownian bridge movement model[53] and "BBMM" package in R[54] to estimate a migration utilization distribution (UD) for each animal and then averaged the individual UDs to create population-level migration UD. For animals that had migration data for more than one migration, we averaged all UDs together so that each animal only contributed one migration UD to the population-level UD. Once the population-level UD was estimated, we defined and mapped the migration corridors as high use areas (>20 percent of UD values), medium use areas (10-20 percent of UD values) and low use areas (<10 percent of UD values).

For each deer herd, we overlaid migration corridors on DVC patterns to identify highway crossings where those migrations are incurring numerous collisions. These are places where highways are potentially threatening habitat connectivity for migrating animals.

Winter Ranges

We used GPS data collected from December 1 through March 15 to document winter distribution patterns of mule deer for the same six herds, plus one additional herd, for which migration routes were calculated, using the number of animals and years as follows:

- Pinedale: 107 winter periods from 68 animals, 2009 – 2014.
- Atlantic Rim: 120 winter periods from 97 animals, 2004 – 2010.
- Red Desert: 92 winter periods from 52 animals, 2011 – 2013.
- Chokecherry: 86 winter periods from 44 animals, 2012 – 2014.
- Platte Valley: 134 winter periods from 67 animals, 2013-2014.
- Wyoming Range: 98 winter periods from 67 animals, 2013-2014.

- Jackson: 66 winter periods from 34 animals, 2010-2013.

We again used the Brownian bridge movement model to estimate a winter UD for each animal and then averaged the individual UDs to create population-level winter UD. For animals that had winter data for more than 1 year (e.g., 2012, 2013, 2014), we averaged all UDs together so that each animal only contributed one UD to the population-level UD. Once the population-level UD was estimated, we defined and mapped the "core-use" areas based the top 50 percent of UD values.

For each of the 27 DVC hotspots, we overlaid winter core-use areas on DVC patterns to identify highway crossings where winter habitat use is incurring numerous collisions. Where GPS data were not available, we overlaid DVC patterns with the "crucial winter-use area" composite from WGFD, defined above (Chapter 4).

Temporal patterns of collisions

For each of the 27 hotspots, we extracted the total number of collisions that occurred between 2008-2013 in each week of the calendar year. We assembled histograms of the temporal patterns of collisions for each hotspot.

We then used these histograms, in combination with spatial data about migration routes and winter ranges that may be crossing the highway, to identify the temporal patterns of peak DVC for each hotspot. For each hotspot, we assessed whether the peak time of collisions is associated with migrations (October-December and March-June peaks), winter (January-March peak), fall / rut (October-December peak with no corresponding spring peak), summer (June-September peak), or combinations of these.

RESULTS AND DISCUSSION

Spatio-temporal patterns of collisions and their ecological causes

Detailed migration and winter-use information was available for seven mule deer herds in western and southern Wyoming. Simple overlays of DVC patterns with migration routes (figure 16) and winter ranges (figure 17) show strong patterns of association between DVC and these deer movement areas, especially in the Kemmerer, La Barge, Pinedale, and Baggs hotspots.

Temporal patterns of collisions varied widely in time, depending on the location within Wyoming. In western Wyoming, and in the Baggs area of southern Wyoming, most hotspots were associated with a combination of migrations and winter ranges (table 10; figures 18-26). Some focal areas (e.g. Cokeville and Warren Bridge, figure 23 and 20 respectively) were largely associated with migrations, and several others showed year-round patterns with migration peaks — likely reflecting the fact that a portion of the herd remains in winter range year-round.

In central-northern Wyoming (Meeteetse, Cody, Byron, Basin, Worland, Thermopolis, Riverton, Lander), most hotspots were associated with year-round DVC or fall and winter peaks, but the signature of migration was dampened or absent (table 10; figures 27-32). This may be because deer in these areas are largely year-round residents. High DVC rates in the fall are likely caused by erratic behavior from deer that are in rut, deer responding to hunting season pressures, or both.

In eastern Wyoming, hotspots (Sheridan, Buffalo, Glendo Reservoir) were generally associated with peak DVC rates in summer and fall (table 10; figures 33-34). Some experts attribute this to the availability of a second crop of alfalfa during this dry time of year — attracting deer to fields near highways and to right-of-ways where alfalfa and other legumes are often planted.

Understanding the temporal patterns of DVCs in each hotspot, and their ecological causes, helps to identify suitable mitigations. We discuss these further for each hotspot in Chapter 6.

Table 10. Seasonal timing of peak DVC for each hotspot.

	Hotspot	Timing	GPS data?
District 1			
	Baggs	Winter and migration	Yes
	Baggs North	Mostly winter, some migration	Yes
District 2			
	Glendo Reservoir (SE of Douglas)	Summer and fall	No
District 3			
	Jackson	Winter and migration	Yes
	Warren Bridge	Migration	Yes
	Pinedale	Winter and migration	Yes
	La Barge	Winter and migration	Yes
	Kemmerer North	Year-round with peak in fall	No
	Kemmerer	Year-round with migration peaks	Western part
	Cokeville	Migration	Yes
	Smoot	Summer and early fall	Yes
	Evanston North	Migration	No
	Evanston West	Year-round with migration peaks	No
	189 South	Migration and winter	No
	Leroy	Migration and winter	No
District 4			
	Sheridan	Summer and fall	No
	Buffalo	Summer and fall	No
District 5			
	Dubois	Mostly winter, some migration	No
	Meeteetse	Year- round with peak in fall	No

Cody	Year- round with peak in fall	No
Byron	Fall and winter (mostly fall)	
Basin	Fall and winter (mostly fall)	No
Worland	Year-round with peak in fall	No
Thermopolis	Year-round with peak in fall	No
Riverton-Shoshoni	Fall and winter	No
Lander-Riverton	Year-round with peak in summer and fall	No
Lander South	Year-round with peak in fall	No

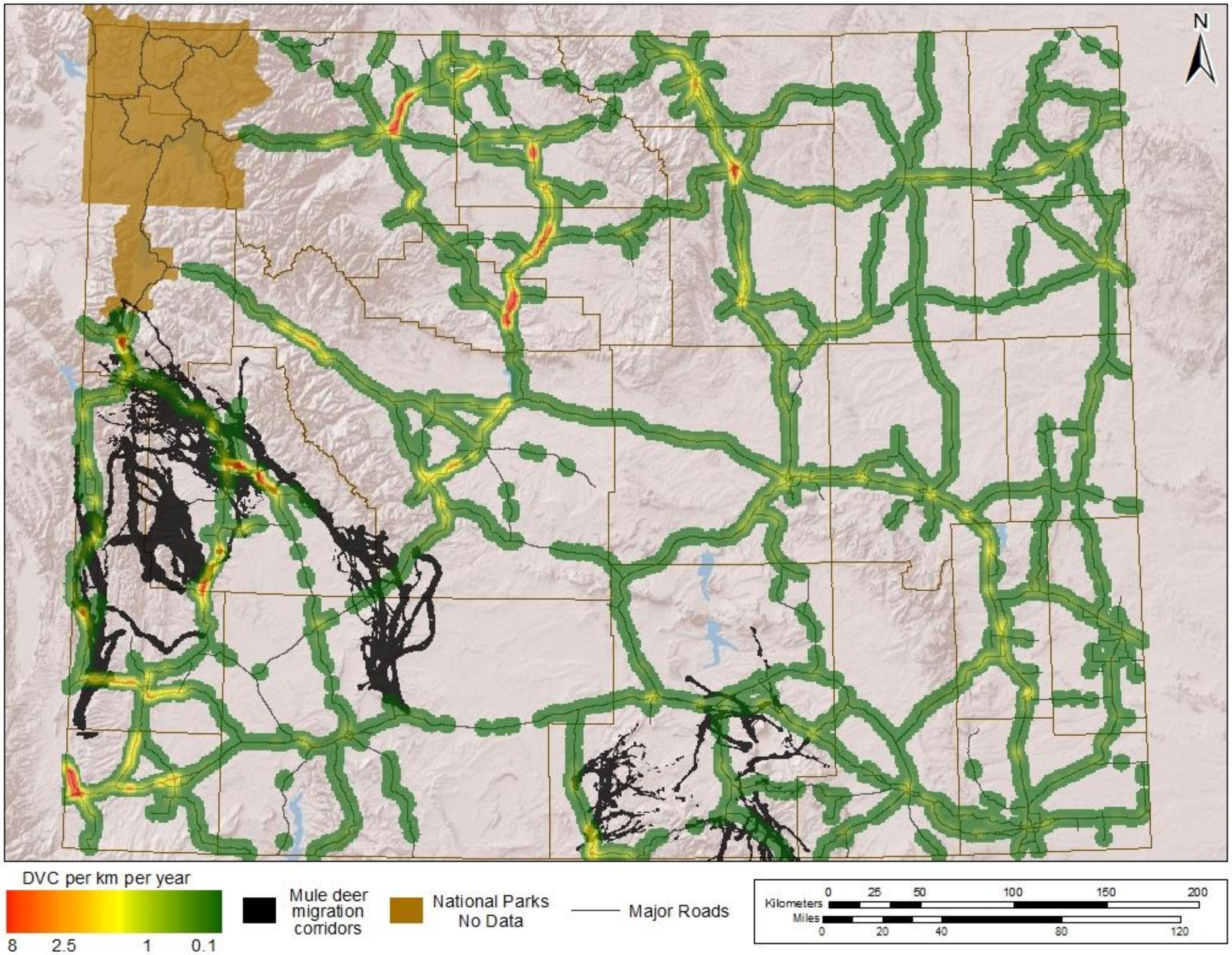


Figure 16. Deer-vehicle collision distribution across Wyoming overlain with migration corridors derived from GPS-collared mule deer.

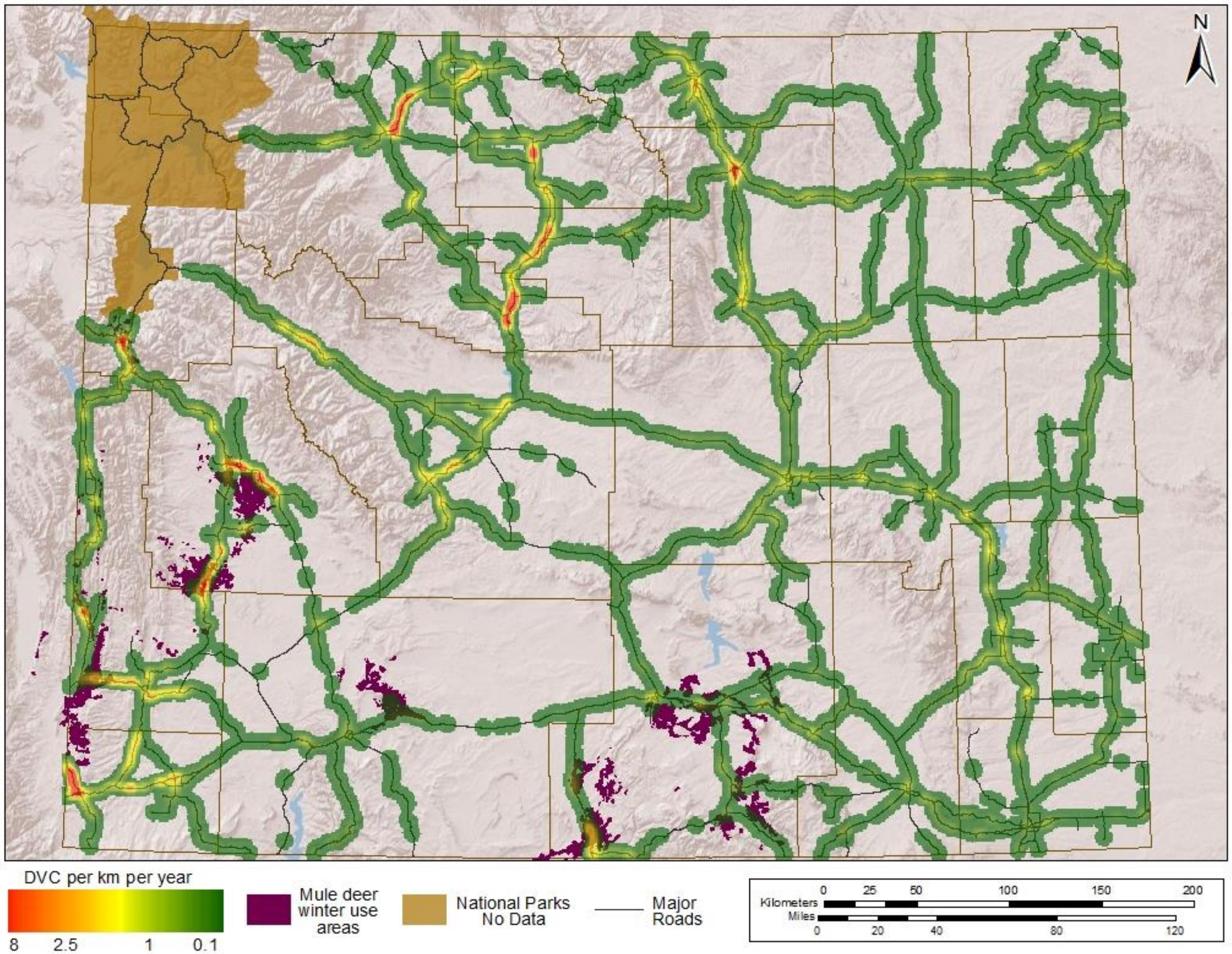


Figure 17. Deer-vehicle collision distribution across Wyoming overlain with winter core-use areas derived from GPS-collared mule deer.

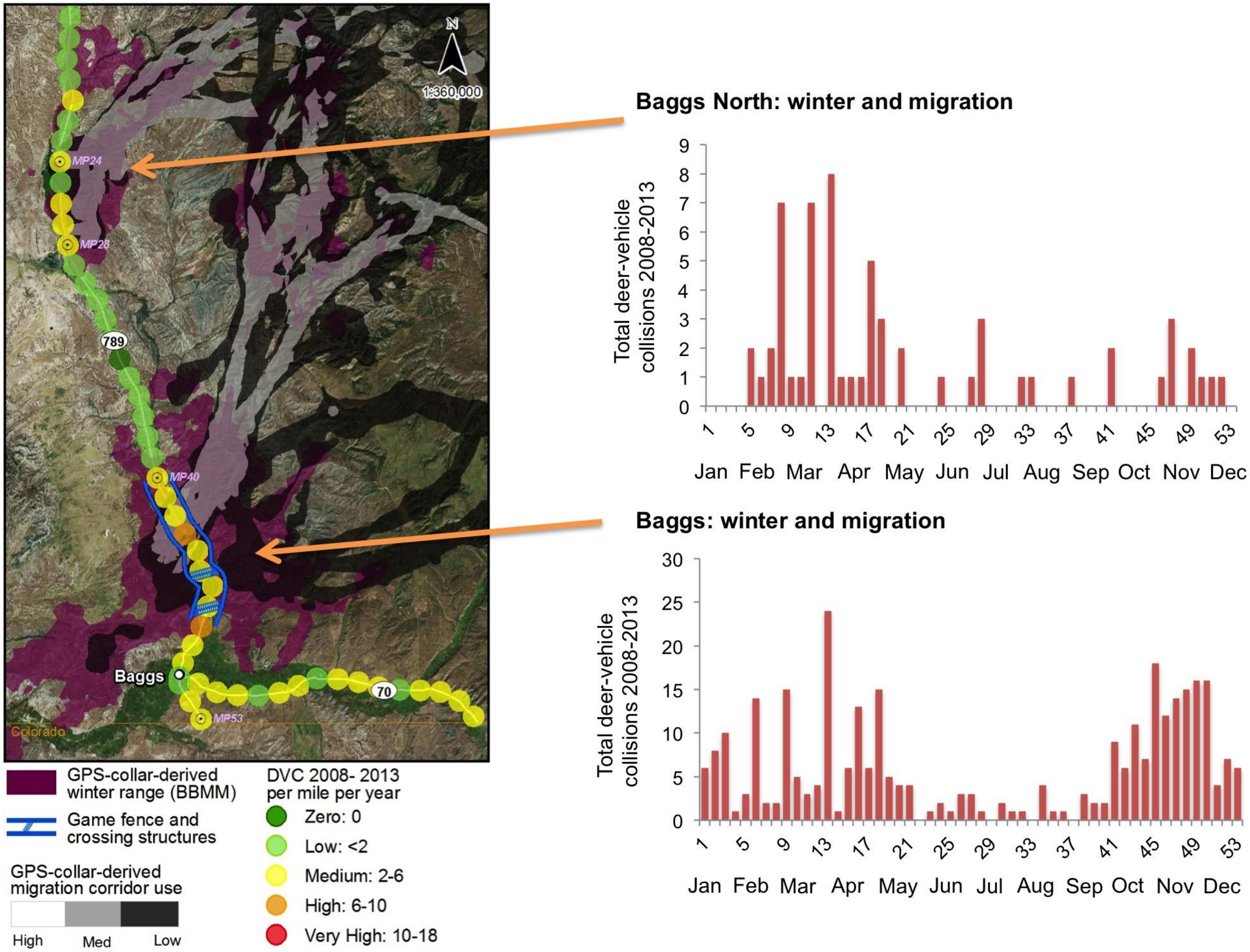


Figure 18. Spatial and temporal patterns of DVC for Baggs and Baggs North.

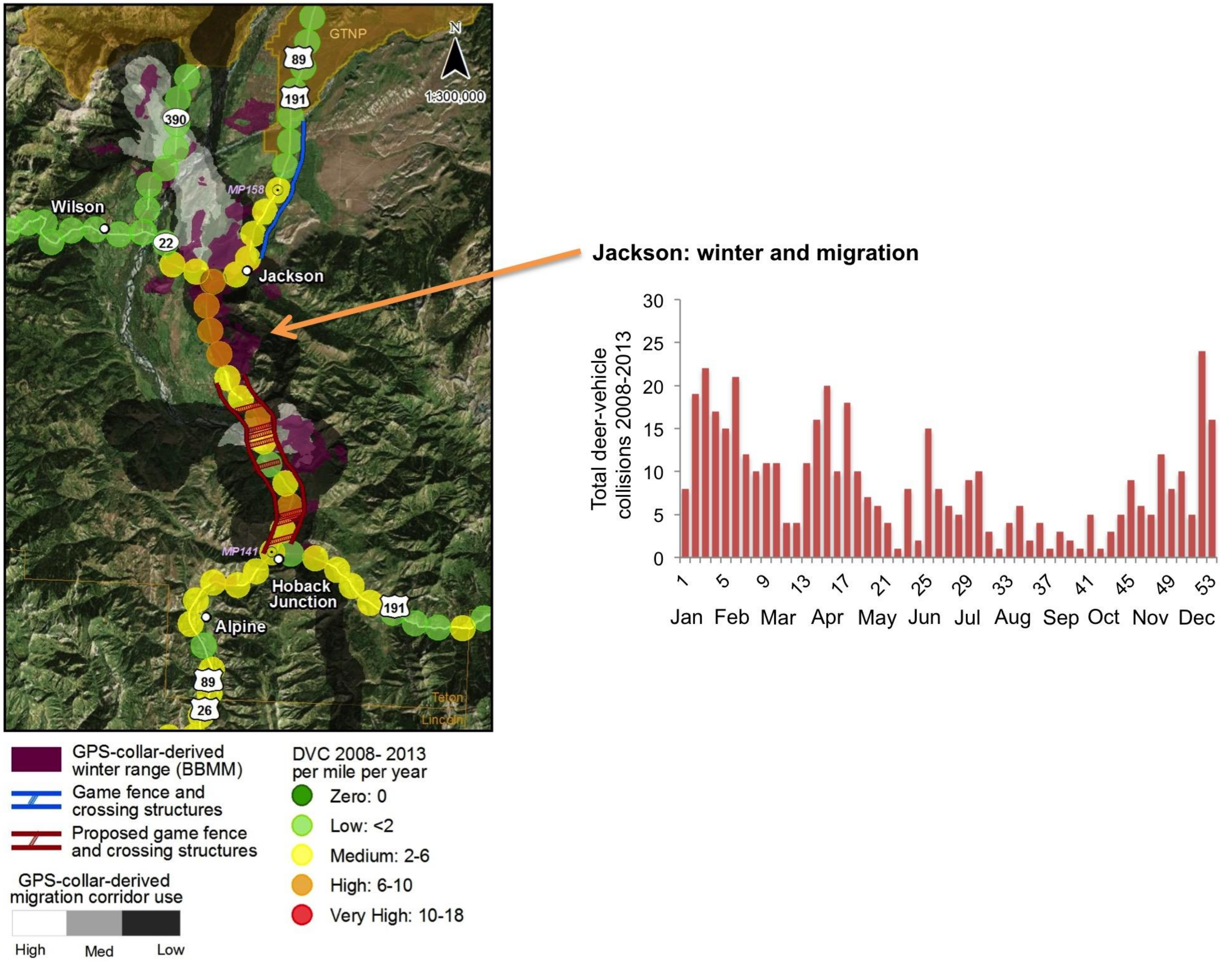


Figure 19. Spatial and temporal patterns of DVC Jackson.

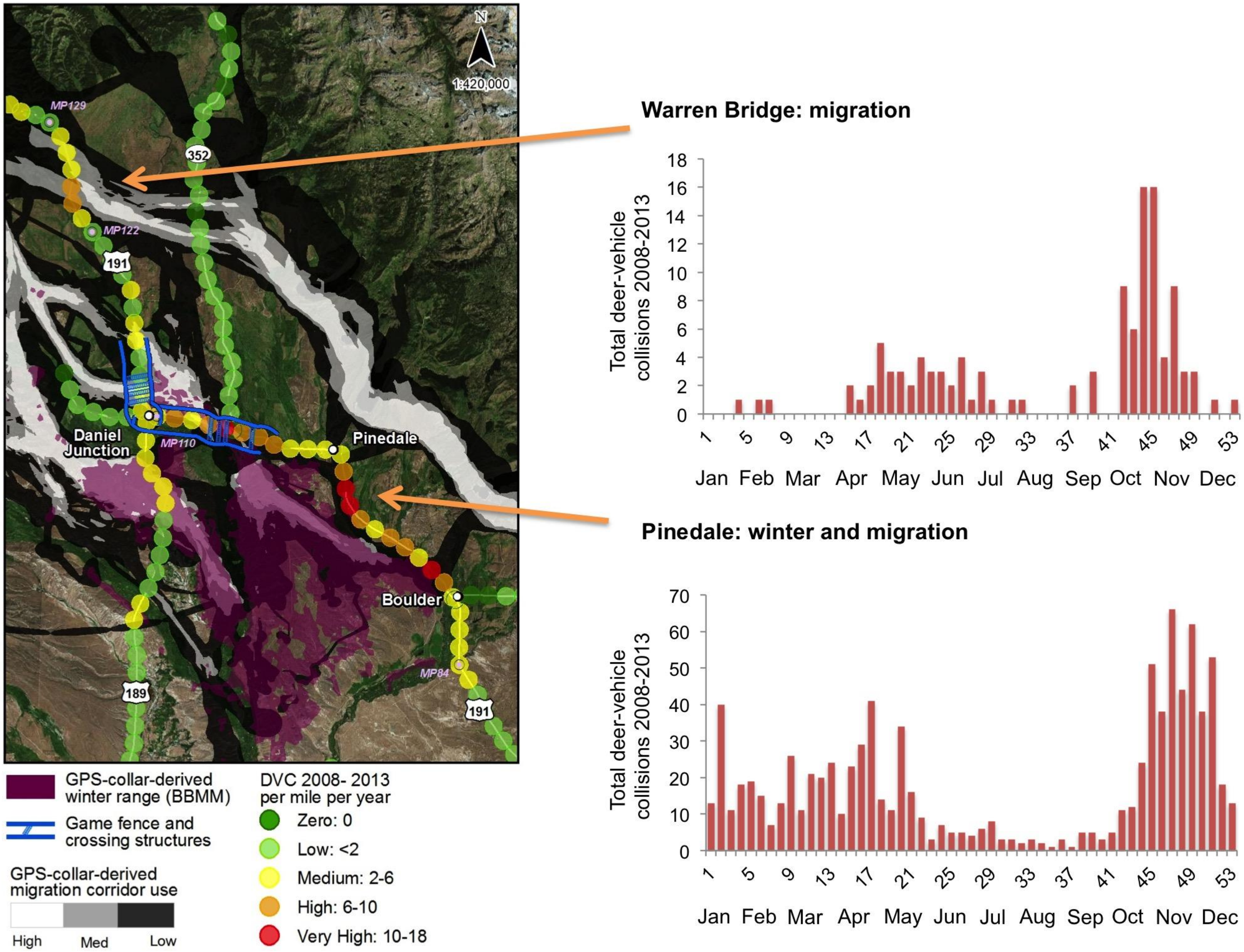


Figure 20. Spatial and temporal patterns of DVC for Pinedale and Warren Bridge.

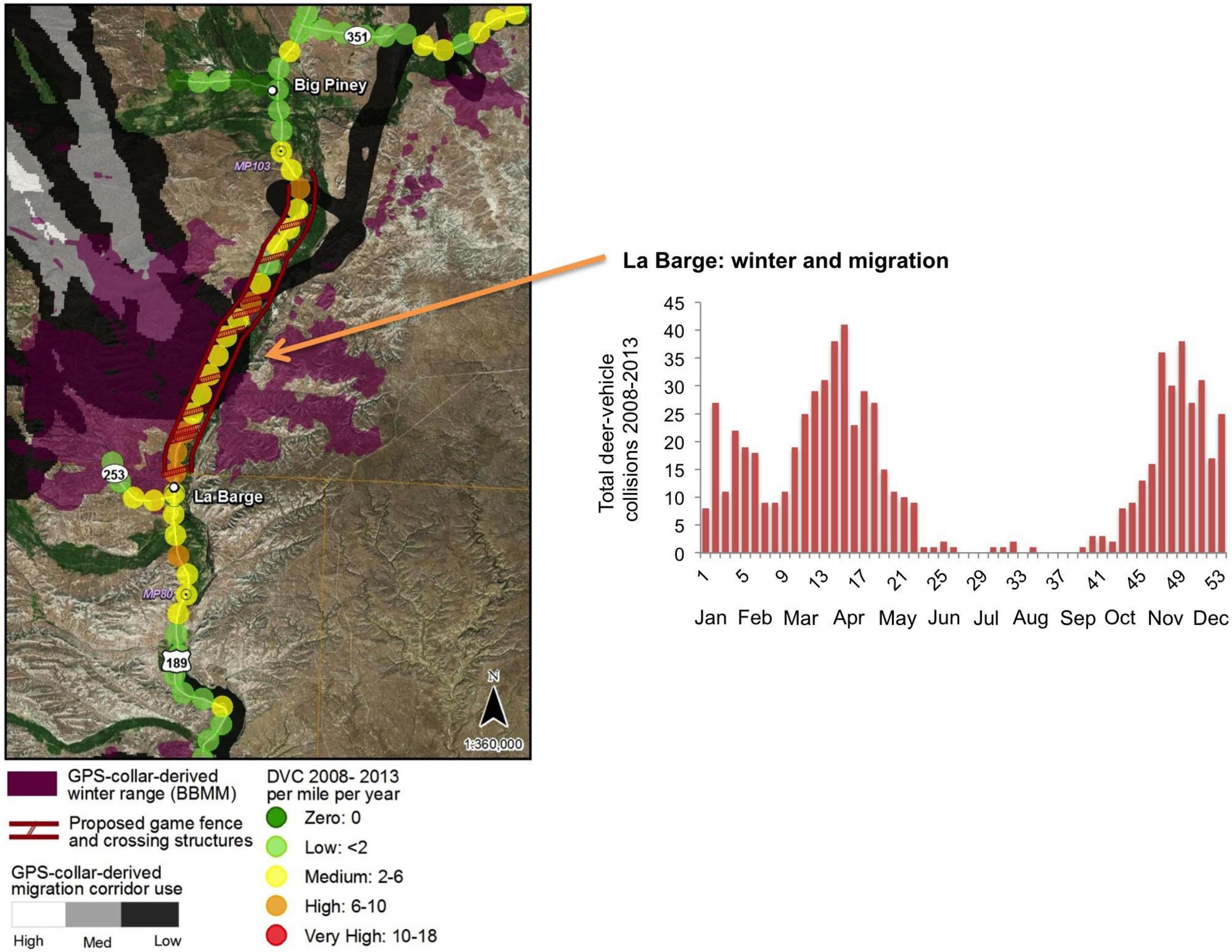


Figure 21. Spatial and temporal patterns of DVC for La Barge.

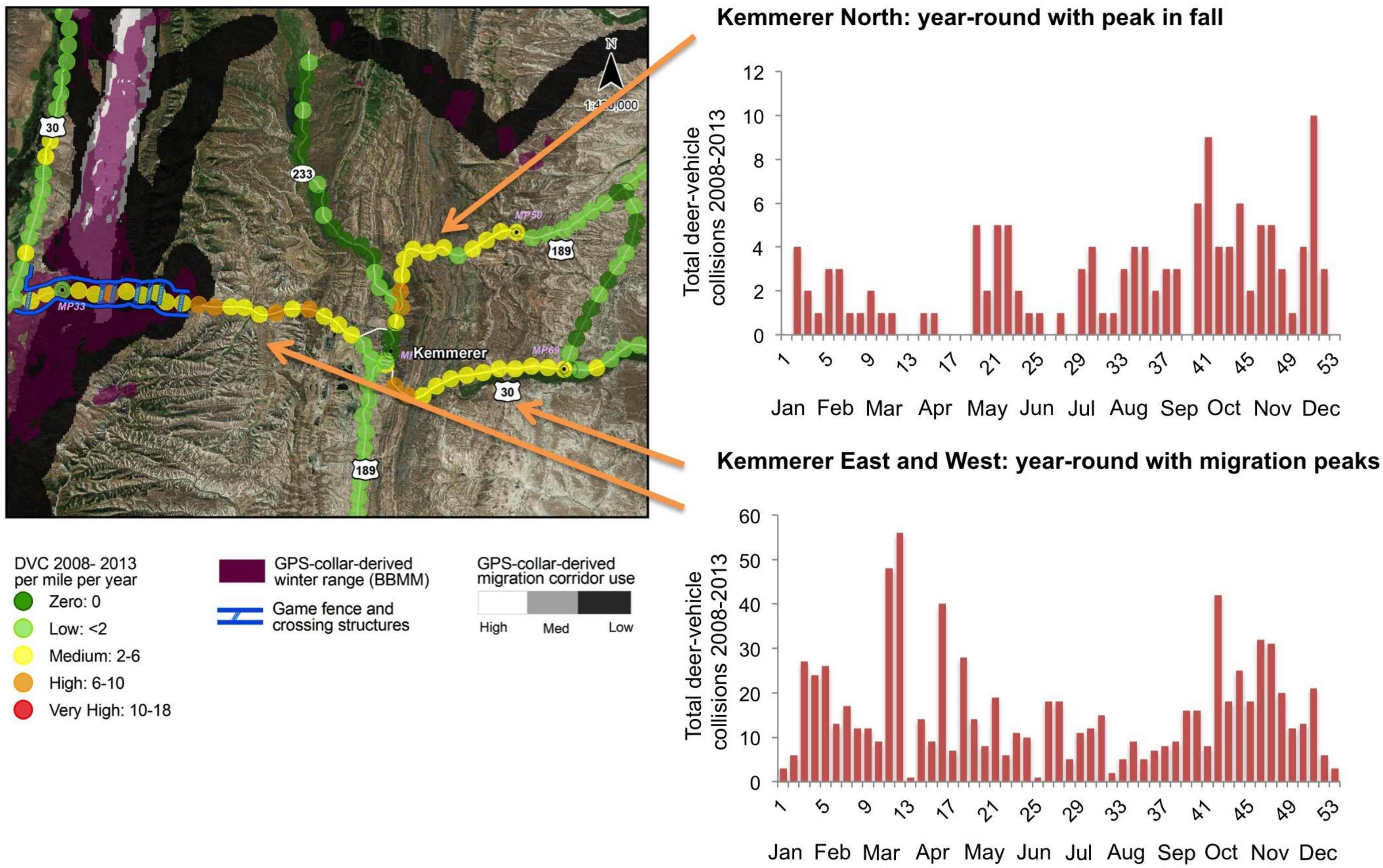


Figure 22. Spatial and temporal patterns of DVC for the Kemmerer area.

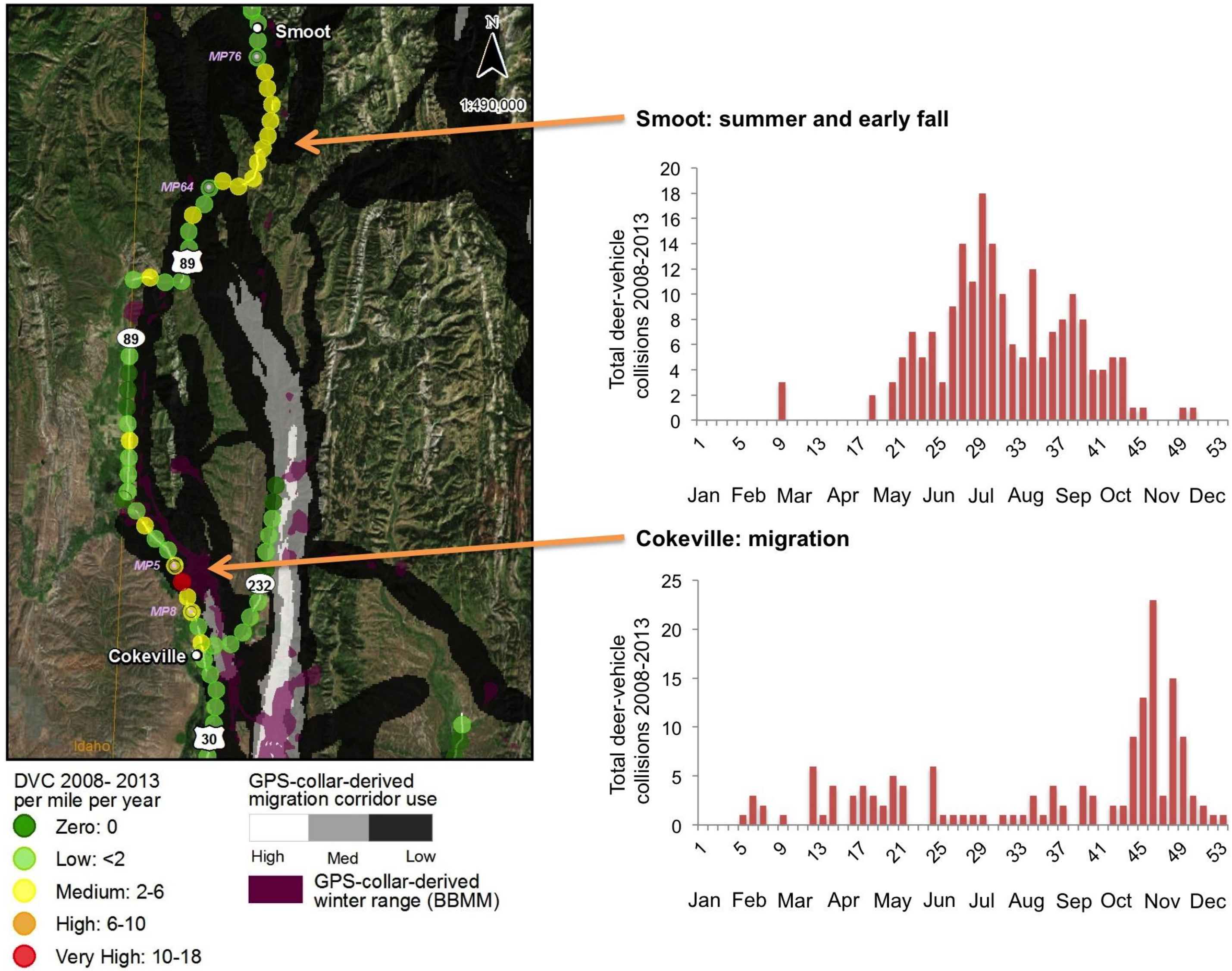


Figure 23. Spatial and temporal patterns of DVC for Smoot and Cokeville.

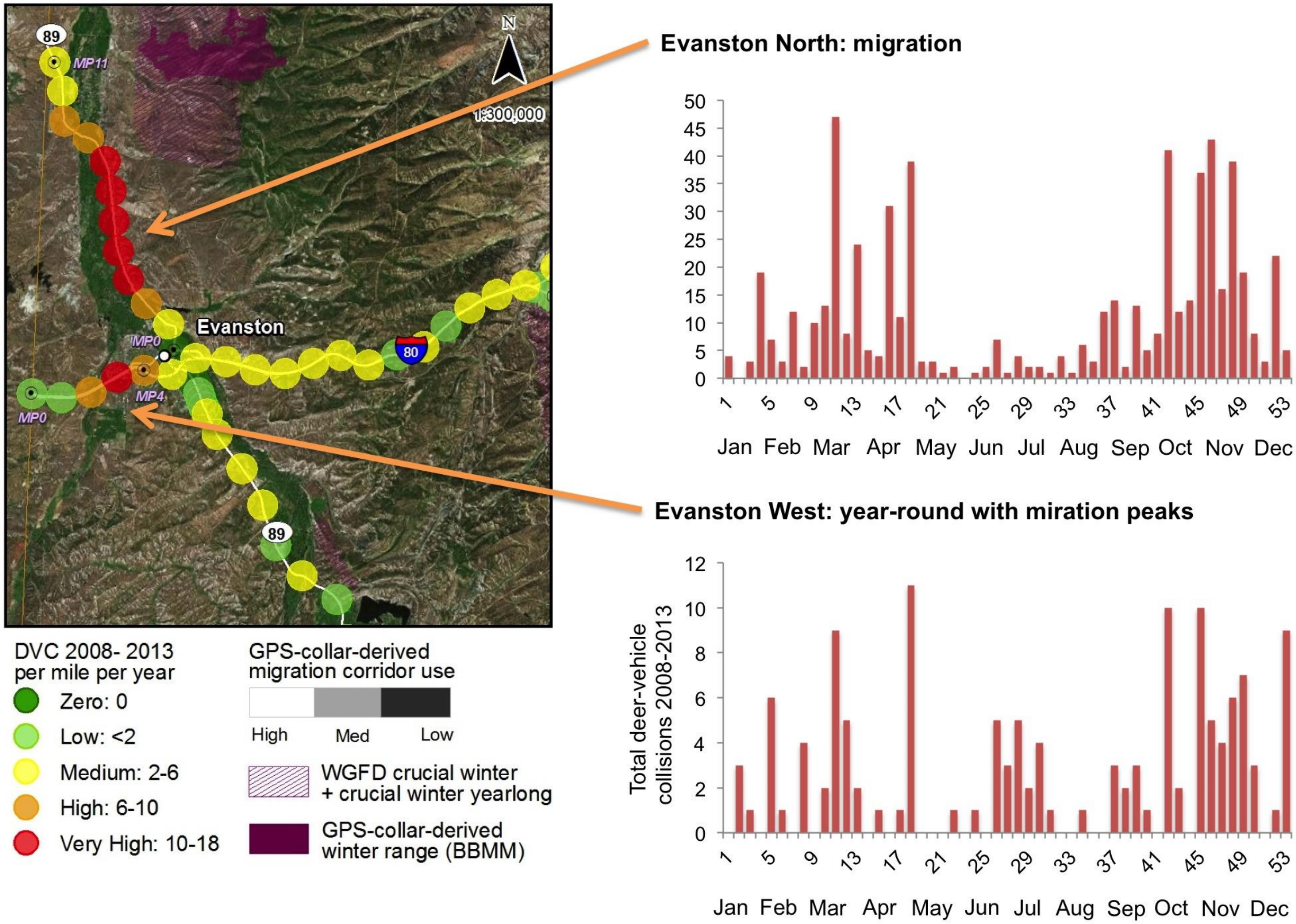


Figure 24. Spatial and temporal patterns of DVC for the Evanston area.

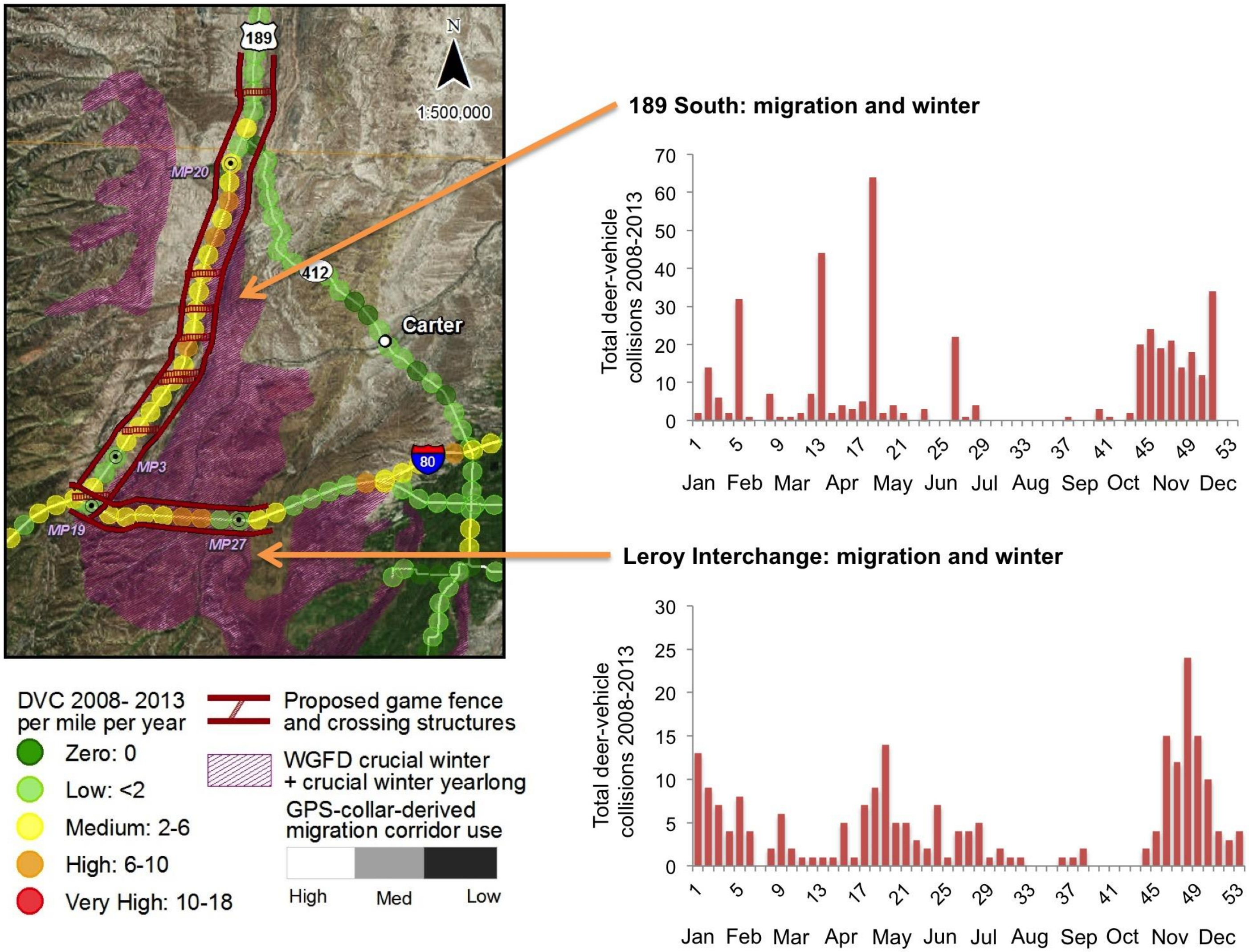


Figure 25. Spatial and temporal patterns of DVC for South 189 and Leroy Interchange.

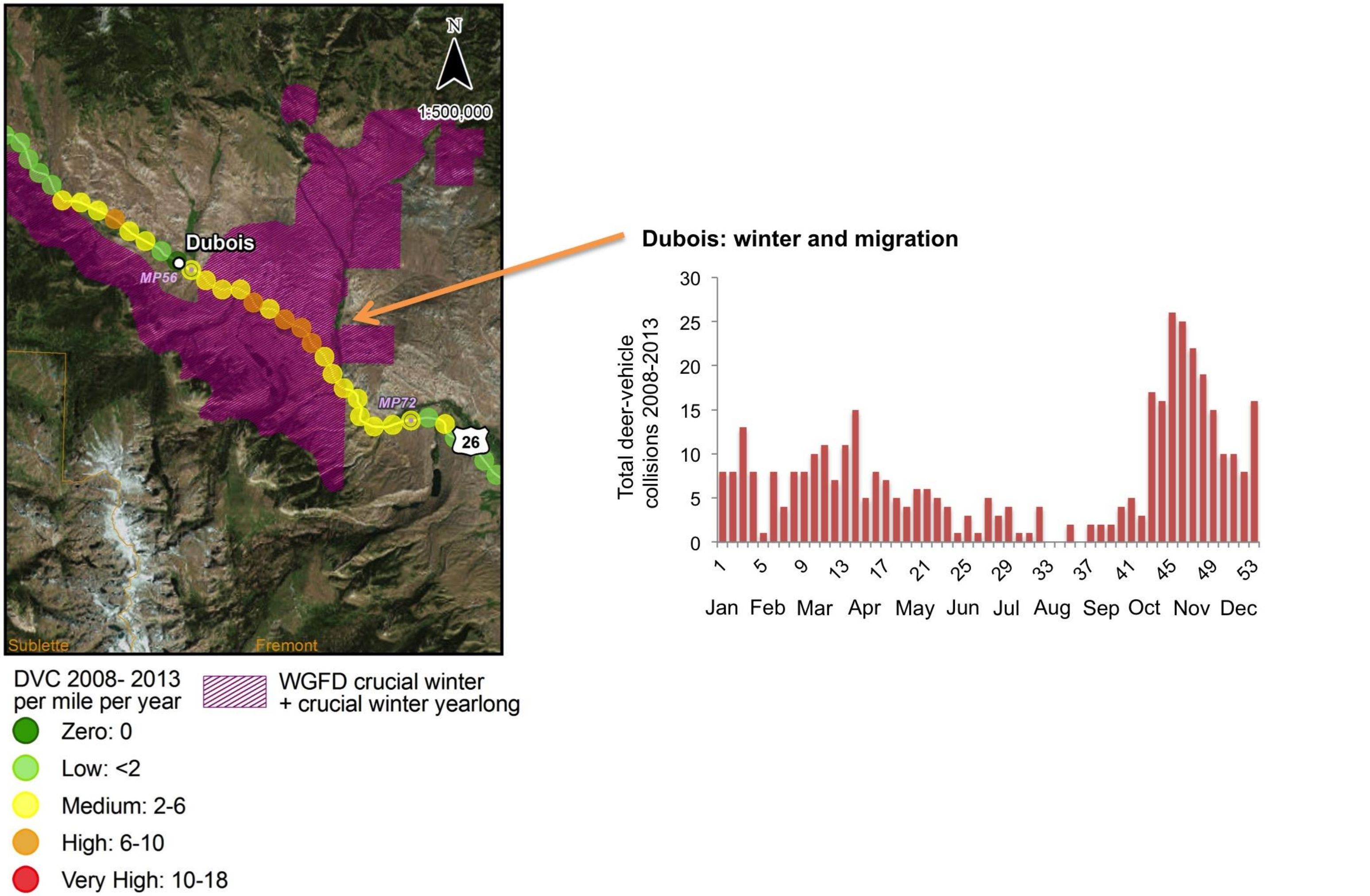


Figure 26. Spatial and temporal patterns of DVC for Dubois.

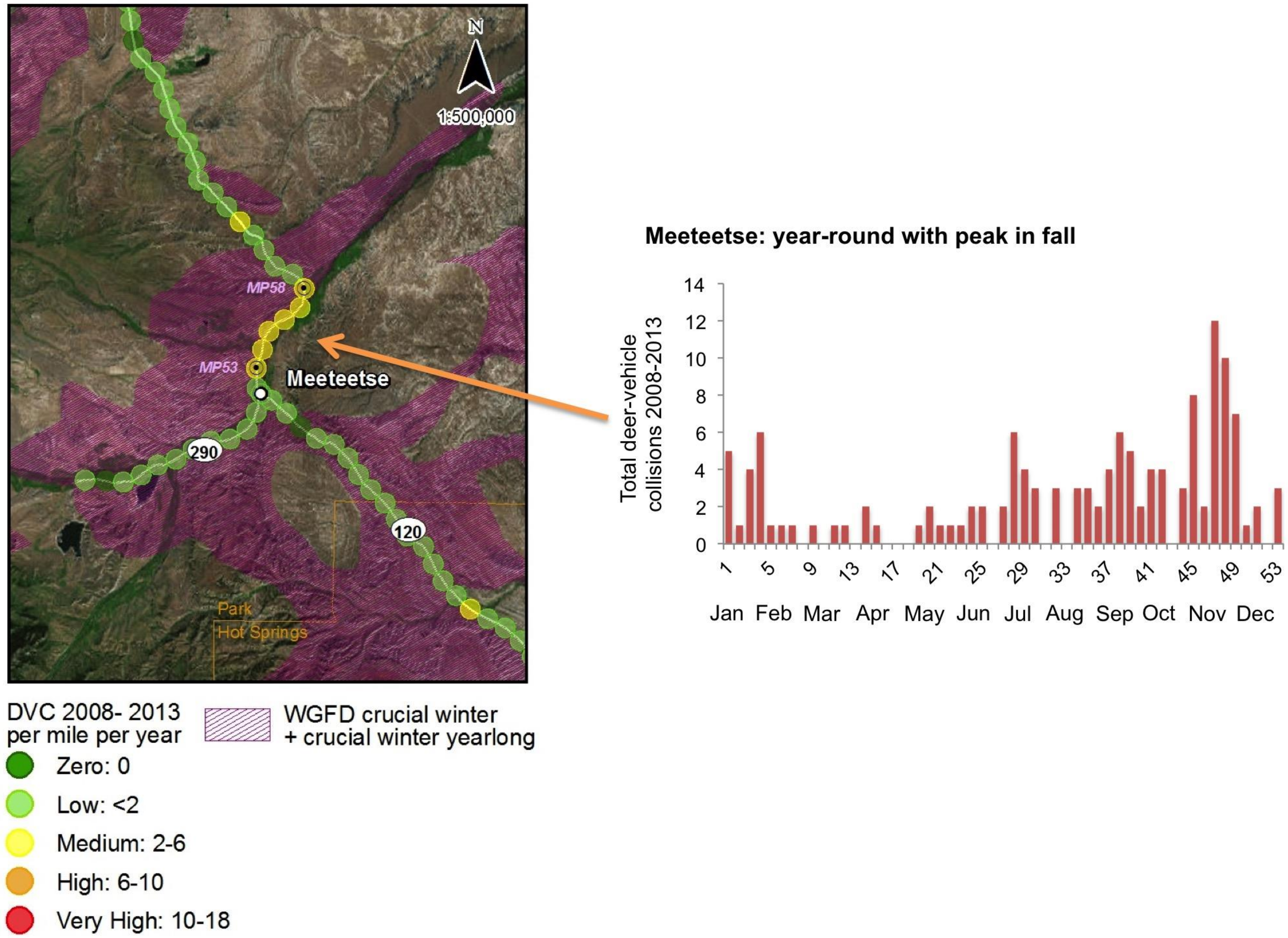


Figure 27. Spatial and temporal patterns of DVC for Meeteetse.

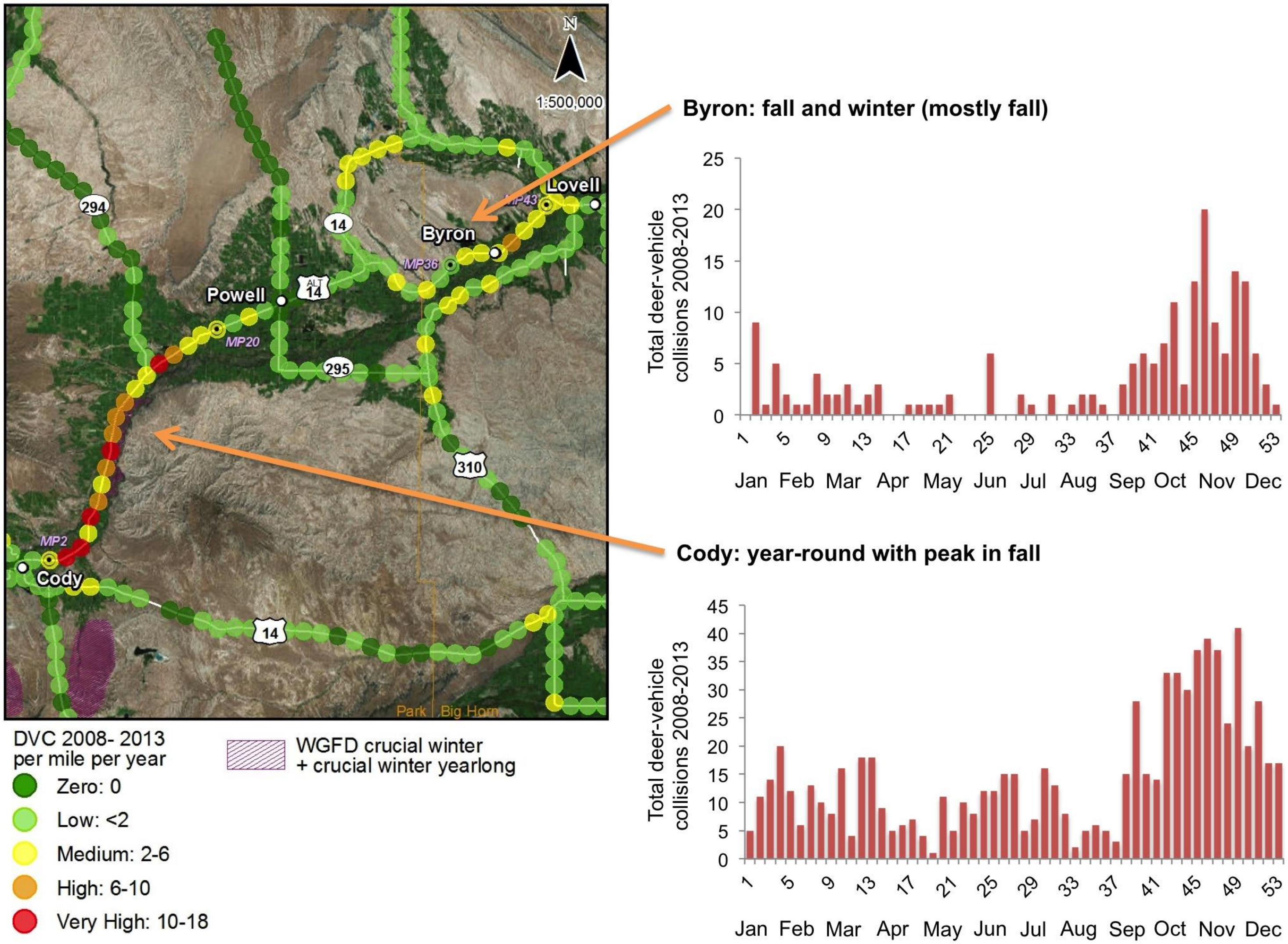


Figure 28. Spatial and temporal patterns of DVC for Cody and Byron.

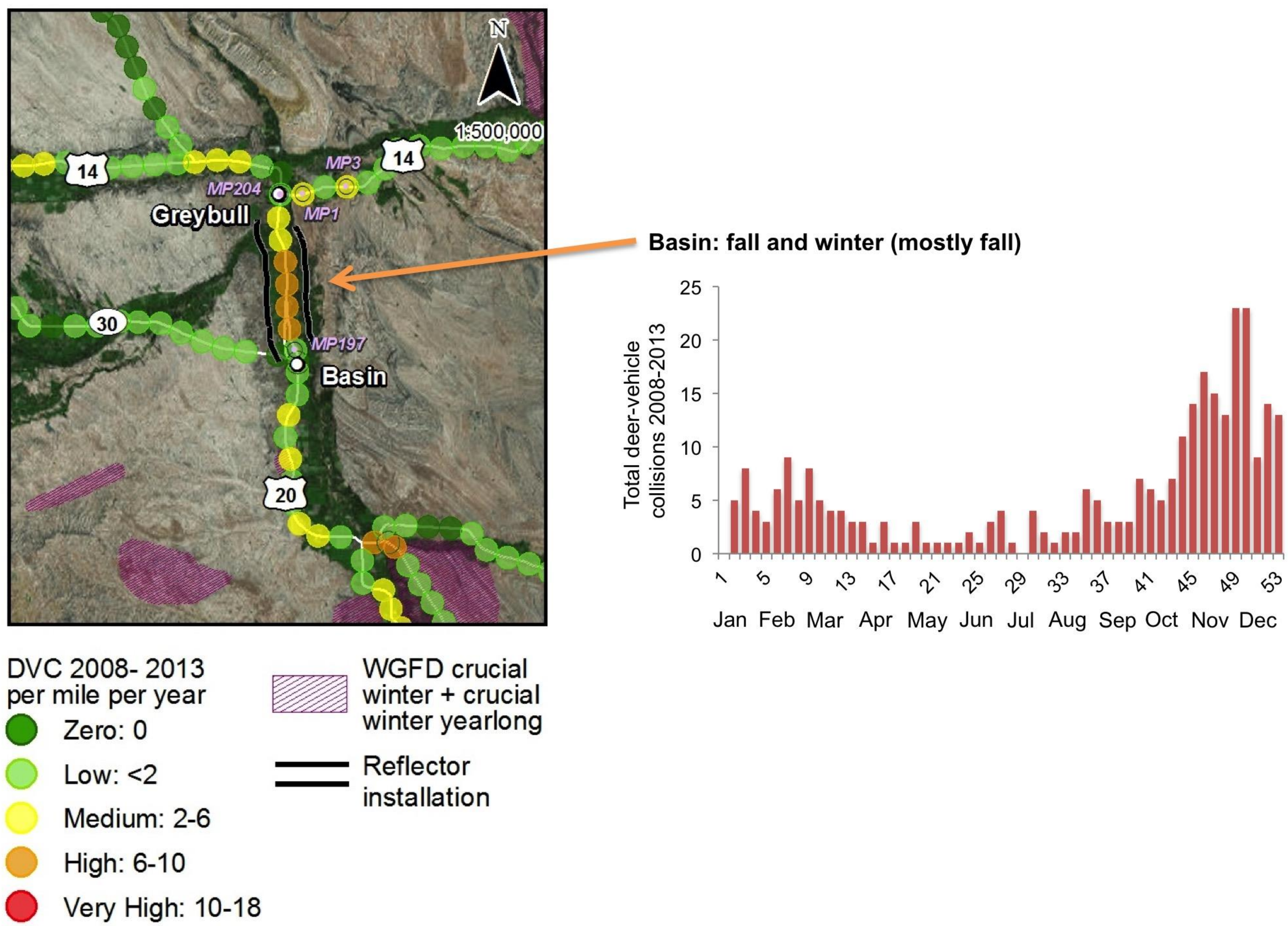


Figure 29. Spatial and temporal patterns of DVC for Basin.

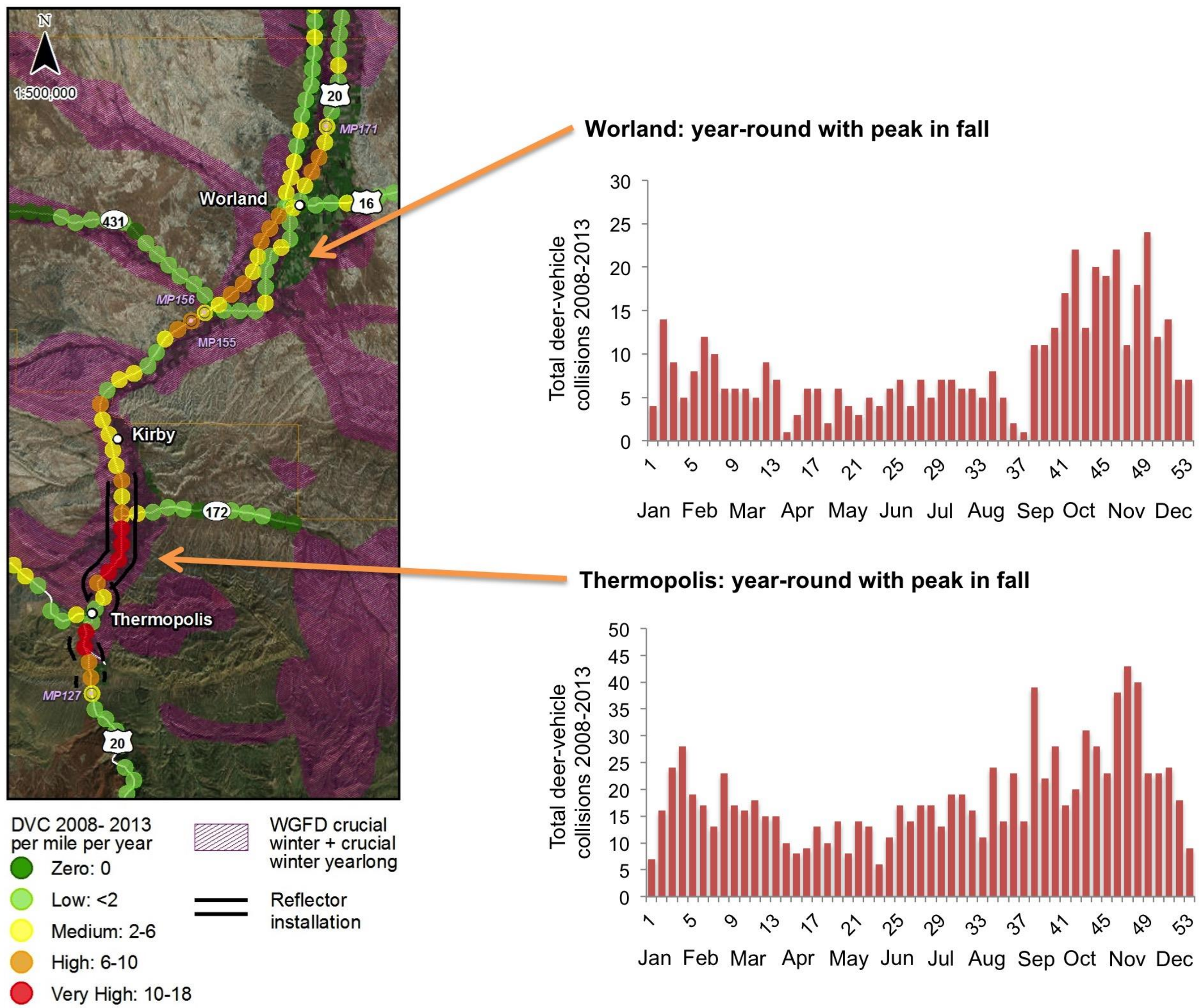


Figure 30. Spatial and temporal patterns of DVC for Worland and Thermopolis.

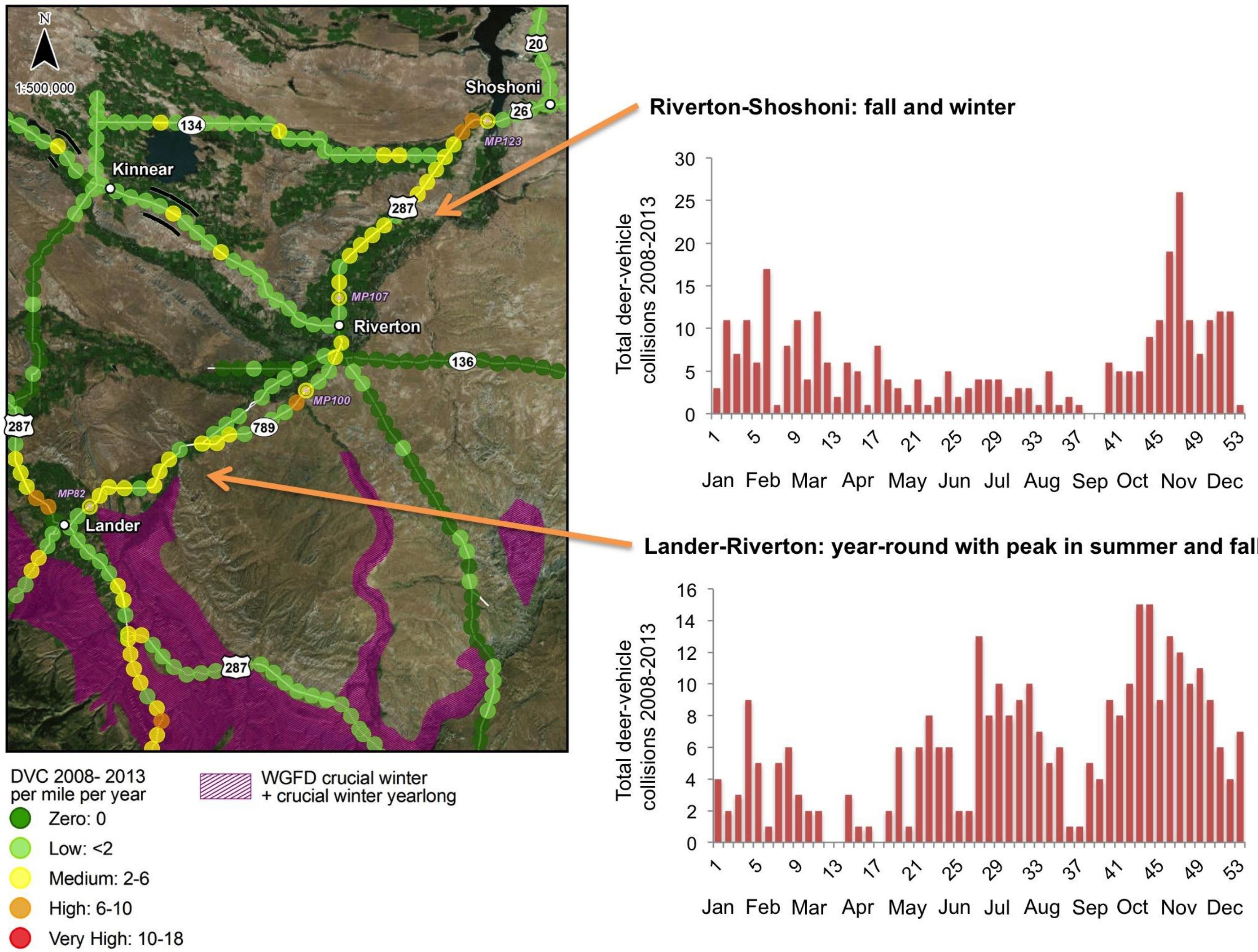


Figure 31. Spatial and temporal patterns of DVC for Riverton-Shoshoni and Lander-Riverton.

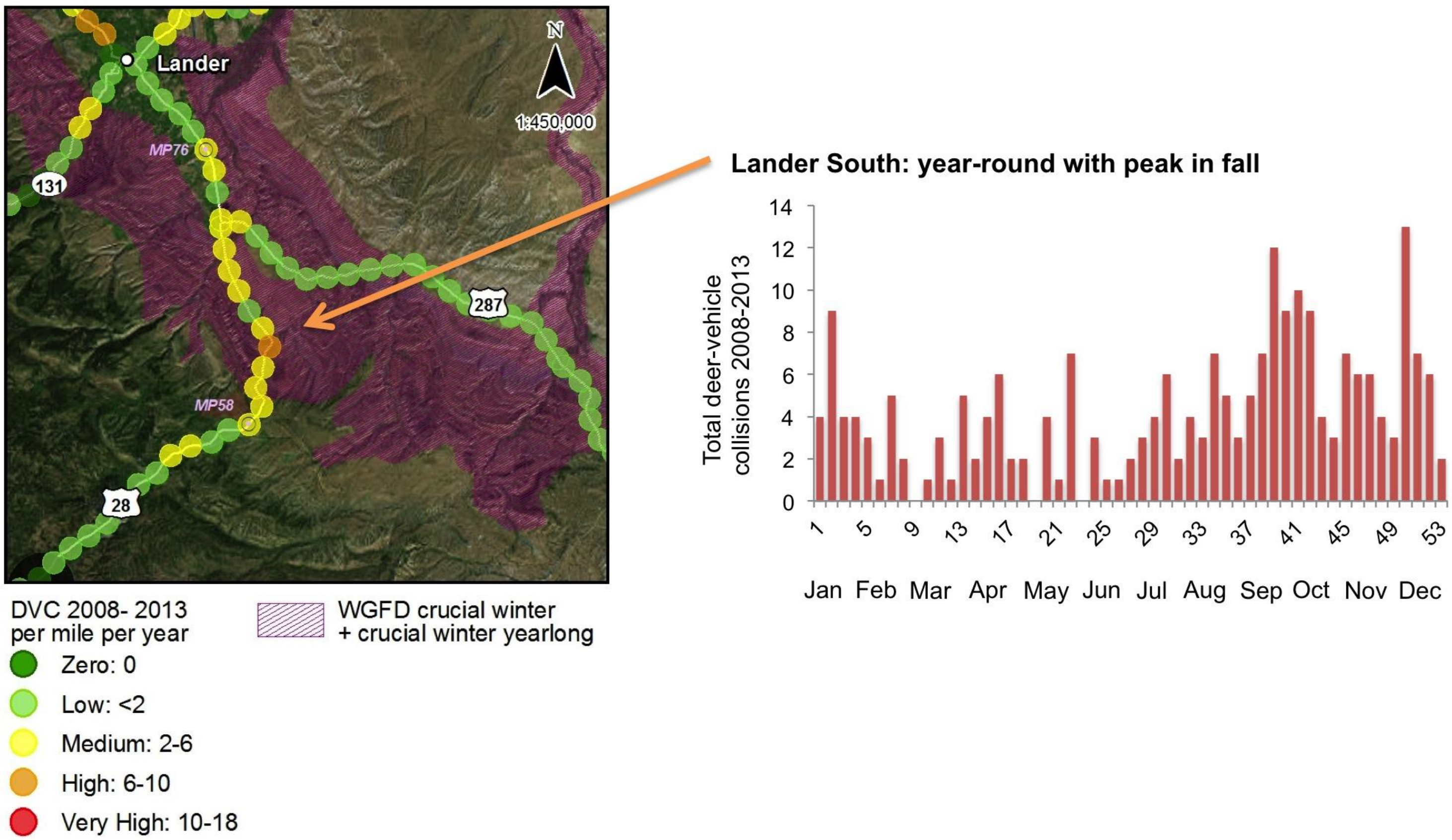


Figure 32. Spatial and temporal patterns of DVC for Lander South.

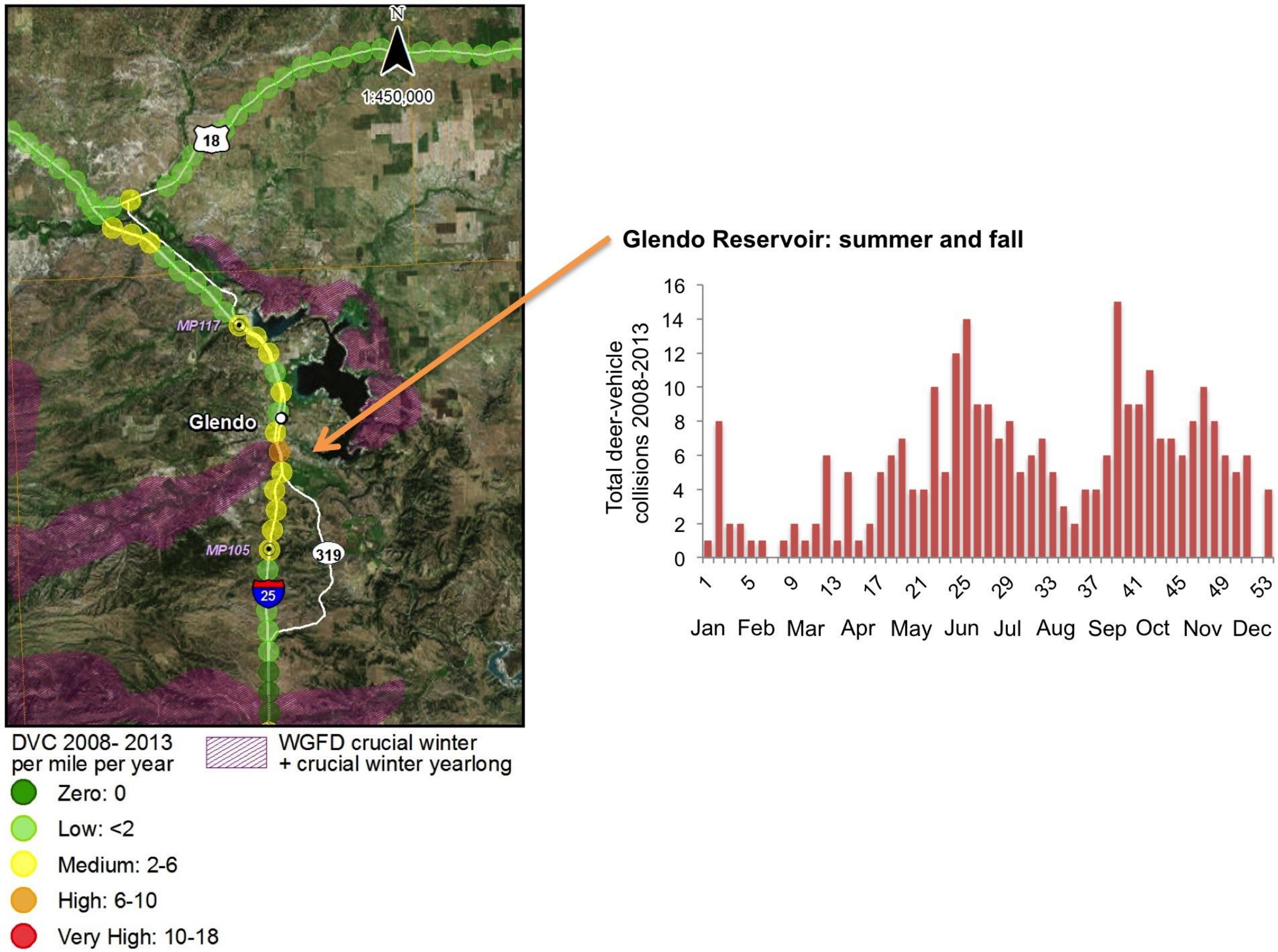


Figure 33. Spatial and temporal patterns of DVC for Glendo Reservoir.

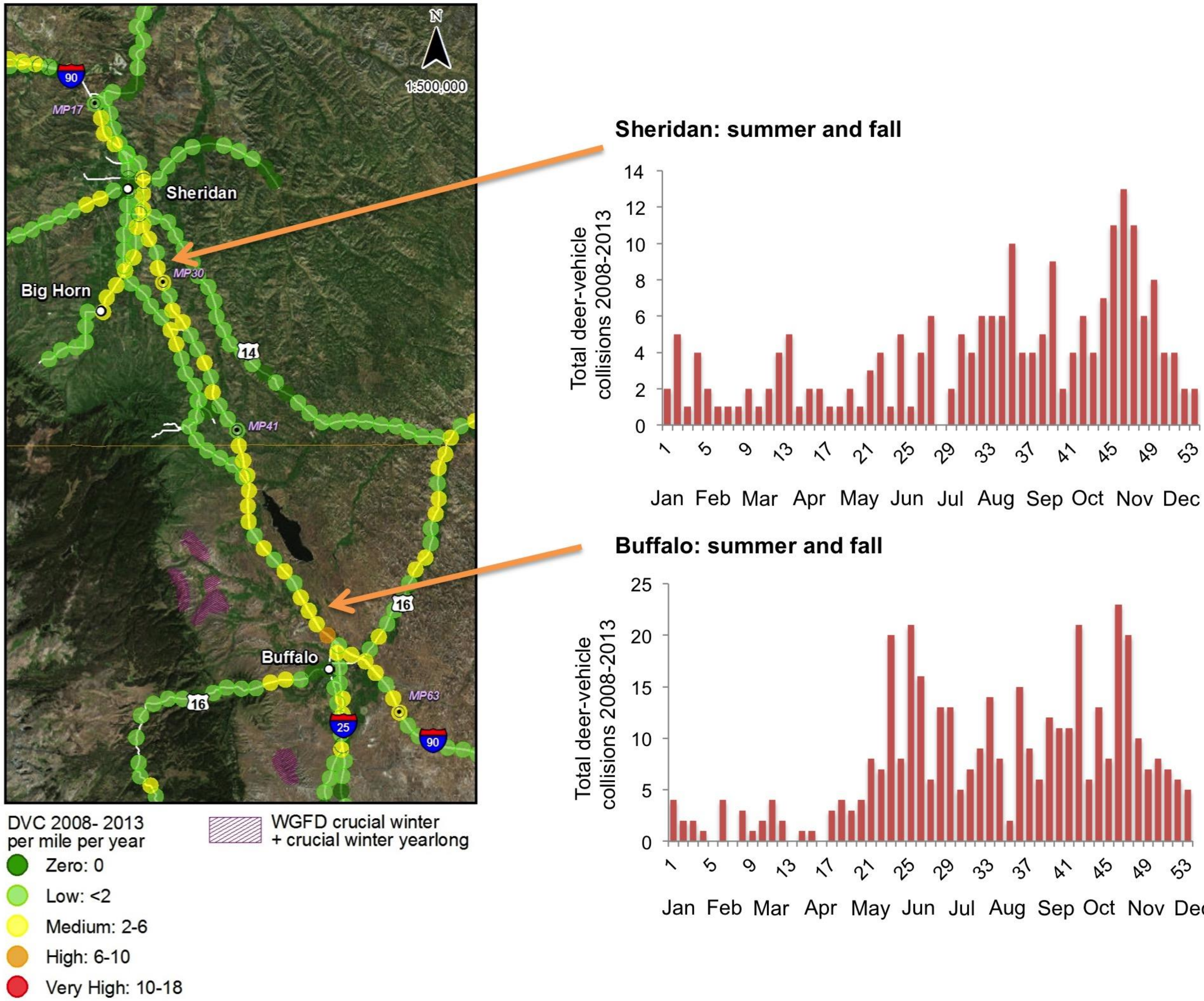


Figure 34. Spatial and temporal patterns of DVC for Sheridan and Buffalo.

Vulnerable areas along migration routes and in winter core-use areas

By mapping migration corridors and winter core-use areas in relation to DVC per mile, we can identify where migrating and wintering animals can cross highways safely versus where they tend to get hit by vehicles. Moderate to high collision rates suggest that highways present a moderate to high level of threat to habitat connectivity for migrating deer. It is important to note that the absence of DVC does not mean that a road does not present challenges and stresses to migrating and wintering animals; however, it is reasonable to assume that road crossings with high DVC rates are a bigger threat. The exception to this is when a road is a near-complete barrier to deer movements and leads to truncated migration routes or winter range.

Red Desert herd

The Red Desert to Hoback migration (figure 35) crosses WY 28, WY 352, and US 191/189. There is no indication of high DVC rates at the crossings for WY 28 and WY 352. There are, however, several miles of high DVC rates with no mitigation at the major crossing of US 191/189 (Warren Bridge hotspot; figure 20), and moderate DVC rates further west of the Rim Station along the same highway where the migration route crosses at multiple locations in a diffuse fashion. The winter core-use area for this herd comes to a marked dead-end on the northern side of I-80, suggesting that the highway is effectively a barrier across former winter range. This herd's migration route is the longest known terrestrial migration in the lower 48 states, and conserving habitat connectivity for this herd is a high priority.[13]

Pinedale herd

The Mesa (northern) portion of the Pinedale herd crosses US 191 just west of Pinedale and US 191/189 north of Daniel Junction (figure 36); these areas have historically had high and very high DVC rates, but the recently-completed fencing and crossing structures have reduced DVC by 81 percent in this area.[34] The six underpasses are also being used extensively by mule deer throughout the winter, indicating that the underpasses have substantially improved winter range connectivity.[34] However, the northern portion of game fence ends right at a major migration corridor for this herd (at MP 115, ML13); migrating deer are to now be using the underpasses, but new migration collar data will help shed light on whether deer continue to cross outside of the fence. In addition, some animals from this herd cross US 191/189 at the Warren Bridge area, also used by the Steamboat herd, and this area has high DVC rates. High and very high DVC rates also persist on US 191 east of Pinedale, where there is no current mitigation. These may be caused by deer crossing the highway through the winter, since their winter core-use area abuts the highway.

The Ryegrass (southern) portion of the Pinedale herd has a major migration corridor crossing US 189 just south of Daniel Junction (figure 36). This is also a place where the herd's winter core-use area straddles the highway. This area experiences a moderate number of DVCs and has no mitigations. This herd's migration routes also cross US 191/189 further northwest in a number of places west of the Rim Station, some with moderate DVC levels.

Wyoming Range herd

The southern portion of the Wyoming Range herd has a major migration corridor and winter use area straddling US 30 just east of the Idaho border in the Nugget Canyon area (figure 37; figure 22). This area has historically had high and very high DVC rates, but new fencing and crossing structures have reduced the number of collisions in this area by 81 percent.[55] A portion of this herd also crosses US 30 further north, near Cokeville, in a spot that experiences very high DVC rates, with no current mitigation (figure 37; figure 23). The herd's summer use areas may be responsible for moderate DVC rates south of Smoot on US 89.

The northern portion of the Wyoming Range herd has migration routes that end in their core winter use area between La Barge and Big Piney along WY 189 (figure 37, figure 21). This area has moderate and high DVC rates. WYDOT has long planned to mitigate this area with fencing, underpasses, and overpasses, but has not yet been able to fund this mitigation.

Jackson herd

The Jackson deer are short-distance migratory deer (~8-12 mi or ~13-19 km). Migration routes cross US 89/189/191 in several places with moderate to high DVC rates (figure 38). The overwhelming majority of DVC, however, are associated with deer in their winter ranges rather than migrations.[56] The high DVC rates in this area indicate that the highway creates a challenge to deer movements, particularly during winter. Fencing and underpasses are in the process of being installed in the southern part of this area.

Atlantic Rim herd

The Atlantic Rim herd has migration routes and winter core-use aeras that cross WY 789 in two areas (figure 39). In the southern crossing area, just north of Baggs, fencing and crossing structures have recently been completed. The northern crossing area currently has no mitigation. DVC rates are moderate in this area.

Platte Valley herd

The Platte Valley herd has migration routes and winter core-use areas that straddle WY 70, WY 230, WY 130, WY 30, and US 80 (figure 40). Apart from I-80, these are generally minor roads with very few DVC. Extensive fencing and some underpasses have been installed along I-80. The Platte Valley herd has migration routes crossing I-80 at approximately MP 249-253, MP 252, and MP 259. All of these locations have some kind of underpass; however, DVC rates are high at MP 252, suggesting that this underpass and/or fencing are not adequately preventing deer from entering the road.

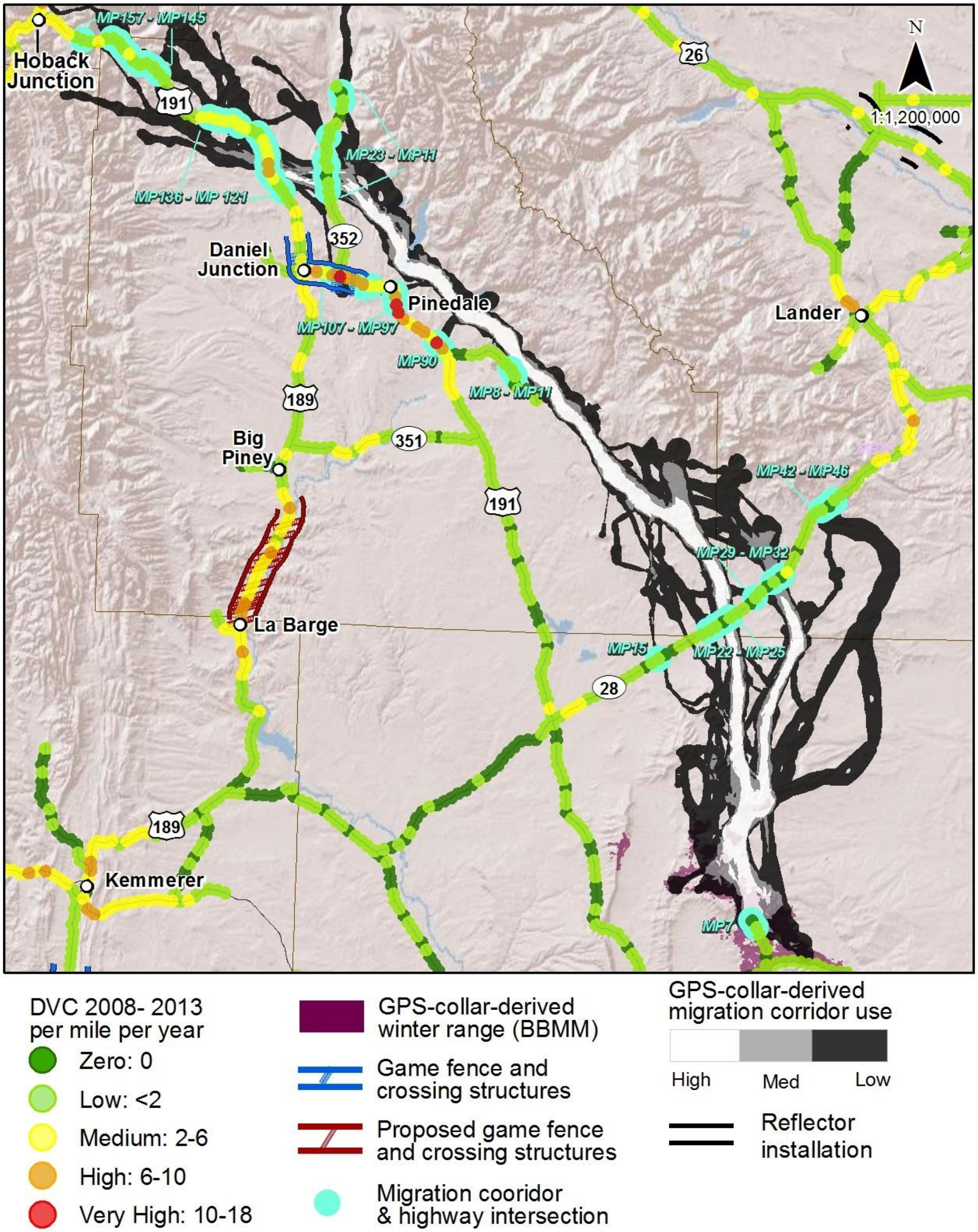


Figure 35. Known migration routes in relation to highways and DVC patterns for the Red Desert Herd.

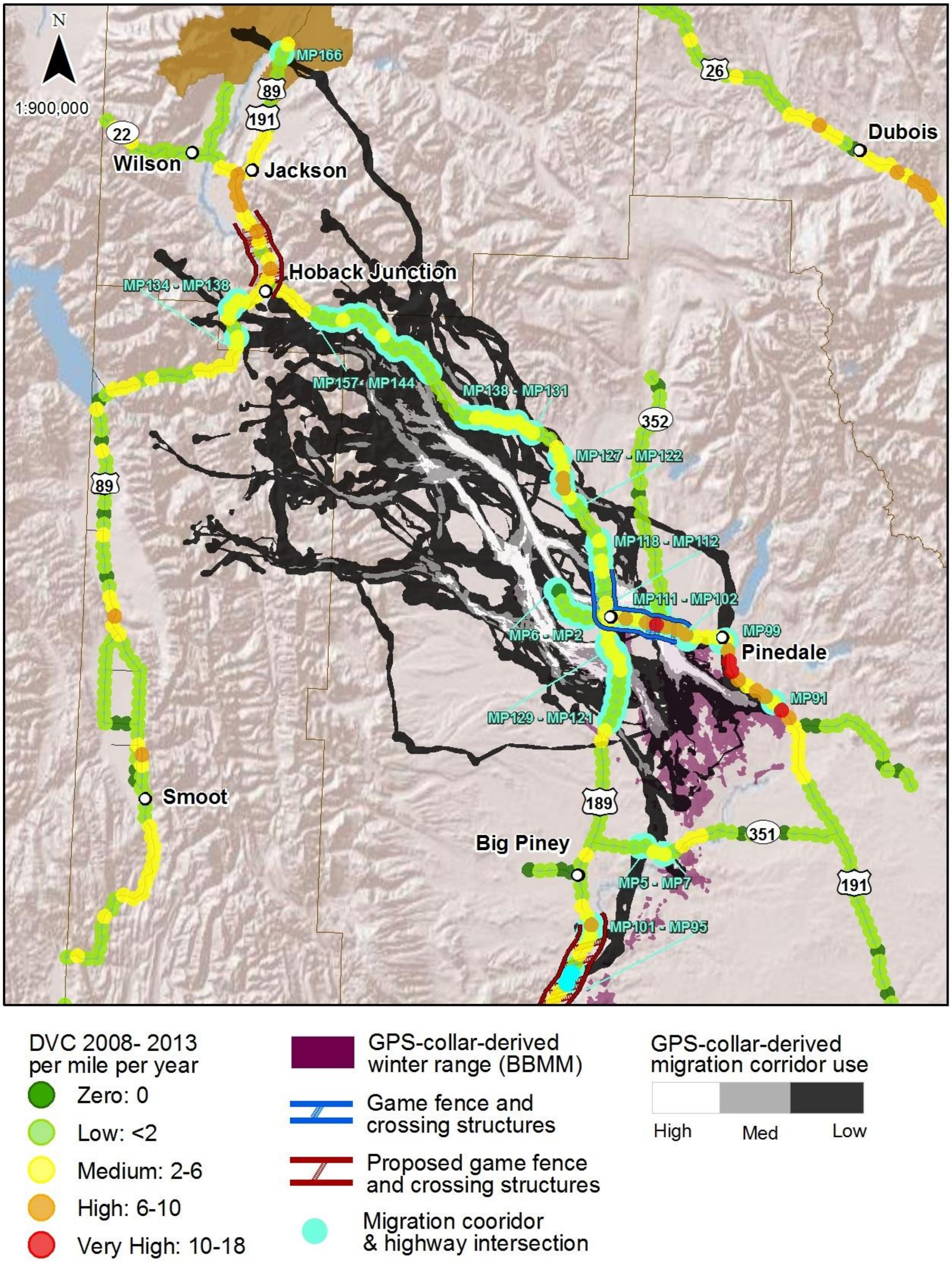


Figure 36. Known migration routes in relation to highways and DVC patterns for the Pinedale Herd.

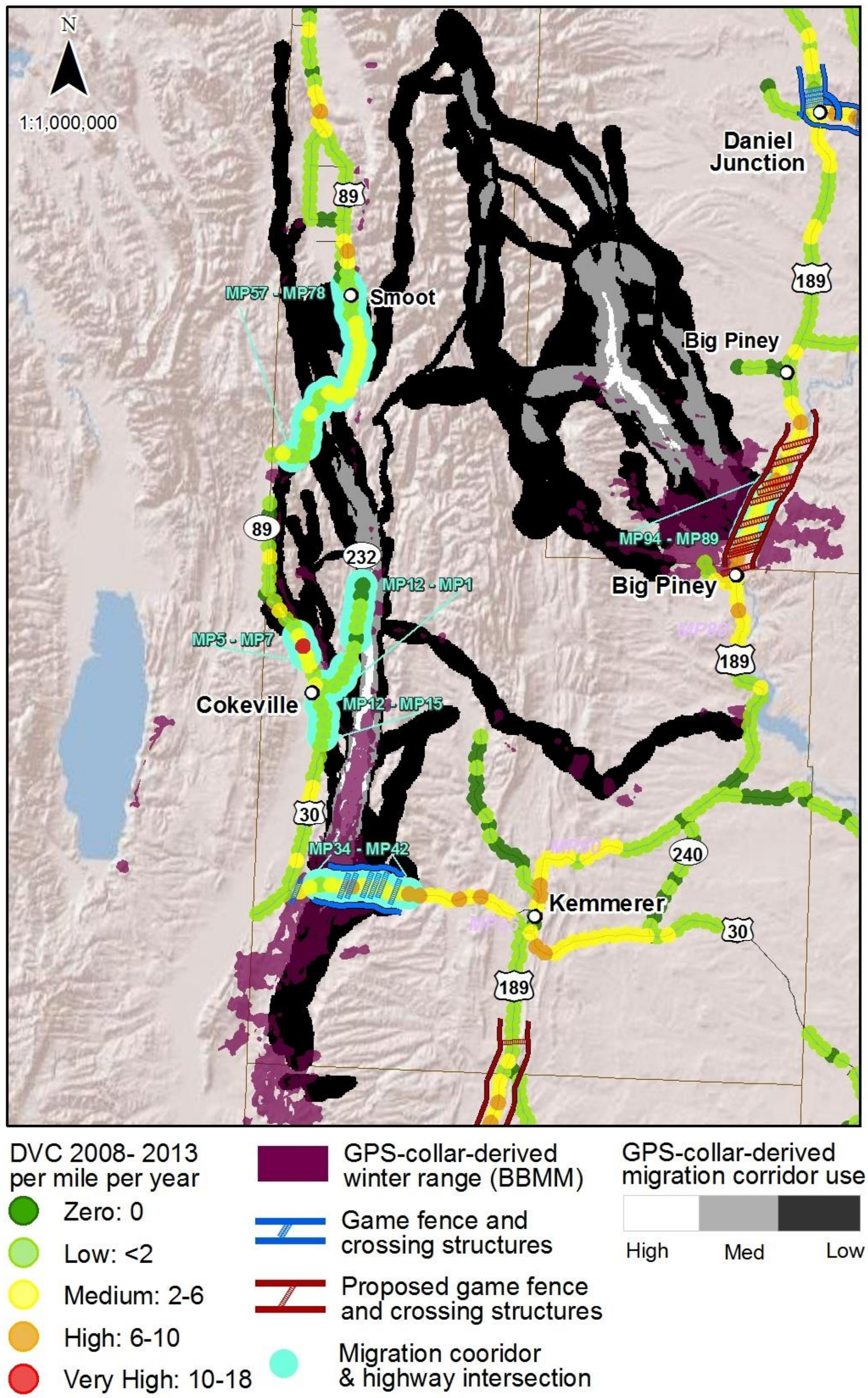


Figure 37. Known migration routes in relation to highways and DVC patterns for the Wyoming Range Herd.

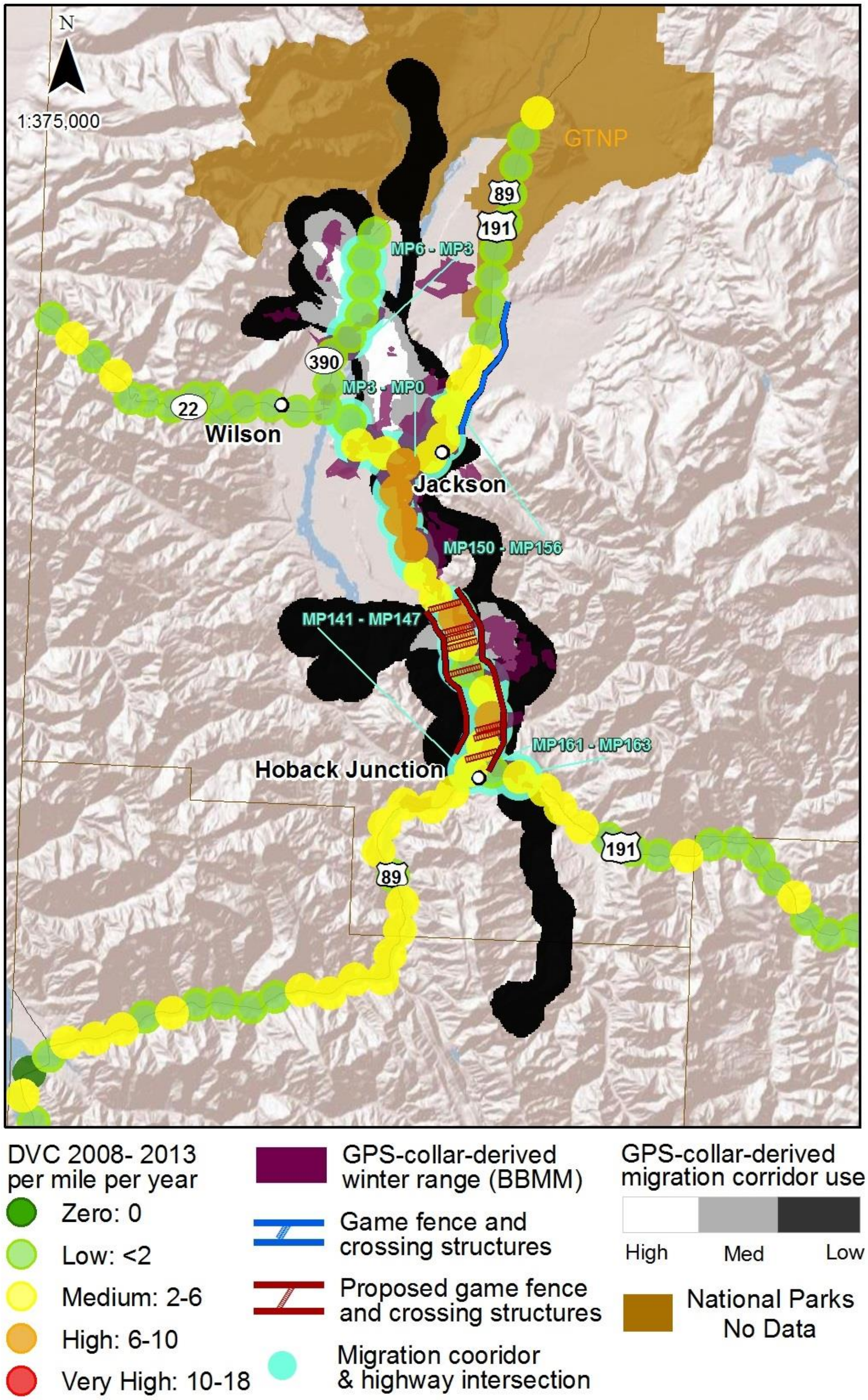


Figure 38. Known migration routes in relation to highways and DVC patterns for the Jackson Herd.

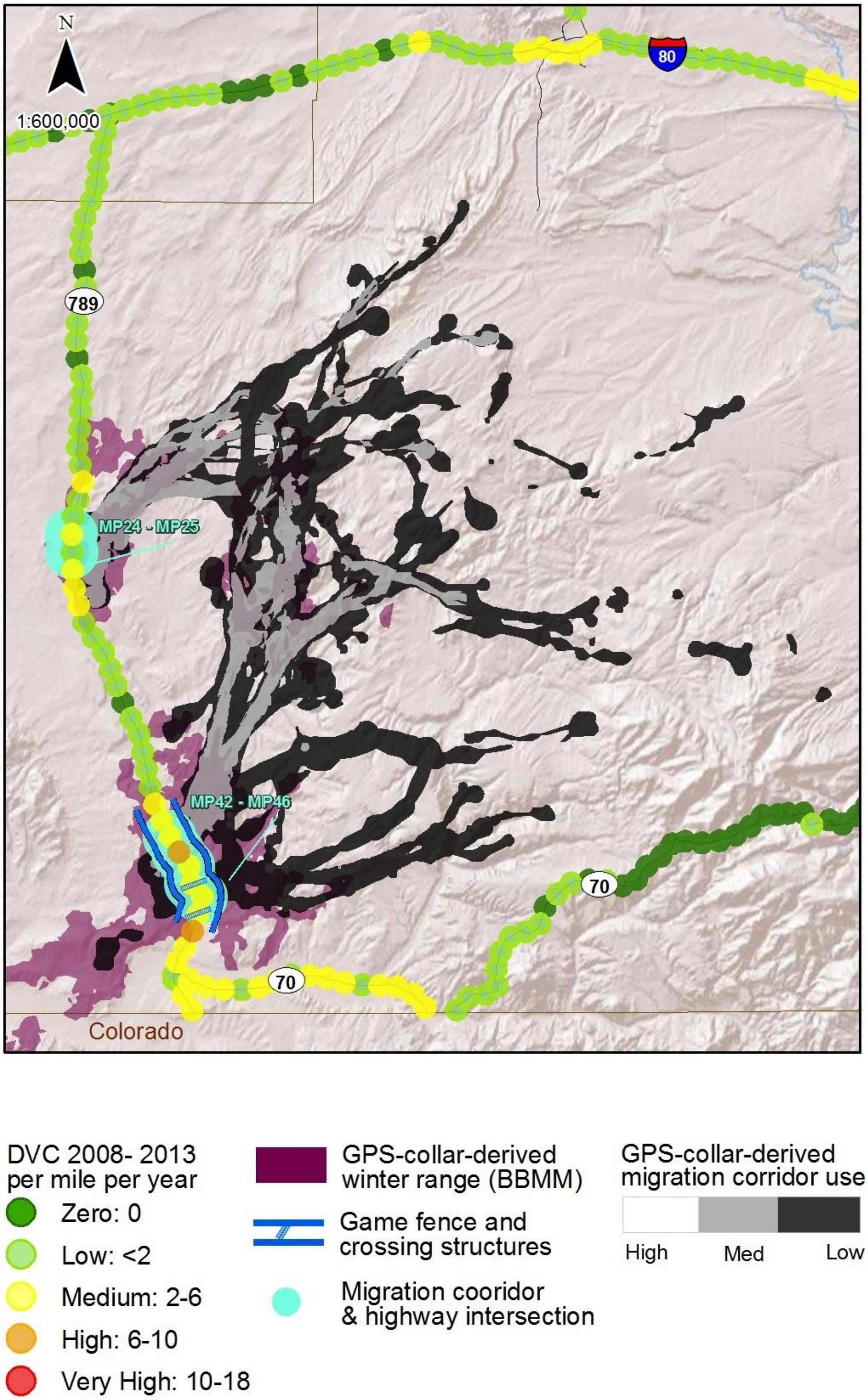


Figure 39. Known migration routes in relation to highways and DVC patterns for the Atlantic Rim Herd.

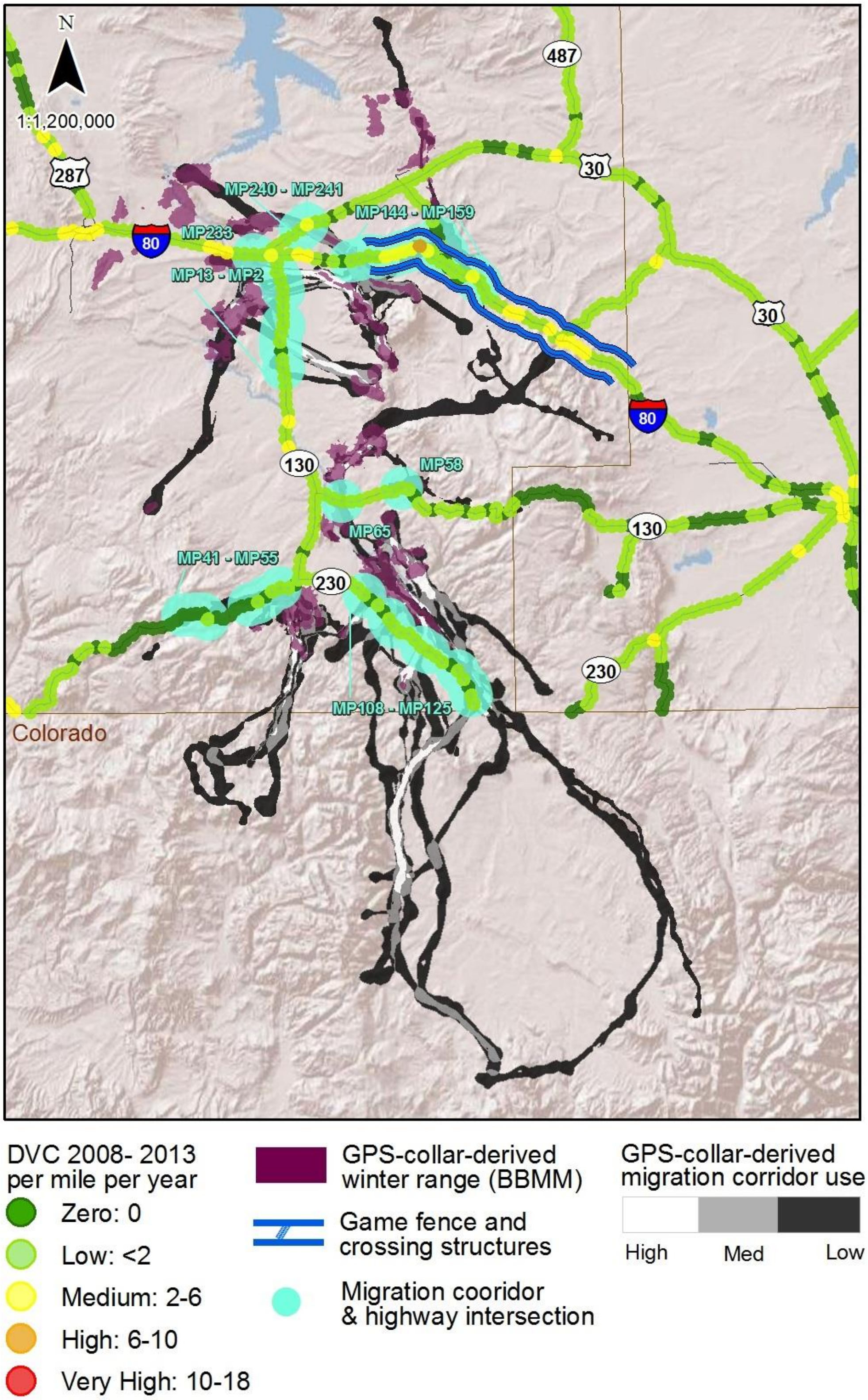


Figure 40. Known migration routes in relation to highways and DVC patterns for the Platte Valley Herd.

Hotspots without GPS collar data

When available, GPS collar data provides very accurate and valuable information about where deer cross roads and how those crossing areas relate to DVC patterns.[20] This can help to identify high priority areas for mitigations and also guide some decisions about what type of mitigation is most suitable. For most hotspots, however, there is no GPS collar data currently available. Even where there is collar data, it is very possible that there are migration pathways and winter-use areas not represented by the 30-60 collared deer. The Wyoming Migration Initiative continues to collar deer in new places, which will ultimately improve our understanding of deer movement and habitat use patterns in relation to roads and DVC hotspots.

In our examination of the temporal patterns of DVC at each hotspot, temporal patterns matched expectations very well for hotspots that did have GPS collar data associated with them. For example, the Pinedale hotspot shows evidence of migration and winter collisions, which is supported by GPS collar data showing presence of migration routes and winter core-use areas (figure 20). The Warren Bridge hotspot just northwest of Pinedale shows only collisions during migration times, which is supported GPS collar data showing a major migration corridor (but no winter use area) crossing the highway at that location (figure 20). This verification from GPS collar data indicates that temporal patterns of DVC can be used to make inferences about the ecological causes of DVC hotspots. This may help to identify new migration routes as well as suitable mitigation strategies.

In the next chapter, we discuss possible mitigations for the DVC hotspots we have identified in Wyoming.

CHAPTER 6. RECOMMENDATIONS

GENERAL RECOMMENDATIONS

We have identified 27 hotspots of DVC in Wyoming that should be prioritized for mitigations (figure 15). These are generally areas with clusters of miles with moderate DVC rates (>2 DVC per mile per year) often including at least several miles with high (6-10 DVC per mile per year) and very high (>10 DVC per mile per year) DVC rates. Several hotspots have more than 100 DVC occurring per year. Several others have relatively few total DVC per year (20-30), but are places where highways bisect important deer migration or seasonal range. Several of these hotspots have been partially or completely mitigated using game fencing and crossing structures (highway under- and over-passes). Crossing structures with fencing is unquestionably the most effective method for reducing large ungulate WVC, but also the most costly. While the ultimate goal may be to install fencing and crossing structures at all of these hotspots of DVC, we recognize that this is not feasible in the short-term (e.g. crossing structures may be cost-effective, but there may not currently be funds available to construct them). In this chapter, we suggest a variety of mitigation options, recognizing that there are tradeoffs between effectiveness and feasibility but that partial mitigation is better than no mitigation.

Overview of mitigations

There are many WVC mitigations currently in use around the world. These vary widely in cost and effectiveness. Here, we provide a general overview of some of the most commonly-used methods before making specific recommendations for Wyoming's hotspots.

Permanent signs

As discussed in Chapter 3, permanent signs are the most commonly-used WVC method and also one of the least effective. Studies have concluded that permanent signs are only effective immediately after installation or at a gap in a fence with a designated wildlife crosswalk painted on the road surface.[32] While there is little harm in installing permanent signs, it is important to recognize that they are unlikely to reduce WVC unless coupled with a crosswalk and fencing.

Temporary signs

Temporary or seasonal signs have been shown to reduce WVCs by 9-50 percent.[32] Although unconfirmed by research, it is likely that variable message signs (which are large and noticeable) are more effective than static message signs when put in a specific hotspot location for a relatively short period of time (one season). Temporary signs can also be used to convey temporary speed limit reductions, e.g. dawn and dusk speed reductions during peak DVC seasons, and to specify the distance for which drivers should be vigilant. These signs are probably only effective over relatively short stretches of road, as drivers tend to forget and become more nonchalant as distance from the sign increases. We recommend that temporary signs, especially when coupled with speed limit reductions, might be valuable in places where migration routes cross roads (short, specific duration of time and short stretches of road).

Wildlife warning reflectors

Wildlife warning reflectors are designed to provide a visual "warning" to deer as a vehicle's headlights approach and reflect off of the roadside reflectors. Most studies of wildlife warning reflectors have concluded that they have little to no effectiveness.[57] Wildlife warning reflectors have been installed north and south of Thermopolis and between Basin and Greybull. A recent evaluation of their effectiveness concluded that they are reducing DVC by as much as 33 percent.[58] Given the general scientific consensus that they are not effective, we recommend that wildlife warning reflectors be considered only in situations where there are no other suitable options and that if installed, their effectiveness should continue to be evaluated carefully, ideally using a robust before-after-control-impact study design.

Crosswalks

Wildlife crosswalks are designated "safe" places for wildlife to cross the road. They are usually marked (e.g. painted road surface) and accompanied by signage to warn drivers. They are most effective if positioned in specific locations where animals frequently cross the road. Their effectiveness is greater (40 percent reduction in WVC) if they are coupled with funnel fencing to guide animals to cross at the crosswalk.[27]

Animal detection systems

Animal detection systems include a variety of different methods for detecting large mammals as they approach a road.[59] Typically the animal detection system is coupled with signage that alerts drivers to the presence of wildlife near the road. They can be used without funnel fencing but are more effective when used with fencing. Animal detection systems can be anywhere from 33-97 percent effective for large mammals.[32] Animal detection systems are appealing because they are less costly than crossing structures, but they have a range of technical challenges including false positive and false negative signals and high maintenance needs. An animal detection system was tested in Nugget Canyon in 2000 and 2001, and found to be ineffective.[60] Animal detection system technologies have improved substantially over the last several decades and have recently been found to be highly effective. However, they should still be considered experimental. We do not specifically recommend animal detection systems for any of the focal hotspots, but we recommend that they be considered among the suite of future options, especially as technologies improve.

Crossing structures

Crossing structures — highway over-passes and under-passes coupled with funnel fencing — are the only WVC mitigation method that separates animals from the road. They are the only means to maintain wildlife habitat connectivity where the road creates a substantial barrier to animal movements (e.g. where traffic volume is too high for wildlife to easily cross roads). Crossing structures are also the most effective mitigation method currently available, with WVC reductions up to 97 percent.[27,30,61] In Wyoming, crossing structures coupled with fencing have reduced WVC by 81 percent and improved habitat connectivity at both Nugget Canyon and Pinedale.[34,55]

A note about fencing

Many of the mitigations listed here require or benefit from game fencing to funnel animals towards a suitable crossing location. This presents challenges in more developed areas where there are many gates, driveways, and other places where people need to access the road.

A recent review of the effectiveness of crossing structures[61] concluded that crossing structures are consistently highly effective (average 84 percent, range 50-97 percent effective, in most cases at least 80 percent effective) when coupled with funnel fencing more than 5 km (3.1 mi) in length. In contrast, crossing structures with shorter fencing were less effective and more variable in effectiveness (average 52.7 percent, range 0-94 percent). The authors concluded that this is because animals frequently cross at fence-ends when fences are less than 5 km (3.1 mi) long. The clear conclusion from this study is that, where possible, long stretches of fence should be installed to funnel animals towards crossing structures. However, the authors also found that deer used underpasses with no fencing or very short fencing much more than crossing at-grade. This indicates that, even with no or minimal fencing, underpasses can still substantially reduce WVC rates.

Finally, it is worth noting that short lengths of fence, boulders, and barriers can be used creatively to either (a) nudge animals towards safer crossing locations (e.g. a crosswalk) and (b) deter animals from crossing at less safe locations (e.g. at curves in roads).

SPECIFIC RECOMMENDATIONS

Caveats

First, these recommendations are based on best judgment using currently-available information. Ongoing studies will yield improvements in our understanding of important considerations such as the effectiveness of different mitigation methods and the traffic volumes at which roads create effective barriers.

Second, we recognize that crossing structures, coupled with fencing > 5 km (3.1 mi) in length, is the most effective mitigation method. Instead of recommending this for every hotspot, we discuss some possible alternatives that could be used until funds are available for crossing structures plus long fences, or in situations where this mitigation is not possible for other reasons.

Third, our recommendations here are based only on deer-vehicle collisions and deer migration and habitat-use patterns. Before any mitigations are undertaken, considerations of other species — including ungulates such as pronghorn, elk, and moose, as well as smaller fauna — should be examined and accounted for, both in prioritizing the locations of mitigations and in choosing suitable mitigations to meet the needs of multiple species.

Recommendations by hotspot

Baggs

Fencing and crossing structures (2 underpasses) were installed in this hotspot between MP 40 and MP 47.8. The fencing spans nearly the entire length of the DVC hotspot (figure 18) and should considerably reduce the number of DVC. Possible further mitigations:

- If not already present, some fence-end obstructions could be used to deter deer from crossing the road at the fence ends.

Baggs North

This hotspot is mostly associated with DVC during February-April, and DVC rates are moderate (figure 18). Traffic volume is also low (AADT ≈1,400). Possible mitigations:

- Seasonal signage coupled with nighttime winter speed limit reductions.
- Crosswalk, with seasonal signage. With or without fencing.
- Underpass with short or even no fencing.

Jackson

This hotspot is mostly associated with DVC in the winter months (December-March). Fencing and eight underpasses are currently being constructed for the southern portion of this hotspot (figure 19). The northern part of the hotspot occurs in an area with much urban development, making it difficult to fence. At the same time, traffic volume is very high in this area (AADT averaging 12,000 but as high as 30,000), making crossing structures warranted. Possible mitigations:

- Seasonal signage coupled with nighttime winter speed limit reductions.
- Crosswalks, with seasonal signage and short fencing.
- Underpasses with short or even no fencing.
- But note, traffic volume is high enough that at-grade mitigations may be ineffective.

Warren Bridge

This hotspot is associated with DVC during seasonal migrations (April-June and October-November) (figure 20) of the remarkably long and ecologically significant Red Desert-Hoback migration. Traffic volume is moderate to low in this area (AADT ≈1,800). Possible mitigations:

- Seasonal signage coupled with nighttime speed limit reductions.
- Crosswalk, with seasonal signage and short fencing.
- Underpass with short fencing.

Pinedale

Fencing and crossing structures (6 underpasses and 2 overpasses) were installed in this hotspot between MP 103 and MP 115, with construction completed in 2012. These crossing structures are already proving highly effective. However, they do not cover the entire span of the hotspot;

there are more than 100 DVCs occurring outside of the fenced area, including several miles with very high DVC rates (figure 15). Collisions in this hotspot occur during both migration times and winter (figure 20), making seasonal signage less relevant. Traffic volume is moderate in this area (AADT ≈4,600). Possible mitigations:

- Nighttime speed limit reductions.
- Crosswalks, with signage and short fencing.
- Underpasses with short fencing.

Other notes about this area:

- The fence at MP 115.3 of ML 13 (US 191/189 north of Daniel Junction) ends right at a major migration corridor. If not present, some fence-end obstructions could be used to deter deer from crossing the road at the fence ends. If DVC continue to occur at this location or GPS collar data show that deer continue to cross at this location, a fence extension should be considered.
- MP 126-130 of ML 11 (US 189 south of Daniel Junction) is a major migration corridor and has moderate DVC rates. Seasonal signage and /or a crosswalk with short fencing may help improve connectivity and reduce DVC in this area.

La Barge

WYDOT has an existing plan to install fencing and 10 underpasses in this hotspot between MP 86 and MP 101.5 (ML 11), pending funding. Collisions in this hotspot occur during both migration times and winter (figure 21), and the road at this hotspot bisects the winter range of an ecologically and economically important deer herd in Wyoming (Wyoming Range herd). Rates of DVC are moderate and high. Traffic volume is low-moderate (AADT ≈2,100). Possible mitigations:

- Implement the existing plan for crossing structures, but extend the fence several miles on either end to increase effectiveness.
- Nighttime speed limit reductions and/or crosswalks and short fencing if the crossing structures cannot be funded.

Kemmerer Area

Fencing and crossing structures (6 underpasses and 2 overpasses) were installed in the Nugget Canyon section of this hotspot between MP 33 and MP 41.5 (ML 12), with construction completed in 2008. These crossing structures have been highly effective. However, they do not cover the entire span of the hotspot; there are more than 100 DVC occurring outside of the fenced area to the east of Nugget Canyon and another ~20 per year occurring to the north of Kemmerer (figure 15). Collisions in this hotspot occur year-round (figure 22), making seasonal signage inappropriate. Possible mitigations:

- Nighttime speed limit reductions.
- Crosswalks, with signage and short fencing.
- Underpasses with fencing.

Smoot

Collisions at this hotspot occur primarily in summer and fall (May-October). Rates of DVC are moderate, and traffic volume is relatively low (AADT ≈1,500). Possible mitigations:

- Seasonal signage.
- Nighttime speed limit reductions.
- Crosswalks, with seasonal signage and short fencing.

Cokeville

The Cokeville hotspot is extremely short but contains one of the miles with the highest rates in the whole state of Wyoming figure 23). Collisions (occur almost entirely during the fall migration (October-December), with some occurring during the spring migration (April-June). Traffic volume is low-moderate ((AADT ≈2,200). Possible mitigations:

- Seasonal signage coupled with nighttime speed limit reductions.
- Crosswalk, with seasonal signage and short fencing.
- Underpass with fencing.

Evanston North

The hotspot north of Evanston on WY 89 includes four miles in a row of very high DVC rates, making this one of the "hottest" hotspots in the state (figure 24). Collisions in this area peak during migration times (March-April and October-November), making seasonal signage a possibility. However, the high numbers of DVC (~100 per year) make this a good candidate for more aggressive mitigations, such as crossing structures. Traffic volume is high-moderate (AADT ≈5,000). Possible mitigations:

- Seasonal signage coupled with nighttime speed limit reductions.
- Crosswalks, with seasonal signage and short fencing.
- Underpasses, ideally with long fencing.

Evanston West

This short (3 mi, 4.8 km) hotspot along I-80 includes both high and very high DVC rates (figure 24). Collisions occur year-round. The hotspot is largely within the city of Evanston. It is likely that these are resident deer. Given the high traffic volume (AADT ≈8,000) and high speed limit on I-80, the only mitigation likely to be effective is fencing with a crossing structure.

189 South and Leroy Interchange

The stretch of US 189 just north of the junction with I-80 and the several miles east of this junction along I-80 are both areas with mostly moderate DVC rates and a few miles of high DVC rates (figure 25). Traffic volume is low on 189 South (AADT ≈1,800) and high on I-80 (AADT ≈6,000). Collisions peak during migration times and winter. It is possible that a migration route and core winter-use area straddle this section of road. In a 2009 TIGER (Transportation Investment Generating Economic Recovery) grant application, WYDOT sought, but did not receive, funds to erect fencing and a total of 13 crossing structures along these two stretches of road (ML 11: MP0-26, and ML 80: MP 18.3-28.7). Based only on deer-vehicle collision patterns, these hotspots do not rank among the top priorities for high-cost mitigations in the state. It is possible that considering pronghorn habitat connectivity and collision patterns would make this area a higher priority for mitigations. Based on deer only, possible mitigations include:

- Seasonal signage and/or crosswalks, with nighttime speed limit reductions, along US 189.
- Crossing structures and fencing, along I-80.

Dubois

The Dubois hotspot includes a mix of moderate and high DVC rates (figure 26) and moderate traffic volume (AADT ≈2,500). Collisions occur primarily in fall and winter. Mule deer are known to migrate into and over-winter in this area. Since numerous collisions occur from October to May, seasonal signage is not appropriate in this area. Possible mitigations:

- Nighttime speed limit reductions, especially in fall and winter.
- Crosswalks, with signage and short fencing.
- Underpasses and fencing.

Meeteetse

The Meeteetse hotspot is relatively short and includes only moderate DVC rates (figure 27). Collisions occur year-round, but there is a distinct peak in the fall. It is likely that these are resident deer. However, given that this is not one of the highest DVC hotspots in the state and that traffic volumes are low-moderate (AADT ≈2,000) along WY 120, mitigations could aim to target the fall peak in DVC. Possible mitigations:

- Seasonal signage in the fall.
- Nighttime speed limit reductions, year-round.
- Crosswalks, with signage and short fencing.

Cody

Collision rates between Cody and Powell along US 14 are mostly high and very high (figure 28). Traffic volume is also high (AADT ≈7,100). Collisions occur year-round, with a peak in the fall. It is likely that these are resident deer that are attracted to the agricultural land in this area. Given the prevalence of agricultural land, long stretches of fencing may not be feasible in this area. Seasonal signage is also not suitable here. Possible mitigations:

- Nighttime speed limit reductions, year-round.
- Crosswalks, with signage and short fencing.
- Underpasses, with short fencing
- But note, traffic volume is high enough that at-grade mitigations may be ineffective.

Byron

The Byron hotspot is relatively short and includes only moderate and one mile of high DVC rates (figure 28). Traffic volume is moderate (AADT ≈2,400). Some collisions occur during winter but most occur in the fall. Possible mitigations:

- Seasonal signage in the fall.

- Nighttime speed limit reductions, particularly in the fall.
- Crosswalks, with signage and short fencing.

Basin, Worland, and Thermopolis

These three hotspots are very similar. All occur along WY 20 and involve year-round collisions with peaks in the fall (figures 29-30) and appear to involve resident deer. Traffic volumes are moderate (Basin: AADT ≈4,800; Worland: AADT ≈3,800; Thermopolis: AADT ≈2,800). The Thermopolis hotspot includes six miles with very high collision rates, including the mile with the single highest collision rates in the state. Together, this makes the Thermopolis hotspot the most significant hotspot in Wyoming. The Basin and Worland hotspots include a mixture of moderate and high DVC rates. All of these hotspots occur along agricultural land, making long stretches of fence difficult to install. Wildlife warning reflectors have been installed in the Basin and Thermopolis hotspots, and the effectiveness of these should continue to be monitored. Additional possible mitigations include:

- Nighttime speed limit reductions, year-round.
- Crosswalks, with signage and short fencing.
- Underpasses with short fencing.

Riverton-Shoshoni, Lander-Riverton, Lander South

These three hotspots are all similar to each other. They are also similar to the Basin, Worland, and Thermopolis hotspots in that they involve year-round collisions with peaks in the fall and are located along agricultural land (figures 31-32). Collision rates are mostly moderate. Traffic volumes are moderate to high (Riverton-Shoshoni: AADT ≈8,100; Lander-Riverton: AADT ≈6,800; Lander South: AADT ≈2,300). Possible mitigations include:

- Nighttime speed limit reductions, year-round.
- Crosswalks, with signage and short fencing.
- However, these at-grade mitigations may not be effective between Lander and Shoshoni, given the high traffic volumes.

Glendo Reservoir

High collisions rates at this hotspot occur from May-December (figure 33), so seasonal signage is probably not suitable. Traffic volumes are moderate (AADT ≈3,300). Possible mitigations:

- Nighttime speed limit reductions, especially in summer and fall.
- Crosswalks, with signage and short fencing.

Buffalo and Sheridan

High collisions rates at these hotspots occur from May-December (figure 34), so seasonal signage is probably not suitable. Traffic volumes are moderate (Buffalo: AADT ≈3,100; Sheridan: AADT ≈4,300) Possible mitigations:

- Nighttime speed limit reductions, especially in summer and fall.
- Crosswalks, with signage and short fencing.

APPENDIX 1: TECHNOLOGY TRANSFER AND OUTREACH

- Daryl Lutz, the chair of WGFD's Mule Deer Working Group, has planned to focus the next Working Group meeting (November 2016) on the topic of deer-vehicle collisions. This will be a chance to engage with experts on mule deer from across the state. Thereafter, we plan to host a larger symposium on the topic of deer-vehicle collisions with invited participants from WYDOT, WGFD, and groups with an interest in funding mitigations.
- Presented preliminary findings at the annual conference of the Wyoming Chapter of The Wildlife Society, Lander, December 2015.
- Presented findings to staff members of The Nature Conservancy, the Wyoming Wildlife Federation, and the Wyoming Game and Fish Department, Lander, April 2016.
- Presented findings to a wide audience at the AMK Ranch Harlow Seminar Series in Grand Teton National Park, June 2016.
- Prepared metadata and shared database of wildlife-vehicle collisions with the Wyoming Geographic Information Science Center (WyGISC) for inclusion in the Wyoming Migration Initiative's online tool, Migration Viewer (http://www.migrationinitiative.org/).
- Mule deer winter range maps and GIS shapefiles (derived from GPS collar data) will soon be shared with partners at WGFD and the Bureau of Land Management.
- Project final report will be shared with all District Engineers in WYDOT.
- Prepared a pamphlet that could be used to educate drivers about wildlife-vehicle collisions in Wyoming.
- Preparing a manuscript based on these findings for submission to the *Wildlife Society Bulletin*.
- Anticipate presenting findings at conferences in the next year: Greater Yellowstone Science Conference (October 2016) and the International Conference on Ecology and Transportation (May 2017).
- Building upon these results in two additional funded projects:
    - Analysis of deer-vehicle collisions in relation to Golden Eagle habitat use in Wyoming, to understand where eagles are most likely to get hit by vehicles as they feed on deer carcasses (funded by the National Fish and Wildlife Foundation).
    - Analysis of traffic volume and gap thresholds in relation to mule deer road-crossing behavior, to further our understanding of where at-grade versus separated deer crossings are most suitable in Wyoming (funded by WYDOT).

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