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Federal Highway Administration

Mule Deer (*Odocoileus hemionus)* Movement and Habitat Use Patterns in Relation to Roadways in Northwest Wyoming

By:

Conservation Research Center
Teton Science Schools
700 Coyote Canyon Road
Jackson, WY 83001

October 2013

FORWARD AND DISCLAIMER

The purpose of this study was to provide the Wyoming Department of Transportation and Wyoming Game and Fish Department with useful information about the patterns of mule deer seasonal habitat use, migration, road crossings, and wildlife-vehicle collisions in the Jackson Hole area. We captured 40 mule deer and fitted them with global positioning system (GPS) collars that collected locations every two hours for up to two years. We identified areas of high seasonal use by mule deer as well as migration routes between these seasonal ranges.

Results show that mule deer use the developed valley of Jackson Hole intensively in the winter months and during migrations. An analysis on winter habitat use indicates that deer most intensively use areas close to supplemental feed sites, hillslopes, and areas with high cover of herbaceous vegetation, golf courses, mixed trees, junipers, and riparian vegetation. Road crossings almost always occurred during winter and were concentrated in a few locations. Road crossings were negatively associated with roadside fencing and positively associated with proximity to preferred winter habitat. Collisions primarily occurred in winter and were concentrated on US-89/191, particularly on the highest traffic volume stretches near the town of Jackson. These results suggest that any measures designed to reduce the frequency of deer-vehicle collisions will have to allow deer to cross major roadways frequently as they move around their winter home ranges. Crossing structures, which are effective for allowing migrating ungulates to cross roadways, may not be effective for facilitating the frequent crossings of non-migrating animals in a highly developed landscape.

Audiences that may be interested in this report include State Departments of Transportation (DOTs), Game and Fish Agencies, along with other wildlife and safety stakeholders.

There have been no previous printings of this publication.

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Abstract
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METRIC CONVERSION CHART

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

AIC—Akaike's information criterion

BBMM—Brownian bridge movement model

BTNF—Bridger-Teton National Forest

CI—confidence interval

DEM—digital elevation model

DF—degrees of freedom

DVC—deer vehicle collision

ESRI—Environmental Systems Research Institute

FHWA—Federal Highway Administration

GIS—geographic information system

GMT—Greenwich Mean Time

GPS—global positioning system

KD—kernel density

MCP—minimum convex polygon

MST—Mountain Standard Time

NSD—net squared displacement

PDOP—position dilution of precision

RSF—resource selection function

RSPF—resource selection probability function

SD—standard deviation

SE—standard error

UD—utilization distribution

USFS—United States Forest Service

VHF—very high frequency

WGFD—Wyoming Game and Fish Department

WVC—wildlife vehicle collision

WYDOT—Wyoming Department of Transportation

CHAPTER 1. INTRODUCTION

Collisions between vehicles and large wild mammals (hereafter, "wildlife-vehicle collisions," WVCs) pose a serious threat both to human safety and to wildlife populations. Wildlife-vehicle collisions involving large ungulates, such as deer (*Odocoileus* spp.), moose (*Alces alces*), or elk (*Cervus elaphus*), are usually fatal to the animal and often result in significant damage to the vehicle and injury to its occupants. An estimated 1-2 million wildlife-vehicle collisions occur annually in the United States, and this number continues to climb as road networks expand and traffic volumes increase.(1)

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.(1) Both of these priorities necessitate an understanding of how wildlife use the landscape in relation to roadways, where and when they are most likely to cross roads, and where and when collisions with vehicles are most likely to occur.

Across the United States, WVCs represent five percent of all reported collisions and incur direct annual costs estimated at 3.39 billion dollars.(1) In Wyoming, 2,487 WVCs were reported in 2012, accounting for 18 percent of all reported collisions.(2) Similar to national patterns, the overwhelming majority of collisions in Wyoming (83 percent) involved deer. These numbers, however, greatly underestimate total annual WVCs, since only collisions incurring more than 1,000 dollars in property damages or bodily injury are reported. Based on our compilation of collision and roadside carcass data (see appendix A for methods used), we estimate that 6,570 wildlife-vehicle collisions took place in Wyoming in 2012—more than double the number estimated from collision reports alone.

Across Wyoming, some of the highest rates of deer-vehicle collisions per mile of road occur in the southern half of Teton County (figure 1), around the Jackson Hole valley. Teton County is situated within the Greater Yellowstone Ecosystem and is home to abundant populations of resident and migratory wildlife. Both the human population and traffic volume in Jackson Hole are growing rapidly; permanent residents grew by 16.7 percent between 2000 and 2010,(3) and the population triples in the summer months as seasonal visitors and workers come to the valley. During this time, traffic volumes have also risen substantially. For example, the stretch of Broadway (US-89/191) between the WY-22 intersection and Jackson town square increased from 45,600 average daily vehicle trips in 2000 to 85,853 in 2010.(4) Other counties in Wyoming, such as Sublette and Lincoln counties, are experiencing similarly rapid growth in human populations and traffic volumes. Growing traffic volumes, coupled with high wildlife densities, presents a threat to human safety and wildlife populations alike.

In 2010, we initiated a study on the movement ecology of mule deer (*Odocoileus hemionus*) in relation to major roadways in Jackson Hole. We tracked the movements, mortality, and behavior of 40 deer between December 2010 and December 2012 using a combination of GPS collars, VHF telemetry, and direct observations. The objectives of this study were as follows:

1. Identify areas of high seasonal (winter and summer) use by mule deer.
2. Identify short-distance migration corridors between seasonal ranges.
3. Identify spatial and temporal patterns of mule deer road crossings.
4. Identify road and roadside variables associated with high likelihood of crossing.
5. Examine mule deer behavior in relation to roadways.
6. Develop a comprehensive public education program based on our research.

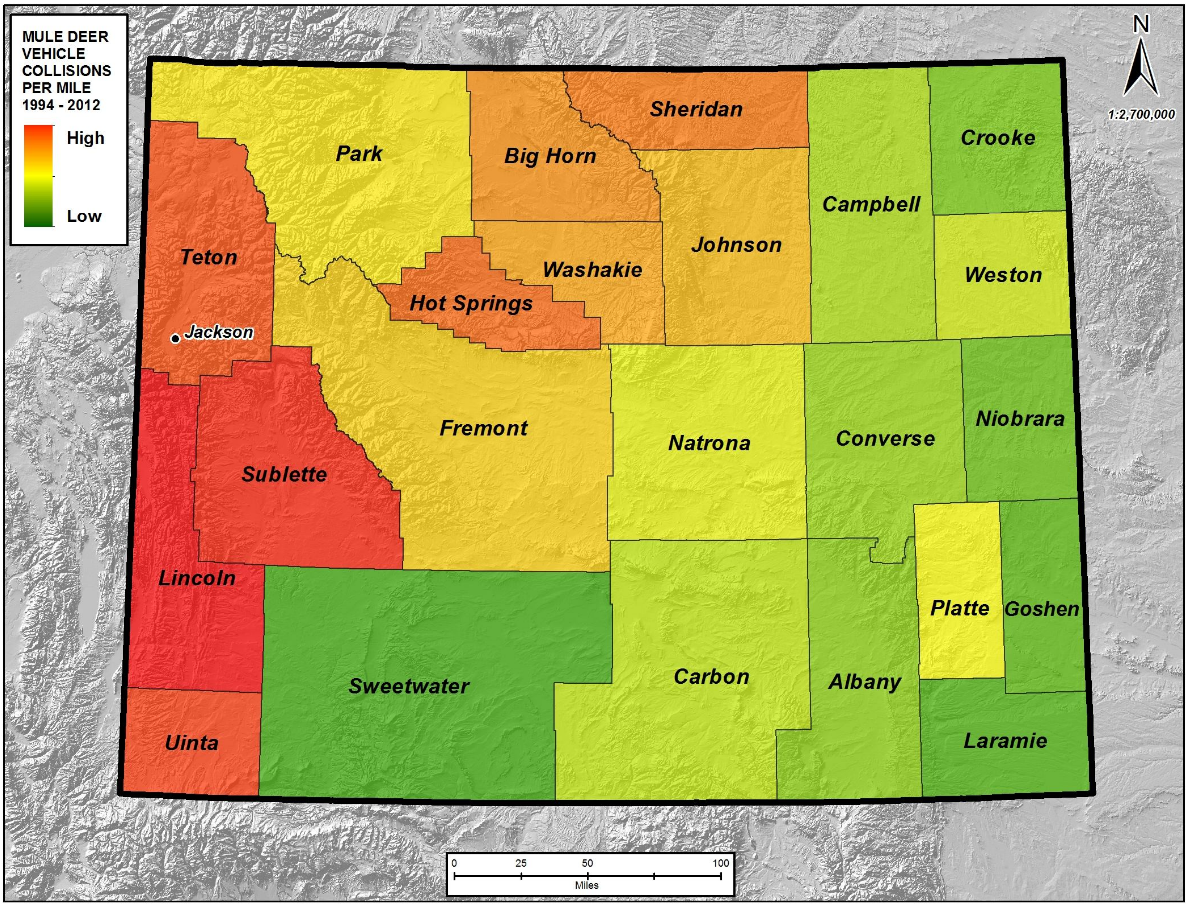


Figure 1. Mule deer-vehicle collisions per mile of roadway in Wyoming, by county (1994-2012). Source data were compiled from WYDOT's collision and carcass data (see appendix A).

CHAPTER 2. BACKGROUND & RATIONALE

Wildlife-vehicle collisions are costly both economically and in terms of the well-being of human and wildlife populations. When all property damage and bodily injury costs are accounted for, deer-vehicle collisions are estimated to cost 6,600 dollars per collision.(5) Costs are higher for larger animals (e.g. elk and moose). While human injuries from a direct wildlife collision are rarely fatal, they can be moderate to severe, depending upon the speed at which the car was traveling and the species of animal involved.(6) Human injuries from indirect collisions—in which a driver swerves to avoid hitting a wild animal and instead collides with another vehicle or drives off the roadway—can range from mild to fatal.(6) While most WVCs do not result in significant bodily harm or property damage, the fraction that does is likely to rise as traffic volumes increase in the coming decades.

The consequences of WVCs for wildlife are also significant, accounting for an estimated 9.2 percent of annual large mammal mortality in the United States.(7) More broadly, roads and road networks can also have negative effects on wildlife populations by disrupting their movement and migration patterns and by reducing the quantity and quality of habitat available to them. Over the last several decades, a variety of mitigation measures have been employed in an effort to reduce WVCs and other negative effects of roads on wildlife. Common mitigation measures include targeted signage, speed limit reductions, reflectors and other wildlife deterrents, animal detection systems, fences, and wildlife crossing structures (underpasses and overpasses).(5,8) However, the suitability and efficacy of these measures depend in large part on understanding where and when animals cross roads.

Wildlife crossings can broadly be categorized into two groups: those associated with habitat use within animals' seasonal home ranges, and those associated with migrations between seasonal home ranges. In montane temperate environments, ungulates such as mule deer typically move between high-elevation summer ranges where forage quality is high and low-elevation winter ranges where forage quality is low but availability is greater through the winter.(9-12) Although low-elevation areas provide a respite from deep winter snows, they are typically more altered by human activity—with agricultural land, urban development, road networks, and fences all more prevalent than in high-elevation areas.

Understanding the difference between road crossings associated with migration versus seasonal home range use is important in considering WVC mitigation options. Ungulate migration routes often follow paths that have been used by the same species for decades, if not centuries.(10,13) Migration routes may include stopover sites as well as pathways of more rapid movement.(14-15) The latter are often linear pathways connecting stopover sites or seasonal home ranges. Migration routes are typically used twice per year, once during the spring (May-June) and once during the fall (October-November). However, the timing of migration can be variable, depending on climatic factors (e.g. spring thaw or first winter snow). Although the timing cannot be predicted with great accuracy, the routes used can (once identified) be predicted into the future, since animals exhibit a high degree of fidelity to established routes. Thus migration mitigation measures should aim to facilitate infrequent and episodic road crossings by many individuals of the target species.

Wildlife road crossings that occur within animals' home ranges are more difficult to predict in space. Animals may cross roads to access forage, cover, water, mates, or other limited resources. Road crossing hotspots may be associated with certain habitat types, particularly when favorable habitat spans both sides of the roadway.[16-17] Crossing hotspots may also occur because landscape features (e.g. topography) or human infrastructure (e.g. roadside fences, buildings) constrain where animals can cross.[17-19] Additionally, crossing hotspots may occur where there is a desirable resource (e.g. high quality forage or salt) close to a roadway.[20-21] Spatial patterns of crossing intensity can further vary depending on season. During the rutting season, in particular, wildlife crossings may be frequent and erratic. Predicting crossing hotspots within animals' seasonal home ranges thus requires a much more functional understanding of animal movement patterns than is needed to predict migration crossing spots. Mitigation measures should aim to facilitate frequent and spatially diffuse crossings.

The State of Wyoming is home to a particularly high abundance and diversity of large wild mammals. This includes some of the longest and best-known ungulate migrations in the Lower 48—for example, the pronghorn (*Antilocapra americana*) migration from Grand Teton National Park to the Little Colorado Desert. Because of this high density of wide-ranging ungulates, WVCs are a major concern for highway safety and wildlife management in Wyoming. Between 2005 and 2010, reported WVCs increased by more than 17 percent—with 11 human fatalities, more than 500 human injuries, and more than 10,000 vehicles damaged.[22] This does not include the thousands of WVCs that result in damages of less than 1,000 dollars—most of which are still fatal to the animal.

Over the last two decades, the Wyoming Department of Transportation (WYDOT) has been at the forefront of efforts to reduce WVCs through a variety of mitigation efforts. Two areas of particular effort are the Nugget Canyon area—a 12 mi (19 km) stretch of US-30 west of Kemmerer—and the Trappers Point area—a 12 mi (19 km) stretch of US-191 west of Pinedale. In both of these areas, extensive wildlife fencing has been erected to funnel thousands of migrating mule deer and pronghorn into a series of under- and overpasses where they can cross the highway safely. Post-installation analysis of the Nugget Canyon project has shown that WVCs have been reduced by 81 percent,[23] and preliminary analyses of the Trappers Point project show similar success.[24] In other parts of the state, mitigation efforts currently being used include wildlife reflectors, signage, and reduced nighttime speed limits.

The Jackson Hole area of Teton County contains one of the highest rates of deer-vehicle collisions per mile of road in the State (figure 1). Due to rising traffic volumes in the area, WYDOT is considering several road improvements. These include: widening a 7 mi (11 km) stretch of US-89/191 south of the town of Jackson from a two- to five-lane highway; adding several wildlife underpasses along this stretch of US-89/191; widening a 7 mi (11 km) stretch of WY-22 west of the town of Jackson, and modifying a 7 mi (11 km) stretch of WY-390 north of Wilson to include one-direction frontage roads and/or create a divided highway. Because of the high densities of wildlife—particularly mule deer, elk, and moose—in this area, a thorough understanding of where, when, and why animals are most likely to cross roads is necessary to evaluate the potential effects that any future road modifications may have on wildlife. Further, a comprehensive understanding of wildlife movements and road crossing patterns is necessary to inform future projects that are aimed directly at mitigating WVCs and maintaining habitat connectivity for wildlife.

This study was initiated in order to gain an understanding of how mule deer—the species of wildlife most commonly involved in WVCs—use the landscape and roadways in and around Jackson Hole. In doing so, this study supports WYDOT's Overall Strategic Plan and Balanced Scorecard goals of (1) keeping people safe on the state transportation system, and (2) exercising good stewardship of our resources.

CHAPTER 3. METHODS

STUDY AREA

This study centers on the major roadways around the town of Jackson, WY, extending north from Jackson to Gros Ventre Junction, south to Hoback Junction, and West to the town of Wilson. The study area includes a mixture of private land and public land (primarily the Bridger-Teton National Forest and Grand Teton National Park). The major roadways within the study area are US-89/191/26, WY-22, WY-390, Spring Gulch Road, and the northern portion of South Park Loop Road (figure 2).

The study area includes the relatively flat valley floor in the floodplain of the Snake River, several buttes around the town of Jackson, and the higher elevation Bridger-Teton National Forest and Grand Teton National Park surrounding the valley. The valley floor is a mixture of urban, ex-urban, and agricultural land used primarily for livestock grazing and hay production. The lower elevation south-facing hillslopes are typified by stands of Rocky Mountain juniper (*Juniperus scopulorum*) or mixed mountain shrub communities of big sagebrush (*Artemesia tridentata*), antelope bitterbrush (*Purshia tridentata*), Saskatoon serviceberry (*Amelanchier alnifolia*), common snowberry (*Symphoricarpos albus*), chokecherry (*Prunus virginiana*) and various grasses and forbs. North-facing slopes are typified by a mixture of Douglas fir (*Psuedotsugia menziesii*) and quaking aspen (*Populus tremuloides*). Higher elevation areas transition to stands of lodgepole pine (*Pinus contorta*), limber pine (*Pinus flexilis*), subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*) interspersed with aspen, subalpine meadows and tall forblands. Riparian areas in this area are dominated by willows (*Salix* spp.), russet buffaloberry (*Sheperdia canadensis*), silverberry (*Eleagnus commutata),* blue spruce (*Picea pungens*) and narrowleaf cottonwood (*Populus angustifolia*).

Precipitation in this area averages 40.4 cm (15.9 inches) annually, falling primarily as snow between November and April. Temperatures vary considerably throughout the year, with an average January temperature of -9 C° (16 F°) and average July temperature of 16 C° (61 F°). Winter is severe in Jackson Hole, with five consecutive months (November to March) having average temperatures below freezing and average snow depth 22-30 cm (9-12 inches) on the valley floor. Snow cover melts from the valley floor in April and May and from higher elevations as late as July.

MULE DEER CAPTURE AND MORTALITY SURVEYS

Deer were captured in the winters of 2010-11 and 2011-12 using a combination of clover traps, free-darting, and net-gunning from a helicopter. Capture areas were selected based on a combination of topography, vegetation, "crucial winter range" designation, access, distance to roadway improvement projects and proximity to wildlife-vehicle collision hotspots. We distributed our sampling efforts throughout the study area and collared animals in proportion to their relative abundances across the study area; areas with higher recorded numbers of deer[25-26] had a greater number of collared animals relative to areas with lower recorded abundances.

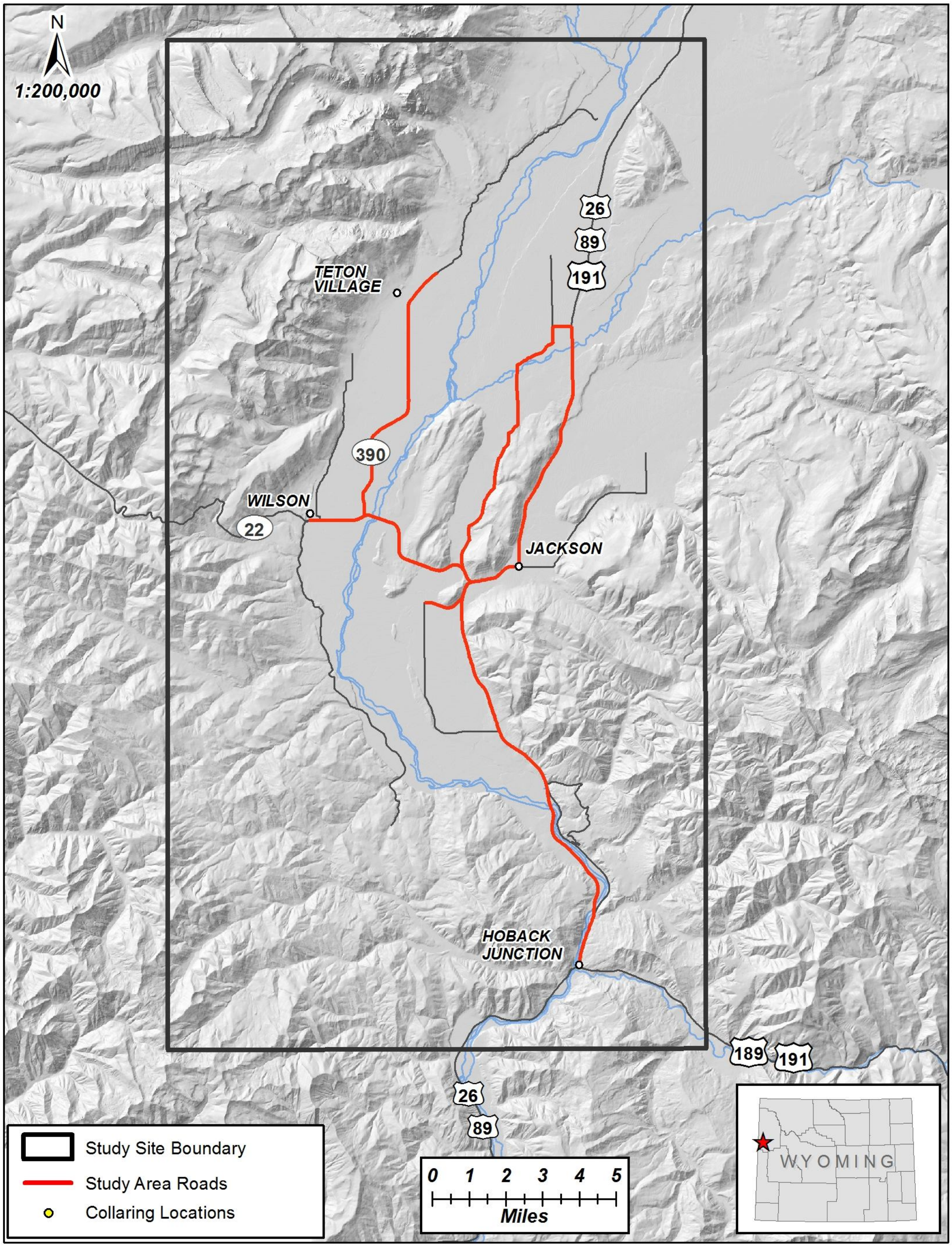


Figure 2. Study area of Jackson Hole Valley with deer collaring locations shown.

Clover-trapped and ground-darted animals were baited with apple pulp and alfalfa. Captured deer were physically restrained, blindfolded and immobilized with an intramuscular injection of ketamine (7mg/kg) and xylazine (0.7 mg/kg).[27-28] Once an animal was processed, we antagonized the ketamine/xylazine with 0.125mg/kg yohimbine[27] and monitored the recovery process. Net-gunned animals were hobbled and blindfolded to minimize stress, but were not chemically immobilized. Helicopter chase times were kept under five minutes to reduce capture-related mortality and post-capture myopathy. Animals were released immediately following processing. All animal handling was conducted in accordance with guidelines from project veterinarians, the Wyoming Game and Fish Department (WGFD) (Chapter 33 permit number 763), and the American Veterinary Medical Association.

A total of 40 does (26 in 2010-11, 14 in 2011-12) were fitted with Telonics T-4500 store-on-board Global Positioning System (GPS) collars (Telonics, Inc., Mesa, AZ). Collars were additionally equipped with activity sensors, mortality sensors and very high frequency (VHF) radio transmitters. Collars deployed in 2010-2011 were programmed to record GPS locations every two hours between September 30th and June 30th of each year, and every 24 hours between June 30th and September 30th of each year. Collars deployed during winter 2011-2012 recorded a GPS location every 1.5 hours between December 1st and June 30th, three locations each day between July 1st and September 30th, and one location every hour between October 1st and December 10th. All collars dropped off automatically in December 2012, except in cases where the deer died before this time (see below), or in the case of one collar that malfunctioned and dropped off early and two collars that did not release properly and were retrieved by chemical immobilization of the collared deer in early 2013.

We attempted to locate all individuals at least once each week using VHF receivers to confirm the animal's location and survival. In cases where the mortality sensor was activated, the carcass was located and removed. When possible, technicians conducted a necropsy on the carcass either in the field or in the lab. If the carcass was too decomposed to yield viable samples, technicians conducted a coarse-level assessment to evaluate animal condition at the time of death. In particular, bone marrow composition and evidence of trauma were noted. Cause of death was determined where possible.

Over the course of two years, more than 164,000 collar locations were recorded. Upon recovery, each collar's data were downloaded and converted to an ESRI ArcGIS 9.3 file geo-database feature class. GPS fix times were converted from GMT to MST, accounting for daylight savings when appropriate. Pre-deployment and post-mortem points were manually removed. Points with low GPS precision were also removed (two-dimensional fixes with horizontal error greater than 100 m (328 ft) and position dilution of precision (PDOP) greater than 4 as well as all points with PDOP greater than 15).

BEHAVIORAL OBSERVATIONS

We conducted direct observations of deer behavior in order to determine whether their behavior varied with distance from roadways. Behavioral observations were conducted from January to April of 2011 and 2012, when deer were on their winter range and most likely to be near roadways. Wherever each collared deer and its associated group was located we conducted a five-minute focal observation of the collared deer and at least one other individual in the group. Within this five-minute focal period, we recorded the total number of seconds for which the deer was engaged in each of six behaviors: foraging, vigilant, standing, moving, bedded, and bedded-vigilant. The age (fawn versus adult) and sex (for adults) of the deer, time of day, distance to the nearest road, habitat type, and distance to cover were also recorded. A total of 948 deer observations were recorded.

For each focal observation, we calculated the percent of time the deer spent foraging, vigilant, standing, moving, bedded, and bedded-vigilant. Data were arcsine-square root transformed to more closely meet analysis of variance assumptions of normality. Deer observations were categorized into three distances from roadways: less than 100 m (328 ft), 100-200 m (328-656 ft), and greater than 200 m (656 ft). Roads were also classified by traffic volume into three categories: low, medium, and high. High traffic volume roads include major highways (e.g. US-89/191; WY-22; WY-390), medium traffic roads include major thoroughfares (e.g. Spring Gulch Road, Fall Creek Road), and low traffic volume roads include residential and Forest Service roads.

We analyzed each behavior using analysis of variance, considering sex/age class, road distance class, traffic volume class, and interactions among these as explanatory variables. Habitat type was not considered as all deer were observed in open shrub vegetation on south-facing hillslopes. Distance to cover was not a significant predictor of behavior and was dropped from all models. Post-hoc comparisons were made using Tukey's test. All analyses were conducted in R.[29]

SHORT-DISTANCE SEASONAL MIGRATIONS

We examined the spatial and temporal movement patterns of each deer and categorized each deer as a migrant or non-migrant using a combination of visual inspection of the data and calculations of the net squared displacement (NSD) for each animal. Net squared displacement measures the straight line distances between the starting location and each subsequent location for a particular movement path [30] and is an effective tool for differentiating between migratory and non-migratory individuals.[31] Non-migrant deer showed no seasonal spatial segregation in their home ranges and moved frequently between core areas of their home ranges throughout the year. Conversely, migrant deer showed clear spatial segregation of winter and summer ranges, and these ranges were connected by clear migration corridors.

Collar locations for all migratory deer were categorized into winter and summer ranges for each year of the study or fall / spring migration routes using both visual inspection of the data and NSD calculations. Migration points were defined as consecutive GPS locations that occurred between the winter and summer ranges during a specific migration season and year (spring or fall). The start (and end) of migration was defined as the locations that occurred outside (or inside) a minimum convex polygon created by the points classified as summer and winter ranges.[32] If the collared deer made more than one foray into the migration route, only the final movement path that resulted in a seasonal shift in habitat was delineated as the seasonal migration. We calculated the time, distance traveled, and number of GPS locations for each documented migration path.

We used Brownian bridge movement modeling (BMMM) [14,33] to analyze the spatial patterns of short-distance migrations made by migratory deer. Brownian bridge movement modeling generates a utilization distribution (UD), or probabilistic surface of animal use, based on the distance and elapsed time between successive GPS locations as well as the location error of each fix and the estimated "Brownian motion variance," which represents the individual animal's mobility.[14,33] Brownian bridge movement modeling has recently gained wide acceptance as the preferred method for delineating migration routes and important stopover sites among migratory animals.

We first employed BBMM to generate a UD for each migration path (e.g. spring 2011, fall 2011, spring 2012, or fall 2012) taken by each migratory deer. The GPS locations used in this analysis included the migration points delineated for each migration and a buffer of all GPS locations recorded in the 24-hour period prior to, and following the migration.[14] In order to represent all documented migrations simultaneously, we created a population level UD grid using a two-step process.[14] We first combined the individual migration UDs from each animal. For animals with more than one documented migration, we summed the cell values of their UDs and then scaled the resulting grid to sum to one, such that each animal was weighted similarly in the population level UD. Each resulting UD from each collared animal was then summed and the result re-scaled to sum to one to produce the final population level migration UD. The BBMM package [34] for the R language and environment for statistical computing [29] was used for BBMM estimation.

SEASONAL HABITAT USE

Patterns of Winter and Summer Habitat Use

In order to facilitate visualization of mule deer habitat use, we generated separate population-level utilization distributions for winter and summer. We did this using a three-step process similar to the process for generating population-level migration UDs (outlined above). First, within each season, we calculated kernel density UDs for each individual deer. The kernel densities were created using the h_{href} smoother and a 30 m (98 ft) grid cell size in the adehabitatHR package [35] in R.[29] We then combined the UDs across years (e.g. combining winter 2011 and winter 2012) for individuals for which there was multi-year data. We did this by re-scaling the cumulative cell values of each individual's within-season kernel density UD to sum to 1 and adding the grid cell values together across years. Finally, we added the grid cell values for all individuals together and again re-scaled the cell values to sum to one.[14] This approach weights each individual's contribution equally, regardless of the number of collar locations recorded (which could differ due to different fix rates, different timing of migration, mortality part way through the season, etc.). Thus, using this approach, we were able to generate and map population-level UDs for winter and summer.

Analysis of Winter Habitat Use

In order to examine landscape features and habitat variables that were associated with mule deer winter habitat use, we used a resource selection probability function (RSPF) approach.[36-37] While the traditional resource selection function (RSF) constrains analyses to a bivariate response variable ("used" versus "available points"), the RSPF approach has the advantage of generating a continuous response variable (intensity of use), facilitating a more finely-tuned functional analysis of the predictor variables associated with the response.[37] The RSPF approach also has an advantage over the traditional RSF approach in that there is no bias due to serially correlated location points.[37]

To implement the RSPF analysis, we systematically sampled deer winter ranges using a lattice of non-overlapping, adjacent circles each with a radius of 100 m (328 ft).[37] Circles were constrained to fall within deer winter home ranges (appendix C) and totaled 3,302 in number. We recorded the number of deer GPS locations contained within each circle as a measure of intensity of use. For each circle we also extracted the following set of potential predictor variables: mean slope; mean aspect; distance to the nearest major road; distance to the nearest supplemental feed site; and percent cover for each of 11 main land cover categories (herbaceous, shrubland, irrigated agriculture, juniper, coniferous, aspen, riparian, mixed trees (ornamentals and mixed aspen-confer), golf course/lawn, and developed).

Supplemental feed sites were located opportunistically during the winters of 2010-2011 and 2011-2012. We located these sites during our weekly behavioral observations. When a feed site was found, we recorded the UTM coordinates, date, food type and the collar identification for each marked individual on the site. We classified food type into four categories: livestock feed (usually hay), pelleted deer feed, bird feed (usually from a bird feeder) and unknown. We did not attempt to determine whether food was provided to deer intentionally or unintentionally. All feed sites were located on private land where supplemental food was provided by private citizens. Due to the opportunistic nature of our feed site location efforts, we do not have a complete census of all feed sites in the study area. However, we developed substantial familiarity with the areas that each deer used through locating the deer every several days. It is unlikely that we failed to detect a feed site that a marked deer routinely accessed in winter months.

Land cover classes were extracted and generalized from the 2012 Teton County Vegetation Mapping Project. This effort was completed by Cogan Technology Incorporated with funding provided by Teton County, Wyoming as well as the Teton Conservation District. Representative stands of vegetation were collected in the field and subsequently used as training data in a hybrid remote sensing classification harnessing 2011 Teton County color infrared aerial imagery (1 ft. or 0.3 m resolution). Public lands not included in the 2012 Teton County Vegetation Map were classified based on interpretation of the 2007 United States Forest Service Bridger-Teton National Forest exist_veg layer as well as the 2007 Grand Teton National Park grte_veg layer. Bridger Teton National Forest exist_veg was completed by USFS's Remote Sensing Application Center. The grte_veg layer was completed by the United States Geological Survey, US Bureau of Reclamation Remote Sensing and GIS Group, and Cogan Technology Incorporated. For the purposes of this analysis the United State Fish and Wildlife Service National Elk Refuge received its own unique classification.

Mean slope and aspect were calculated with the Environmental Systems Research Institute's (ESRI) Surface Toolbox within the Spatial Analyst Extension for ArcInfo 10.0, based on 10 m (33 ft) resolution Digital Elevation Models (DEM) from the National Elevation Dataset. Distance to road and distance to feed site were calculated from the center of each sample circle using ESRI's Analysis Tools.

We estimated a negative binomial RSPF using the glm.nb function of the MASS package [(38)] in R.[(29)] All variables were first inspected to ensure that they were not correlated. We considered linear and quadratic effects of slope and aspect. We thus fitted a maximal model that included distance to supplemental feed, distance to road, slope, slope^2, aspect, aspect^2, and percent cover of herbaceous, shrubland, irrigated agriculture, juniper, coniferous, aspen, riparian, mixed trees, golf course/lawn, and developed land. We used the corrected Akaike's Information Criterion (AICc) to guide model selection. In order to estimate the upper and lower confidence intervals (CIs) of parameter estimates in the final RSPF model, we bootstrapped individual deer 1,000 times; we used the standard error of the 1,000 estimates of each model parameter to define the upper and lower 95 percent confidence interval (CI) of that parameter estimate for the pooled (all individuals included) model.[(37)] This approach provides a means to account for any variation among individual deer that may be driving results of the pooled model.

ROAD CROSSING BEHAVIOR

Identification of Road Crossing Locations

We identified where deer crossed major roads by intersecting these roadways with lines connecting successive collar locations. Only locations where deer crossed WYDOT-maintained state and county roads were considered; we assumed that deer crossed residential and Forest Service roads with relative ease. Collar locations that were more than two hours apart (July-September) were not considered, since the large amount of time between fixes introduced a high degree of uncertainty about where the crossings were actually located. Further, very few major road crossings occurred during July-September. A total of 1,796 crossing locations from October-June were retained for analysis.

Temporal Patterns of Road Crossings

We estimated the time of crossing for each crossing location as a function of: *A*—the time of the last collar location before the crossing; *B*—the time interval between successive collar locations; and *C*—the distance from the last location before the crossing to the roadway, divided by the total distance between the two successive collar locations. The time of crossing, *T*, was calculated as $T = A + (B \times C)$.[(39)] We then calculated the percent of all crossings that occurred during each hour of the day. Similarly, we calculated the percent of all crossings that occurred during each month of the calendar year. Crossing locations were separated into migration and non-migration crossings to examine whether temporal patterns differed between these two classes of deer movements.

Spatial Patterns of Road Crossings

We used an RSPF approach similar to the above-described methods to examine the road and roadside characteristics associated with crossing locations. To implement the RSPF analysis, we generated 227 systematically located circles (each with radius of 100 m or 328 ft) along the network of major roadways in our study area. Circles were constrained to fall within deer home ranges (appendix C). Adjacent circles were separated by 20 m (66 ft) of unsampled road in order to meet RSPF assumptions of incomplete sampling.[37] In each circle the number of deer crossing locations was counted as a measure of intensity of use. Within each circle we also extracted a set of potential predictor variables, including: road side fence type; distance to supplemental feed site; slope; and percent cover for each of eleven main land cover categories defined above.

Data on land cover, slope, and distance to nearest supplemental feed were derived as described above ("Analysis of Winter Habitat Use). Fence attribute data were collected in the field and captured with handheld GPS receivers. For each major road, we traveled the length of the road and used the GPS receiver to record the start and end point of each different fence type encountered (with each side of the road recorded separately). For each length of fence, we recorded the type of fence (e.g. chain link, buck and rail, post and rail, wire and rail, barbed wire), the height of the bottom wire or rail, the height of the top wire or rail, and whether the top and bottom (if wires) were smooth or barbed. Using local guidelines on wildlife-fence relations, we categorized each length of fence on a scale of 1 to 4, with 1 being almost completely impermeable to wildlife and 4 meeting best practice guidelines for wildlife-friendly fences.[40] Fence lengths were then mapped using these categories and stretches of road were re-classified by simultaneously considering the fences on both sides of the road, as follows: "full fence" = category 1 fence on at least one side; "relatively impermeable fence" = category 2 fence on one side, with category 2, 3, 4 or no fence on the other side; "relatively permeable fence" = category 3 or 4 fence on one side and category 3, 4 or no fence on the other side (categories 3 and 4 grouped because category 4 was very rare); and "no fence" = no fence on either side.

We estimated a negative binomial RSPF using the approach outlined above. Fence type and percent developed land were strongly related; consequently, percent developed land was not included. Our maximal model thus included: fence type, slope, distance to feed site, and percent cover of herbaceous, shrubland, irrigated agriculture, juniper, coniferous, aspen, riparian, mixed trees, and golf course/lawn. As above, we used the corrected Akaike's Information Criterion (AICc) to guide model selection and bootstrapping to estimate the confidence intervals of parameter estimates in the final RSPF model.

SPATIAL AND TEMPORAL PATTERNS OF MULE DEER-VEHICLE COLLISIONS

The locations and timing of mule deer-vehicle collisions in the study area were established from WYDOT Wildlife-Vehicle Collision (WVC) and Carcass databases, highway accidents from the Wyoming Game and Fish Department's (WGFD) Wildlife Observation System (WOS), as well as data from Nature Mapping Jackson Hole and Roadkill Hotline—citizen science initiatives run by the Jackson Hole Wildlife Foundation (JHWF) in cooperation with the Meg and Bert Raynes Wildlife Fund. WYDOT's WVC database contains records of collisions reported by State

Highway Patrol—usually when the collision has resulted in property damage and/or bodily injuries valued at more than 1,000 dollars. The carcass data are collected by Highway Maintenance crews and capture information about collisions that may not have otherwise been reported. Wildlife Observation System data are recorded primarily by WGFD staff. Nature Mapping and Roadkill Hotline data are observations of carcasses or collisions recorded primarily by residents of Jackson Hole and may similarly capture information about collisions not reported elsewhere.

In order to facilitate spatial analysis of deer-vehicle collisions in our study area, we merged the records of all collisions and carcasses that were recorded between 1990 and 2012 and converted tabular data into a spatially explicit geo-database. WYDOT maintains spatial datasets for major travel routes and whole mile reference markers. However, WYDOT WVC and carcass records are referenced to a $1/10^{th}$ mile (0.16 km) marker. In order to join collision and carcass records to WYDOT's whole mile reference system, we created a $1/10^{th}$ mile (0.16 km) marker reference dataset. Tabular records with route and milepost information were spatially joined to the $1/10^{th}$ mile (0.16 km) reference dataset. Any data with geographic/projected coordinates without a $1/10^{th}$ mile (0.16 km) marker reference were snapped spatially to the nearest major travel route, and then to the nearest $1/10^{th}$ mile (0.16 km) marker. Records located more than 152 m (500 ft) from a major road were removed.

Observations across these five data sources are not independent; it is possible that the same deer carcass could have been recorded in all five databases. To remove duplicate records, we first identified records that shared the same carcass number and combined their attributes. We then targeted remaining duplicates by flagging records with the same date and within 0.32 km (0.2 mi) of each other. These flagged records were further inspected to see if the sex and age were identical; if so, these records were combined.

Although collision and carcass records are referenced by $1/10^{th}$ mile (0.16 km) increments, 45 percent of all records were referenced to whole mile markers. We therefore mapped the locations of all mule deer collision records to the nearest mile marker to facilitate comparison with spatial patterns of mule deer road crossings obtained from our collared animals. In order to compare the temporal patterns of mule deer-vehicle collisions and mule deer road crossings, we categorized and charted all recorded deer-vehicle collisions (n=2,131) by month. For the subset of these (n=415) that were derived from the WVC records, accurate temporal data was available (since Highway Patrol reports the time of the collision); for these, we additionally charted the diurnal timing of deer-vehicle collisions.

CHAPTER 4. RESULTS

It is important to note that the analyses that follow are based on data collected from a subset of the Jackson mule deer herd. We captured and collared deer that were on their winter range and targeted deer that were found close to major roadways. It is possible that our findings regarding patterns of habitat use and road crossing would be different had the deer been captured further away from roads; however we intentionally captured deer that had a high likelihood of interacting with roadways so as to better understand the behavior and movement patterns of deer at greatest risk of being involved in a deer-vehicle collision.

DEER MORTALITY

Of the 40 animals that were collared, 16 (40 percent) died during the course of the study. Of these, cause of death could be established with confidence for 11 animals; for the remaining five the carcass was too decomposed by the time it was found to establish the cause of death. Of the 16 mortalities, 6 (38 percent) were attributed to vehicle collisions; 3 (15 percent) were attributed to starvation—with bone marrow fat 5-9 percent and no other obvious cause of death; and 1 (6 percent) was attributed to predation. All three cases of starvation occurred during the winter of 2010-2011, which was a particularly high snowfall winter. It is possible that malnourishment was a contributing factor to other mortalities during this winter—making deer more susceptible to predation or more likely to make risky road crossings (on average, deer crossed roads 40 percent more during winter 2010-11 than winter 2011-12).

BEHAVIOR IN RELATION TO ROADWAYS

In general, deer allocated their time differently depending on both distance from road and the sex/age of the deer. Bucks spent significantly more time bedded than does and fawns (38 percent versus 14 percent and 17 percent, respectively; F=5.8, df=2, p=0.003, where F is the test statistic, df is the degrees of freedom, and p indicates the chance that the observed trend is a false positive). Correspondingly, bucks spent less time engaged in other activities (vigilant, feeding, moving, and standing) than does and fawns. Sex/age was a significant factor in all models and was included to statistically control for differences in behavior along sex/age lines. There were no interactions between sex/age and other variables (e.g. distance from roads) for any of the response variables considered.

After controlling for the effects of sex/age, distance from road was a significant predictor for all deer behaviors except time spent bedded (figure 3). Deer spent 18 percent more time foraging far from roads (greater than 200 m or 656 ft) than close to roads (less than 200 m or 656 ft; F=7.8, df=2, p<0.001). At the same time, deer spent 66 percent more time vigilant close to roads (less than 100 m or 328 ft) than far from roads (greater than 200 m or 656 ft; F=7.8, df=2, p<0.001) and 44 percent more time standing close to roads than far from roads (F=7.8, df=2, p<0.001).

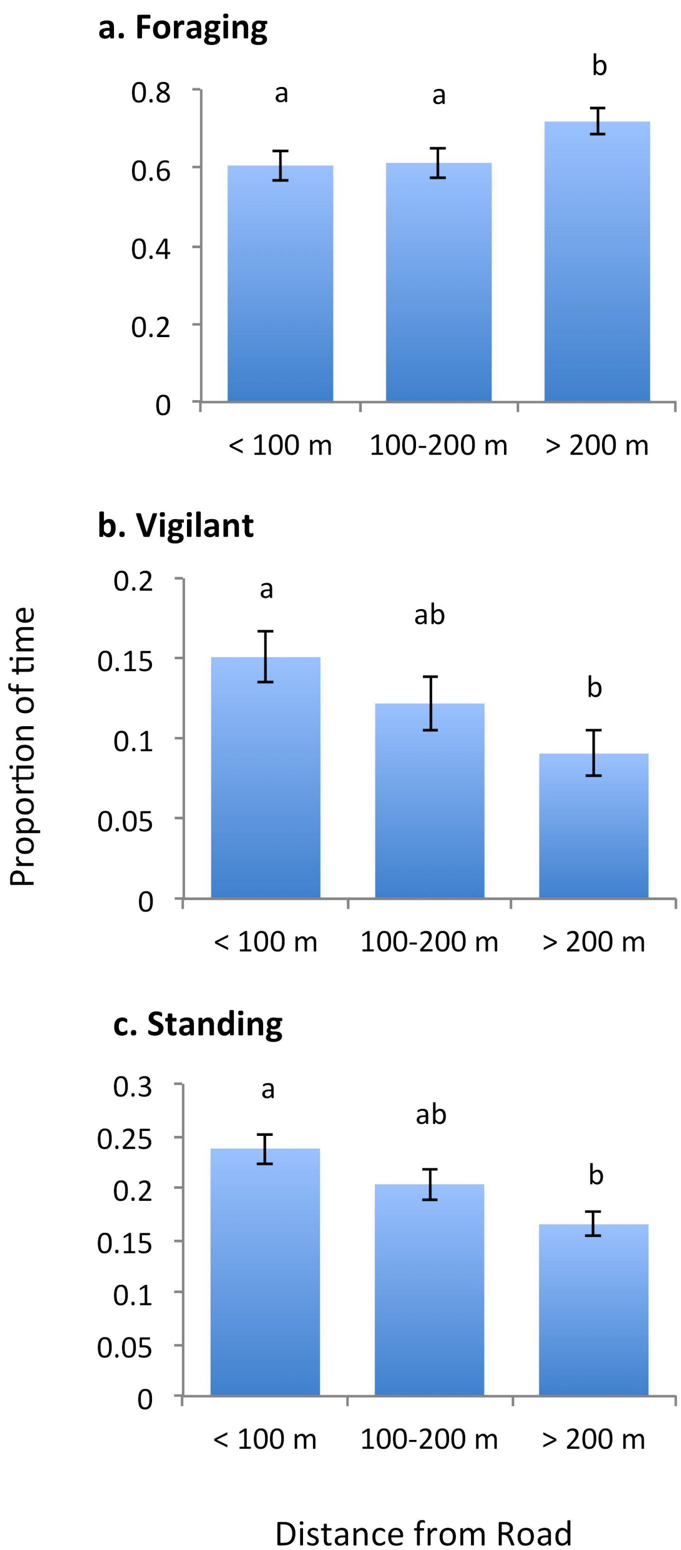


Figure 3. Effects of distance from roads on the proportion of time deer spent (a) foraging, (b) vigilant, and (c) standing. Proportion data are arcsine-square root transformed.

Traffic volume was a significant predictor of the percent of time deer spent vigilant and moving, but not foraging, standing, or bedded. Surprisingly, deer spent 40 percent more time vigilant in the vicinity of low traffic volume roads than in the vicinity of high traffic volume roads (F=2.9, df=2, p=0.05). There was no interaction between distance to road and road traffic volume. For time spent moving, there was a significant interaction between distance to road and road traffic volume (F=2.3, df=4, p=0.05). Deer spent nearly twice as much time moving when they were within 200 m (656 ft) of high traffic volume roads compared to when they were more than 200 m (656 ft) from high traffic volume roads or when any distance from a medium or low traffic volume road (figure 4). Put another way, traffic volume only affected deer movement when deer were close to high volume roads.

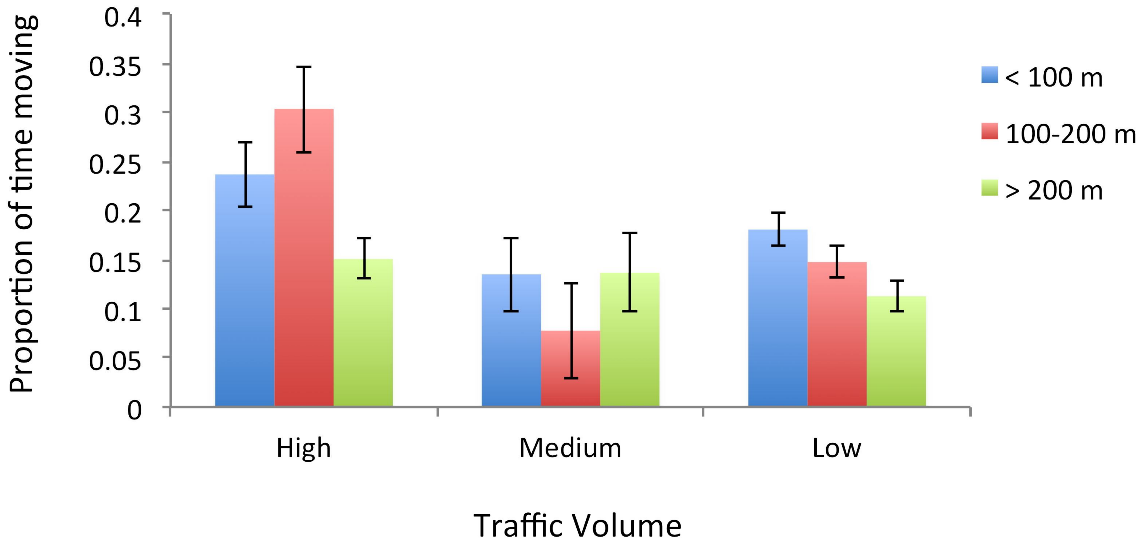
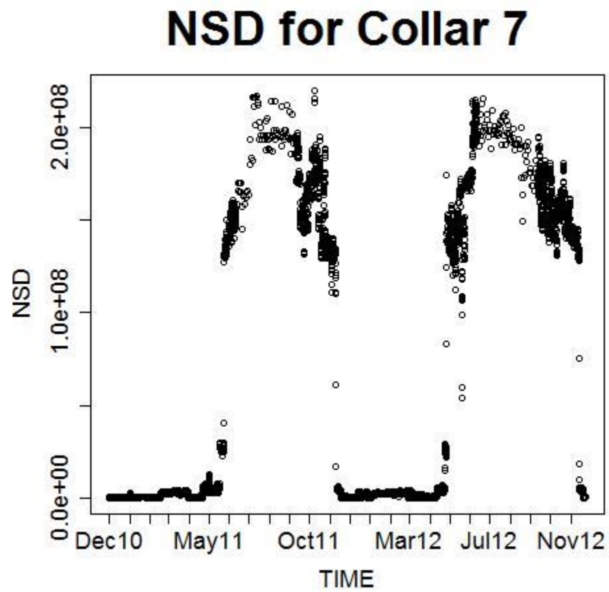


Figure 4. Effects of distance from roads and traffic volume on the proportion of time deer spent moving. Proportion data are arcsine-square root transformed.

SEASONAL HABITAT USE AND SHORT-DISTANCE MIGRATIONS

Of the 40 collared deer, 20 were migratory, seven were non-migratory, 12 died before migratory status could be determined, and one had a collar malfunction that caused it to drop off before migratory status could be determined. Migratory animals showed clear patterns of rapid movement between distinct seasonal ranges, whereas non-migratory animals showed no clear seasonal movement patterns (figure 5; appendix B). We discuss the seasonal habitat use and movement patterns for these two groups separately.

a.



b.

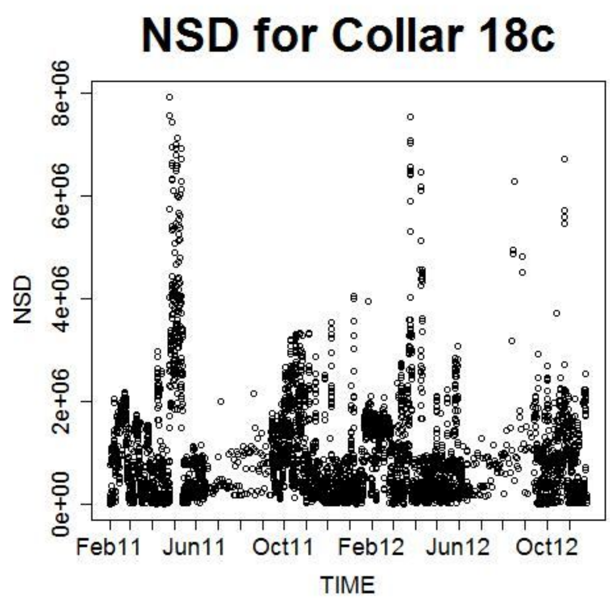


Figure 5. Net squared displacement charts for representative examples of (a) a migratory deer and (b) a non-migratory deer.

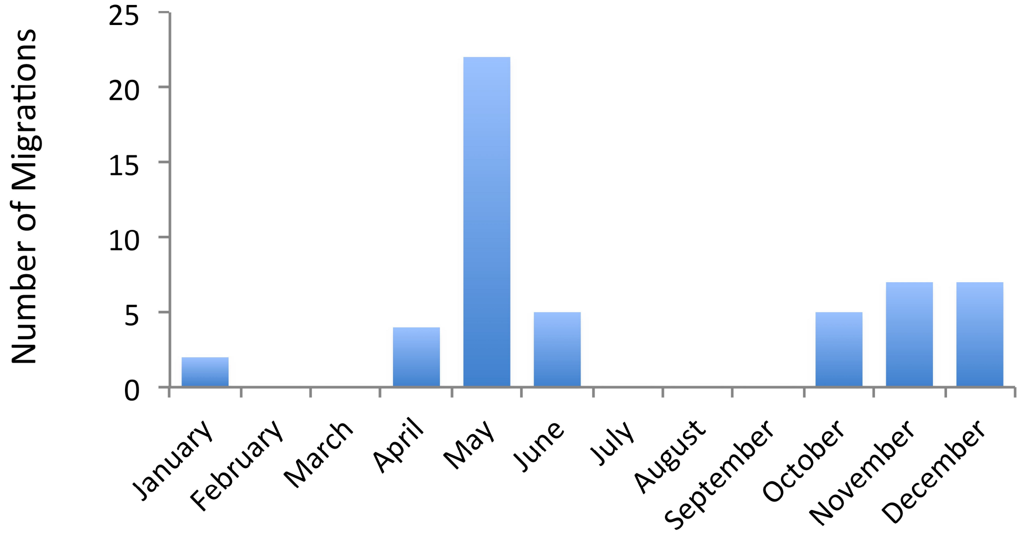


Figure 6. Timing of migration by month, aggregated over the study period.

Migratory Deer

In total, we documented 52 migration paths (fall and spring for each year, times two years for some individuals) from the 20 migratory animals. The mean duration of migrations was 80 hours (±SE=19.5) and the mean distance traveled was 14.8 km (±SE=1.3) or 9.2 mi. Most deer made their spring migration in May (figure 6). The timing of fall migrations was more diffuse, spanning October through December in roughly equal proportions. On average the collared deer spent 182 days (±SE=5.7) in their summer range and 133 days (±SE=5.4) on their winter range. In general, summer ranges were larger than winter ranges (table 1).

Table 1. Mean (± standard error) kernel density estimates of home range size for summer and winter home ranges of 20 migratory and seven non-migratory deer.

	Migratory		Non-migratory
	Summer	Winter	Year-round
50% area (ha)	201 (±37)	124 (±24)	132 (±20)
75% area (ha)	434 (±81)	263 (±49)	269 (±38)
90% area (ha)	747 (±137)	452 (±84)	489 (±65)
99% area (ha)	1504 (±275)	913 (±171)	951 (±139)

An examination of the migration routes of the 20 migratory deer revealed two general groups—one that resided in the north-central part of the valley and one that resided in the southern portion of the valley. Individual deer exhibited a high degree of fidelity to their migration routes—following very similar pathways in both fall and spring and across both years of the study.

The north-central group was made up of 12 does, all of which summered on the eastern slopes of the Teton Range (figures 7 and 8). In the fall, these animals migrated southeastward across WY-390 and the Snake River. All but one of them crossed the Snake River south of its confluence with the Gros Ventre River (figure 9). Many of these animals made use of a stopover site where Lake Creek flows under WY-390, due west of the confluence of the Snake River and Gros Ventre River. After crossing the Snake River, all of these animals continued on to West Gros Ventre Butte—another critical migration stopover site for this group of mule deer. Approximately half of these deer moved over to East Gros Ventre Butte for most of the winter (figures 10 and 11). The other half used both East Gros Ventre Butte and habitat further south of the town of Jackson for their winter range. The general migration path of these deer crossed many of the main roads of Teton County, including WY-390, WY-22, US-89/191, and Spring Gulch Road. The average migration distance for the northern group of deer was 15.3 km (±SE=1.5) or 9.5 mi.

The southern group was made up of eight deer. These animals had an average migration distance of 8.5 km (±SE=2.3) or 5.3 mi, which is significantly shorter than the northern group (t=2.5; p=0.03). With the exception of one deer (which migrated south of Hoback Junction), this group summered on the northern and eastern slopes of Munger Mountain (including Butler Creek, Squaw Creek, Dell's Canyon, and George's Canyon) (figure 12). In the fall, these animals migrated eastward, crossing over US-89/191 and the Snake River, to their winter range in the Porcupine Creek and Game Creek drainages (figure 13). These migrations pathways were both short and rapid (many under two hours) with no notable stopover sites.

Non-Migratory Deer

Seven of the collared deer (26 percent of those which were collared for at least one year) were non-migrants, showing no discernible seasonal movement patterns or temporal partitioning of habitat. Three of these deer occupied developed areas on the valley floor (two in the Jackson Hole Golf and Tennis development south of the airport, and one in the Teton Pines / The Aspens development on Moose-Wilson Road). One non-migrant moved frequently between Boyles Hill and High School Butte, just south of WY-22. The other three non-migrants occupied habitat south of the town of Jackson. One occupied the hillside to the east of US-89/191 opposite the Rafter J neighborhood. The other two non-migrant animals had home ranges centering around the Porcupine Creek and Game Creek drainages and Dell's and George's Canyons adjacent to US-89/191. Non-migratory deer had home ranges similar in size to the winter home ranges of migratory deer (table 1).

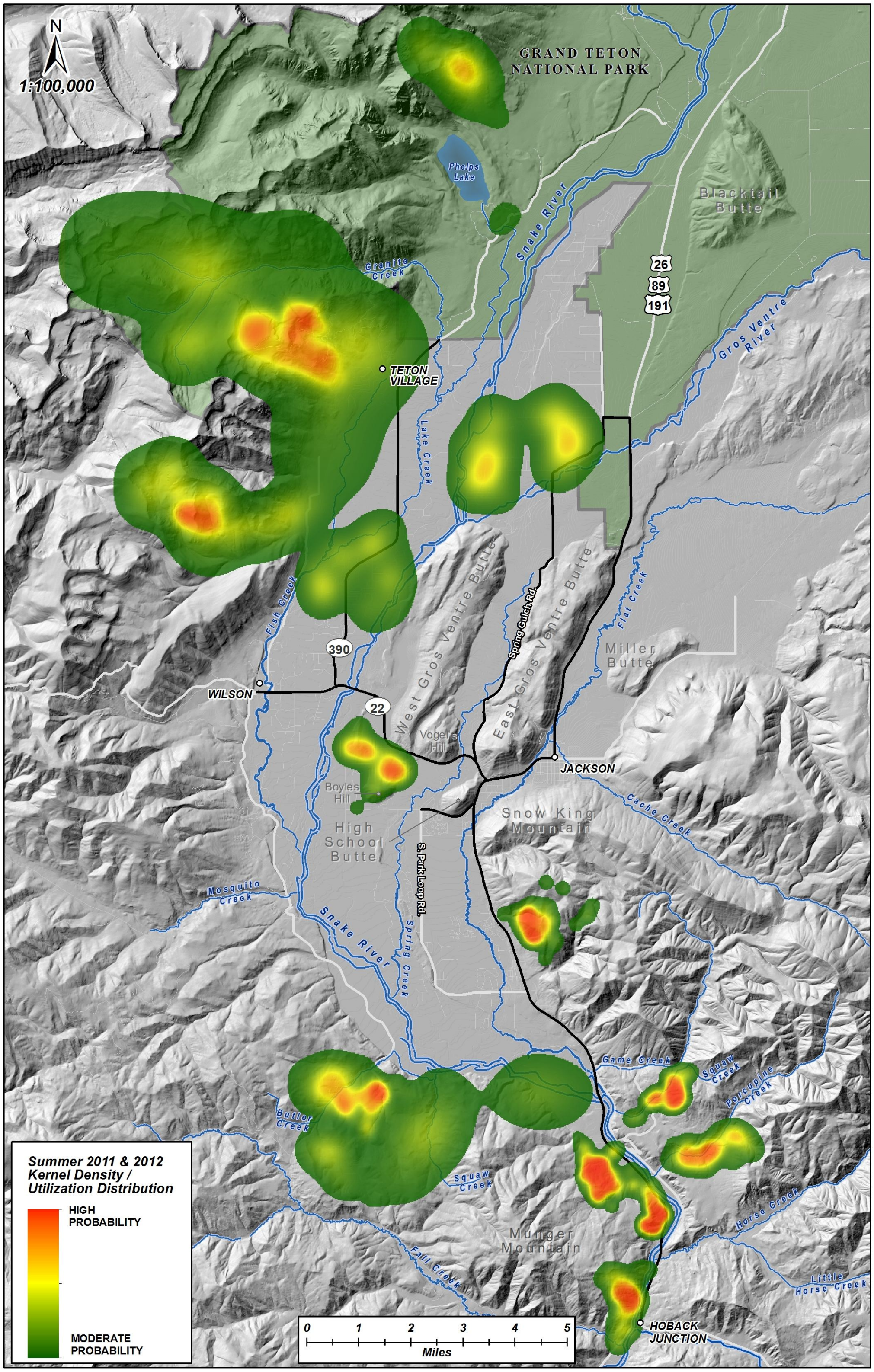


Figure 7. Population-level summer range utilization distribution, calculated by averaging individual deer kernel densities.

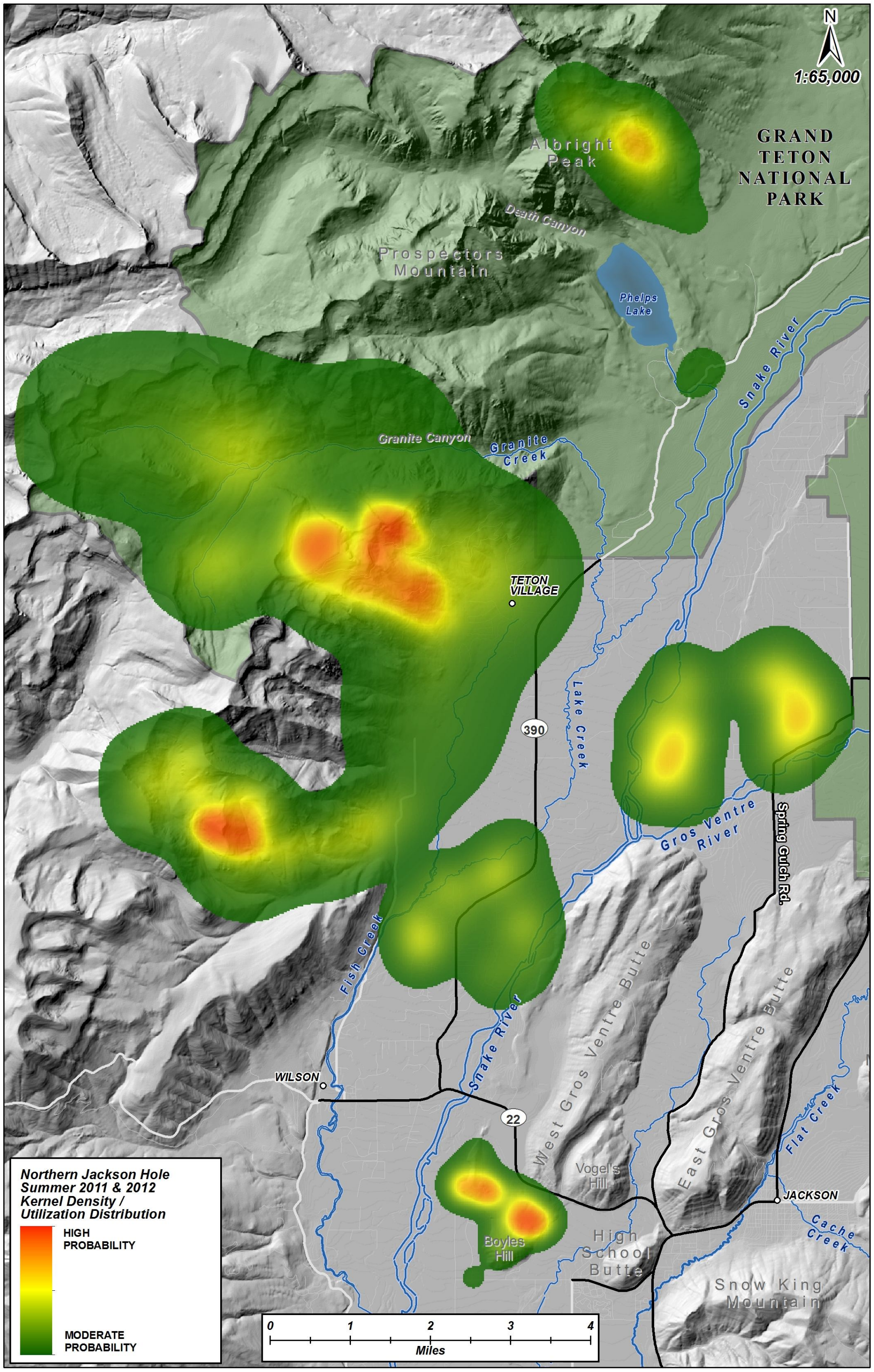


Figure 8. Zoom-in of northern area of the population-level summer range utilization distribution.

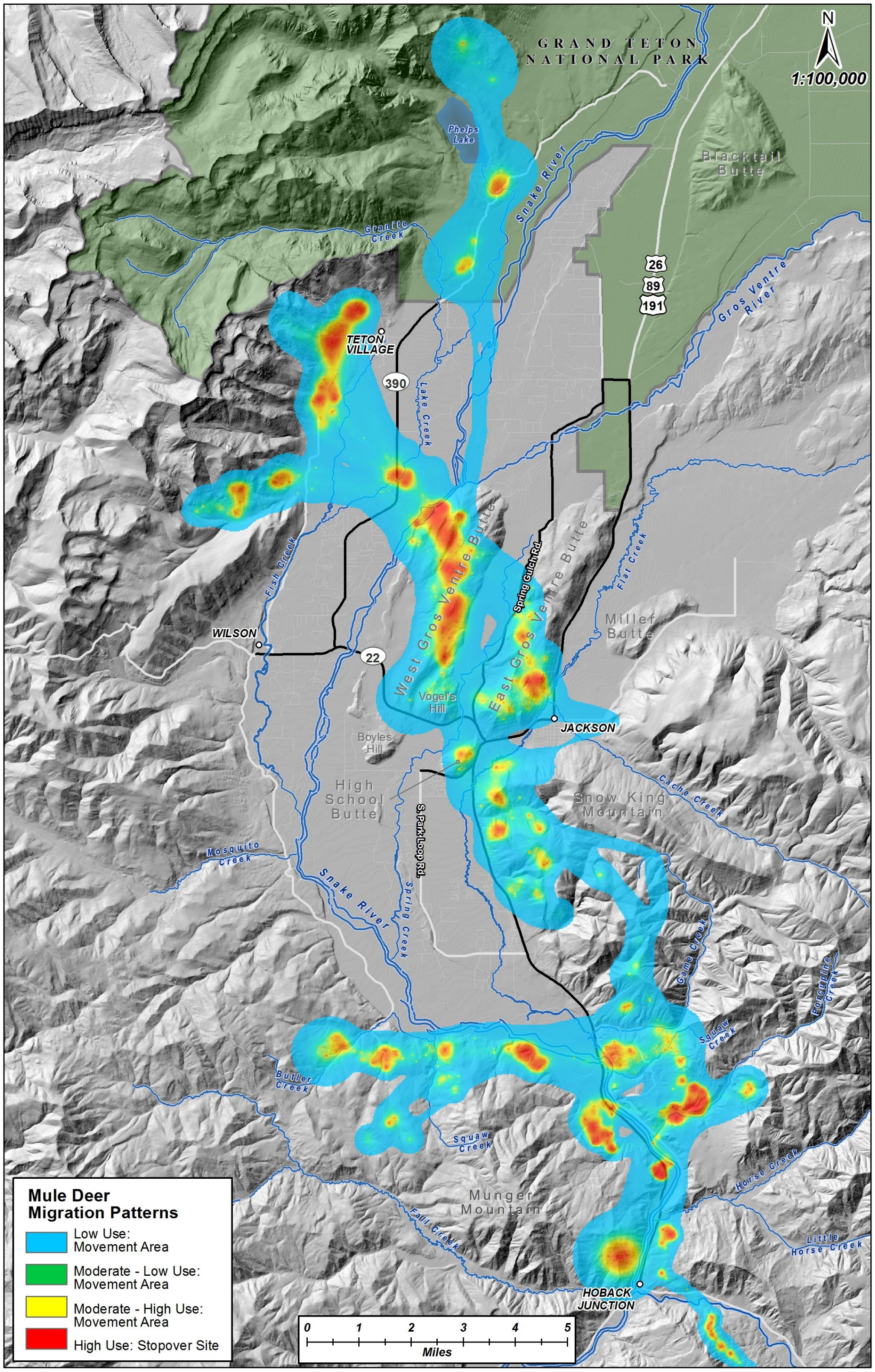


Figure 9. Population-level Brownian bridge movement model (BBMM) utilization distribution, calculated by averaging individual deer BBMM utilization distributions.

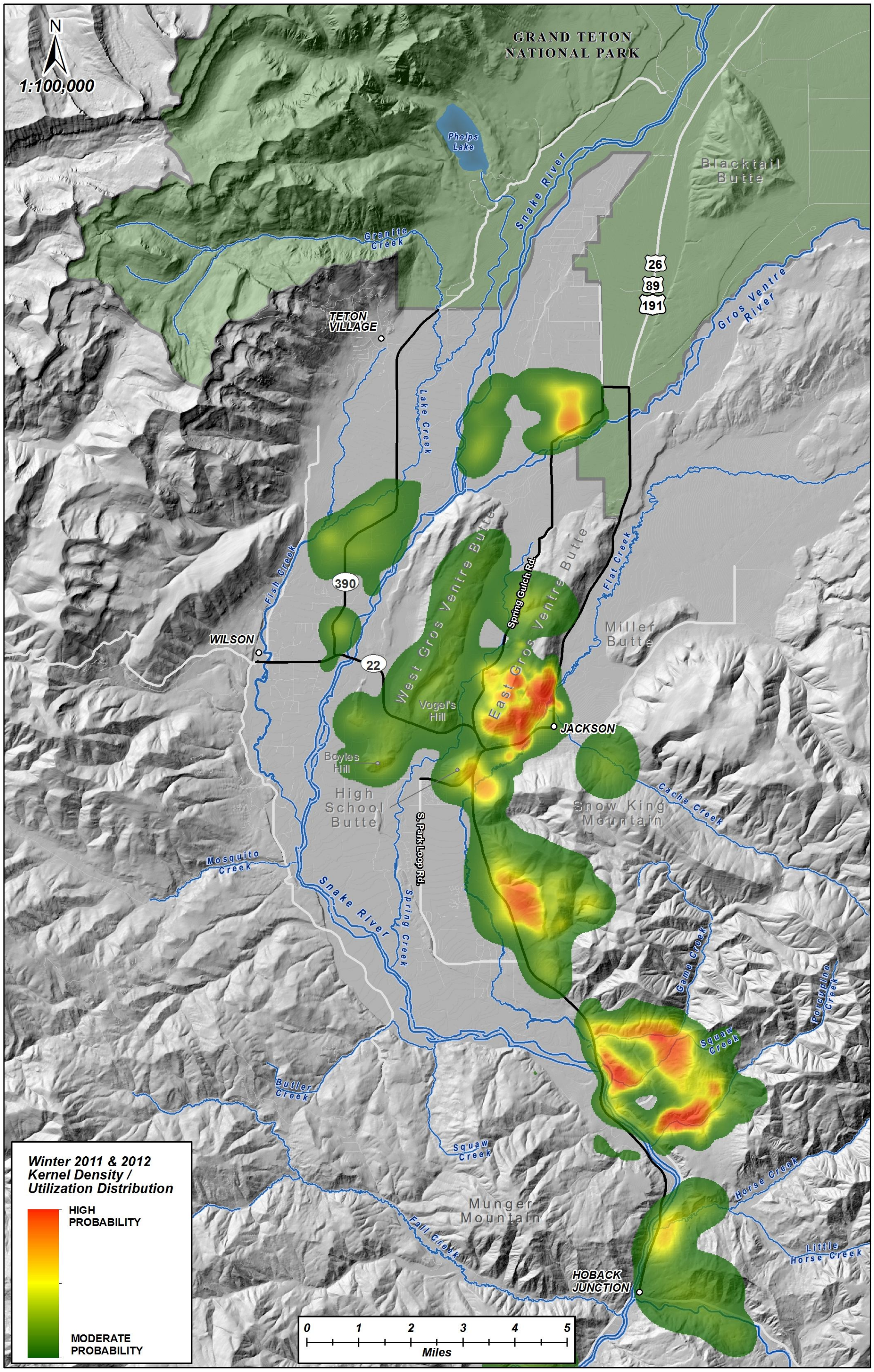


Figure 10. Population-level winter range utilization distribution, calculated by averaging individual deer kernel densities.

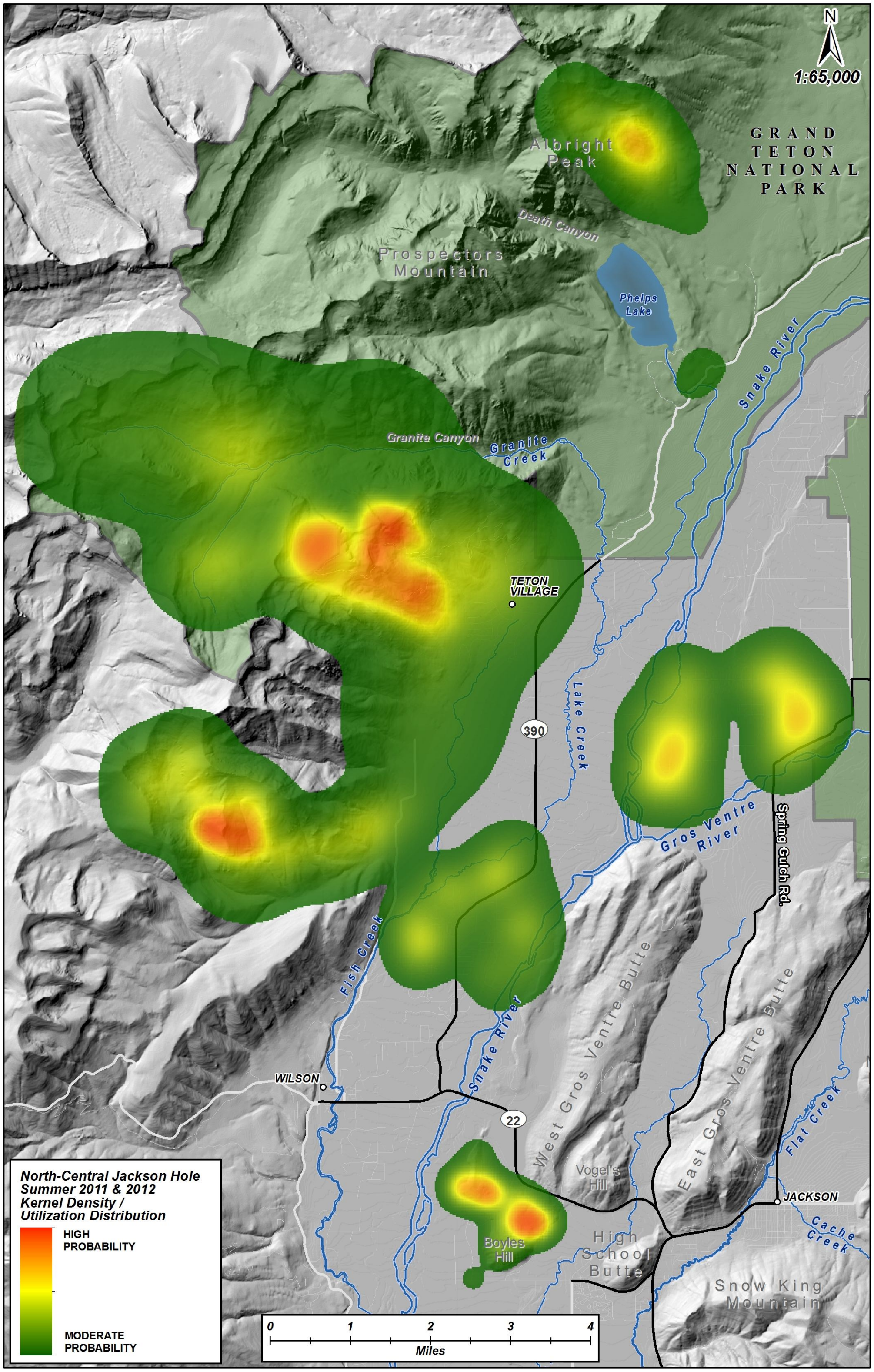


Figure 11. Zoom-in of northern area of the population level winter range utilization distribution.

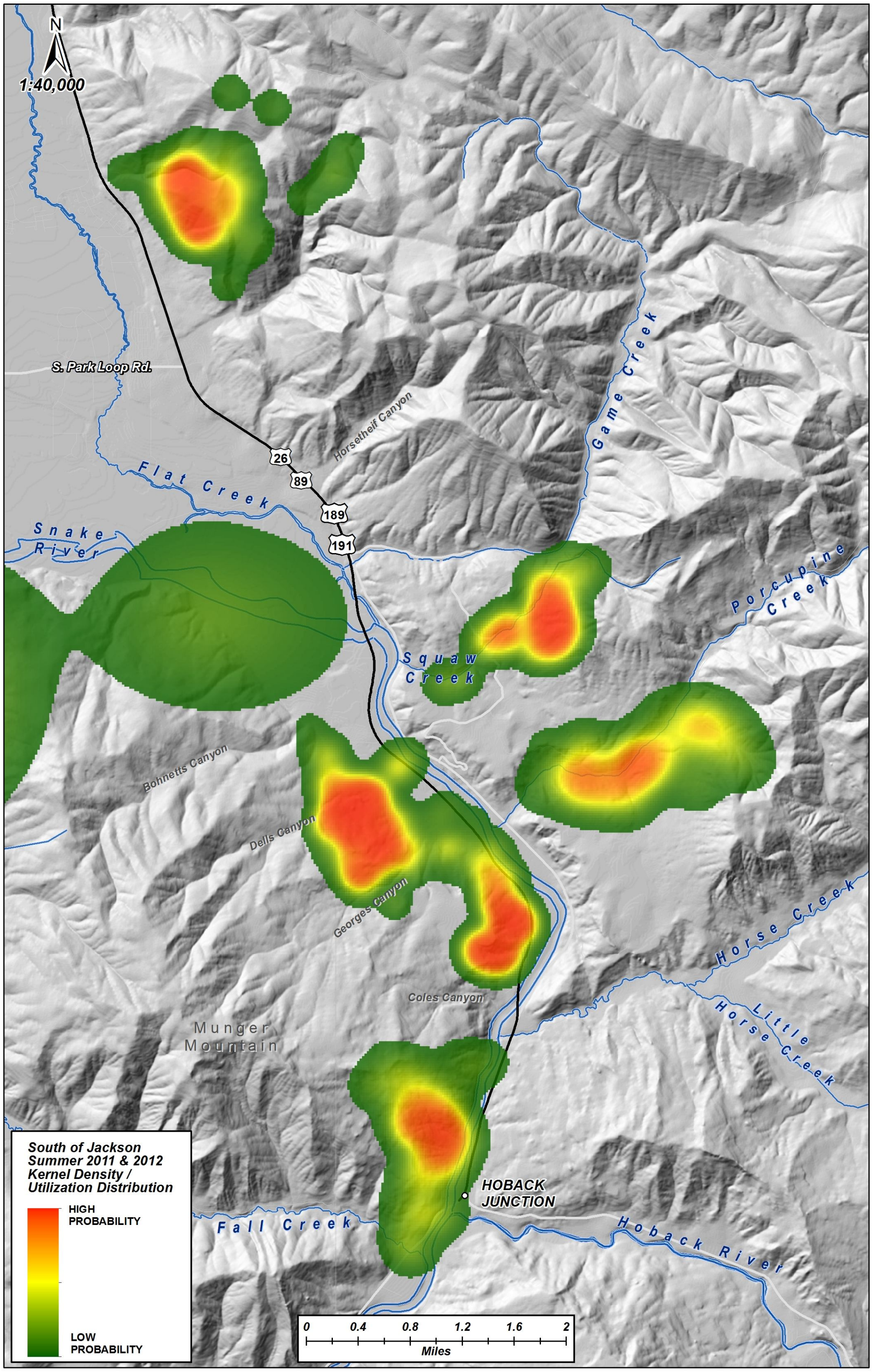


Figure 12. Zoom-in of southern area of the population-level summer range utilization distribution.

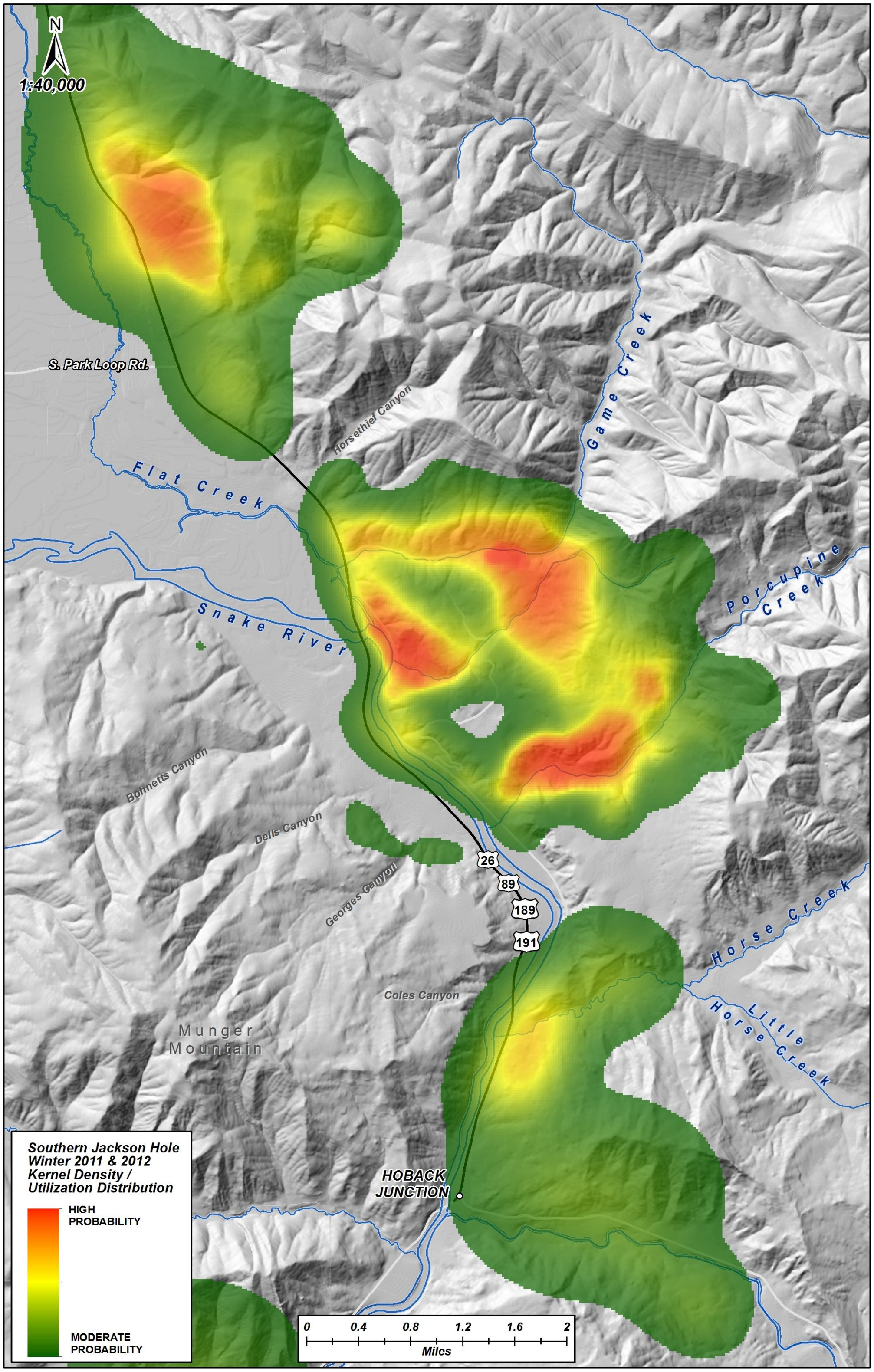


Figure 13. Zoom-in of southern area of the population-level winter range utilization distribution.

PREDICTORS OF WINTER HABITAT USE

Mule deer winter habitat use was strongly associated with a number of habitat variables (table 2; see appendix D for comparison among alternative models). Intensity of habitat use was positively related to slope and percent cover of herbaceous vegetation, shrubs, mixed trees, junipers, golf courses and lawns, and riparian vegetation. Intensity of use was negatively related to percent cover of irrigated agricultural land. Intensity of use was also strongly related to distance to the nearest supplemental feed, with higher intensity of use closer to supplemental feed. There was no indication that deer avoided roads; intensity of use was, in fact, positively related to distance to major road, indicating that deer use areas close to roads relatively intensively. Aspect was not a significant predictor of mule deer habitat use, although visual inspection of the data showed a general pattern of more intense use on south, southeast, and southwest-facing slopes. The absence of an effect for aspect may reflect the fact that aspect is not a useful metric of habitat for the flat valley floor, which comprised a substantial portion of the study area. Percent cover of coniferous vegetation, aspen, and developed land were not significant predictors of mule deer habitat use (table 2; appendix D).

Table 2. Parameter estimates for the probability of mule deer winter habitat use, based on habitat use by 40 collared deer.

	Estimate	Lower CI	Upper CI	Z	*p*
Intercept	-9.77	-1.23e+1	-8.31	-29.05	<0.001
Distance to supplemental feed	-3.07e-4	-6.67e-4	-8.06e-5	-10.01	<0.001
Distance to road	-1.39e-4	-5.01e-4	4.82e-4	-2.81	0.004
Slope	9.51e-2	1.10e-2	2.68e-1	4.74	<0.001
$Slope^2$	-1.01e-3	-5.73e-3	1.32e-3	-1.81	0.070
Aspect	-8.77e-4	-9.91e-3	1.75e-2	-0.41	0.682
$Aspect^2$	4.05e-6	-4.32e-5	2.78e-5	0.65	0.517
Agricultural land – percent cover	-1.60e-2	-3.04e-2	2.98e-3	-4.84	<0.001
Herbaceous – percent cover	1.46e-2	-3.85e-3	3.13e-2	3.39	<0.001
Shrubland – percent cover	1.35e-2	-3.05e-3	2.84e-2	3.98	<0.001
Coniferous – percent cover	6.35e-4	-1.52e-2	1.52e-2	0.17	0.864
Aspen– percent cover	6.35e-3	-1.62e-2	2.22e-2	1.64	0.100
Mixed trees – percent cover	5.25e-2	6.29e-3	7.61e-2	7.28	<0.001
Juniper – percent cover	4.03e-2	1.13e-2	6.70e-2	3.58	<0.001
Golf course and lawn – percent cover	3.44e-2	1.49e-3	5.60e-2	6.95	<0.001
Riparian – percent cover	1.04e-2	-1.09e-2	2.99e-2	3.01	0.002
Developed land – percent cover	4.62e-3	-1.29e-2	2.48e-2	1.00	0.317

ROAD CROSSING BEHAVIOR

Temporal Patterns of Road Crossings

Individual deer were highly variable in how frequently they crossed major roads; the total number of crossings per individual over the course of the study ranged from 0 to 439. Among the animals that were collared for a full two years, the median number of road crossings was 36, or approximately two crossings per month. Certain individuals, however, crossed a major road on average every 1-2 days.

On a diurnal scale, the vast majority of crossings occurred at night. For non-migration crossings 67 percent occurred between 19:00 and 07:00—with the peak between 00:00 and 05:00 (figure 14a). This general pattern was consistent across seasons. For migration crossings, the pattern was more bimodal, with one peak between 22:00 and 02:00 and a second peak between 06:00 and 09:00 (figure 14b). On a seasonal scale, 73 percent of crossings occurred from January to April, when deer were on their winter ranges (figure 15a). This was expected, since we focused our capture efforts on individuals that had a high likelihood of interacting with roadways during the winter. Migration crossings, conversely, peaked in May and, to a lesser degree, December (figure 15b).

Only a small fraction of crossings (4.7 percent) were migration crossings. Further, even though only 25 percent of collared individuals did not migrate, these individuals accounted for 57 percent of all the crossings observed. Two non-migratory individuals in particular accounted for 24 percent and 17 percent, respectively, of all crossings.

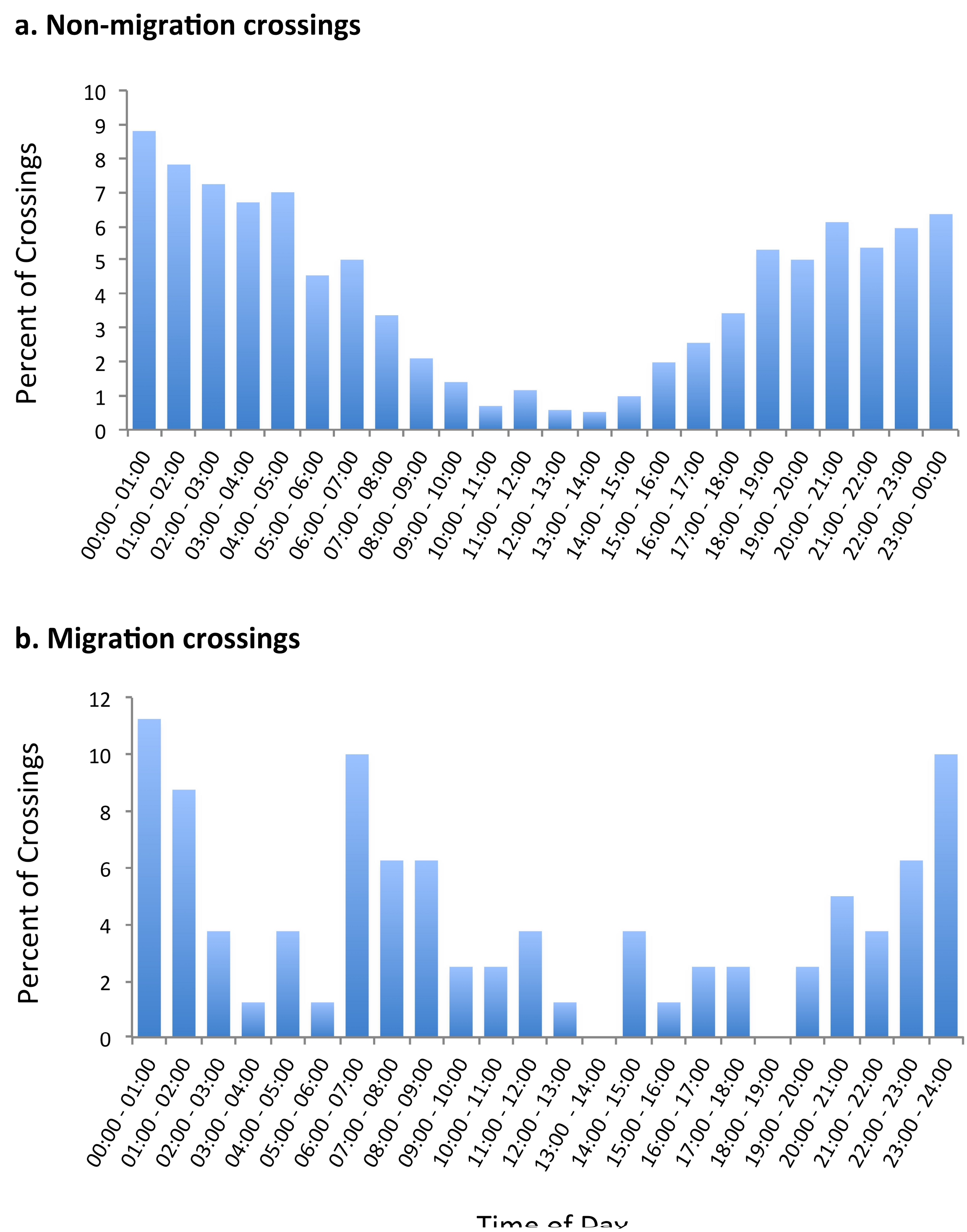


Figure 14. Percent of deer road crossings by time of day for (a) non-migration crossings and (b) migration crossings.

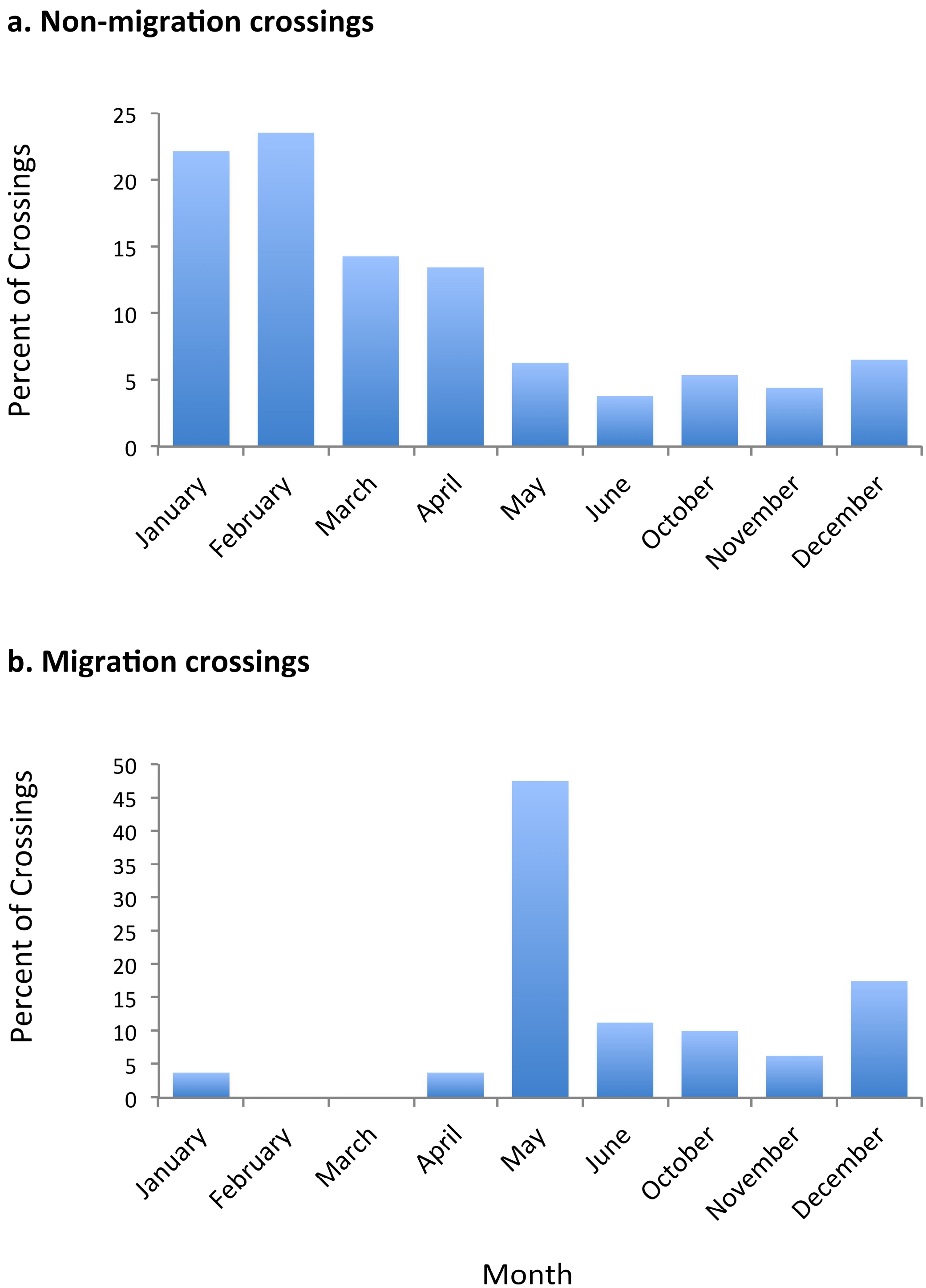


Figure 15. Percent of deer road crossings by month for (a) non-migration crossings and (b) migration crossings.

Spatial Patterns of Road Crossings

Road crossings were highly clustered in space (figure 16). Twenty-five percent of all observed crossings were located on US-89/191 between High School Butte and the southern end of the National Elk Refuge (mile marker 152-155.5). Another 14 percent of crossings occurred on South Park Loop Road, directly west of its intersection with US-89/191. Other areas with numerous road crossings included: WY-390 at and south of Lake Creek Bridge (15 percent of crossings); US-89/191 along the Snake River between mile 142-145.5 (9 percent of crossings); US-89/191 east of the Rafter J development (7 percent of crossings); Spring Gulch Road along the Gros Ventre River (7 percent of crossings); and two spots on Spring Gulch Road along the western side of East Gros Ventre Butte (11 percent of crossings). Notably, no crossings were observed on US-89/191 north of Jackson (along the western edge of the National Elk Refuge).

Many of the road crossings occurred in places where there is no roadside fencing on either side of the road (figure 17). This pattern was also reflected in where deer crossed roads during migration (figure 18). Results of the resource selection probability function analysis confirm that mule deer road crossings were significantly more likely to occur where there was no fence along either side of the road than where there was some kind of fence along at least one side of the road (table 2; appendix D). The effect of fencing was strongest when comparing deer crossings in places with no fence against places with full fencing (game fence, chain link fence, mesh fence) along at least one side of the road. The effect of fencing was intermediate in places with "relatively permeable" and "relatively impermeable" fence types. Results of the RSPF also indicate that road crossings were positively associated with percent cover of herbaceous vegetation, juniper, and mixed trees, and negatively associated with percent cover of agricultural land (table 2; appendix D).

Table 3. Parameter estimates for the probability of mule deer road crossings, based on 1,796 crossings recorded by 40 collared deer.

	Estimate	Lower CI	Upper CI	Z	*p*
Intercept	-5.535	-7.23	-5.25	-23.21	<0.001
Fence – relatively permeable vs. no fence	-0.596	-5.19	-0.51	-1.84	0.064
Fence – relatively impermeable vs. no fence	-0.316	-1.17	-5.7e-3	-0.96	0.338
Fence – full fence vs. no fence	-0.927	-2.17	0.06	-2.14	0.032
Distance to supplemental feed	4.36e-5	-3.7e-4	3.7e-4	0.48	0.627
Slope	0.014	-0.08	0.10	0.38	0.707
Agricultural land – percent cover	-0.022	-0.05	1.5e-3	-2.72	0.007
Herbaceous vegetation – percent cover	0.043	-0.01	0.08	2.29	0.022
Aspen – percent cover	0.007	-0.02	0.04	0.49	0.621
Shrub – percent cover	-0.110	-0.05	0.01	-1.29	0.196
Conifer – percent cover	-0.161	-0.64	0.09	-0.57	0.571
Juniper – percent cover	0.065	-0.13	0.11	1.79	0.073
Mixed trees – percent cover	0.059	9.3e-3	0.11	2.73	0.006
Golf course / lawn – percent cover	0.004	-0.04	0.03	0.38	0.706
Riparian – percent cover	-0.002	-0.04	0.02	-0.21	0.832

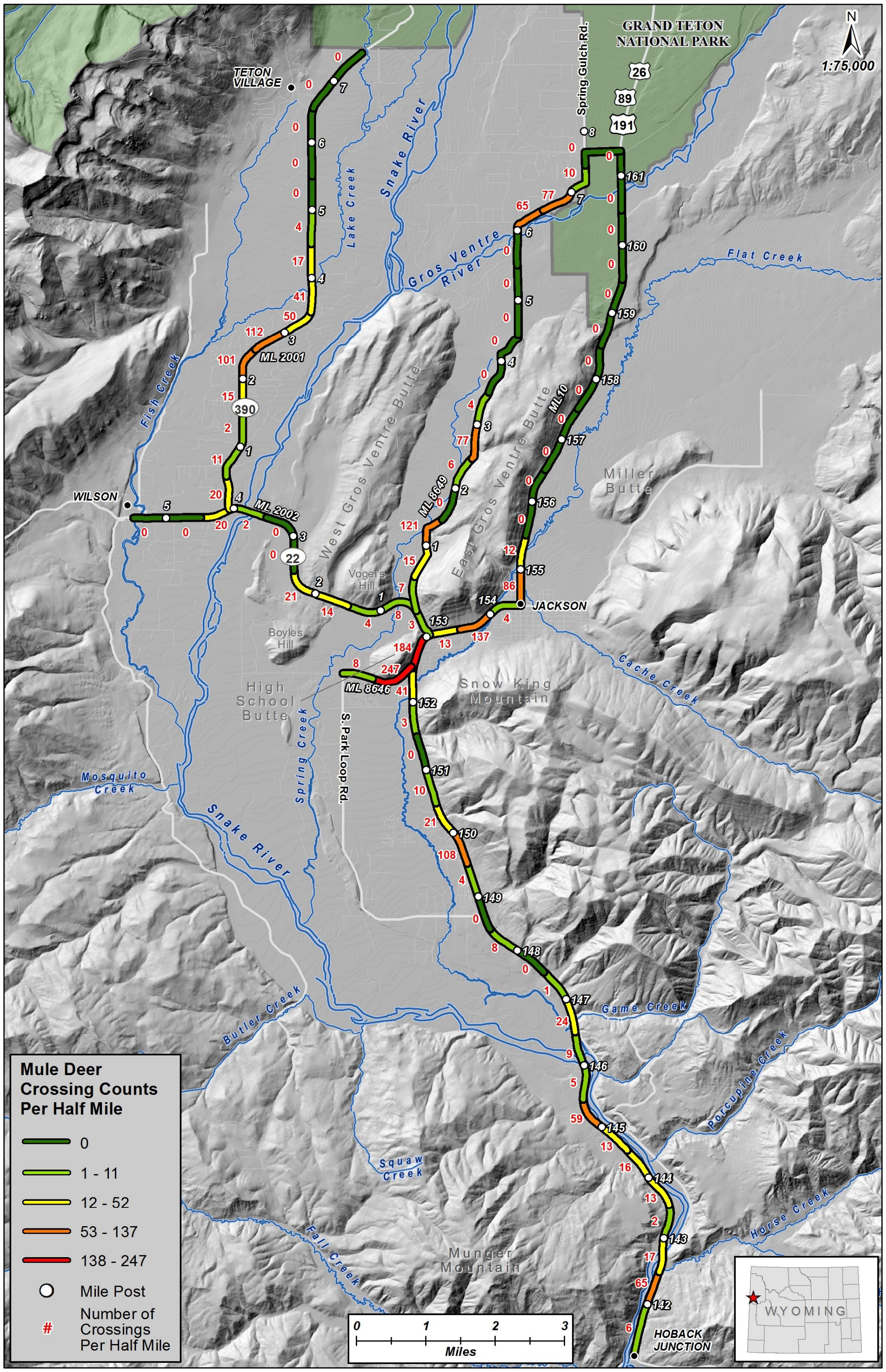


Figure 16. Number of deer road crossings by half-mile road segments. Mile markers are shown.

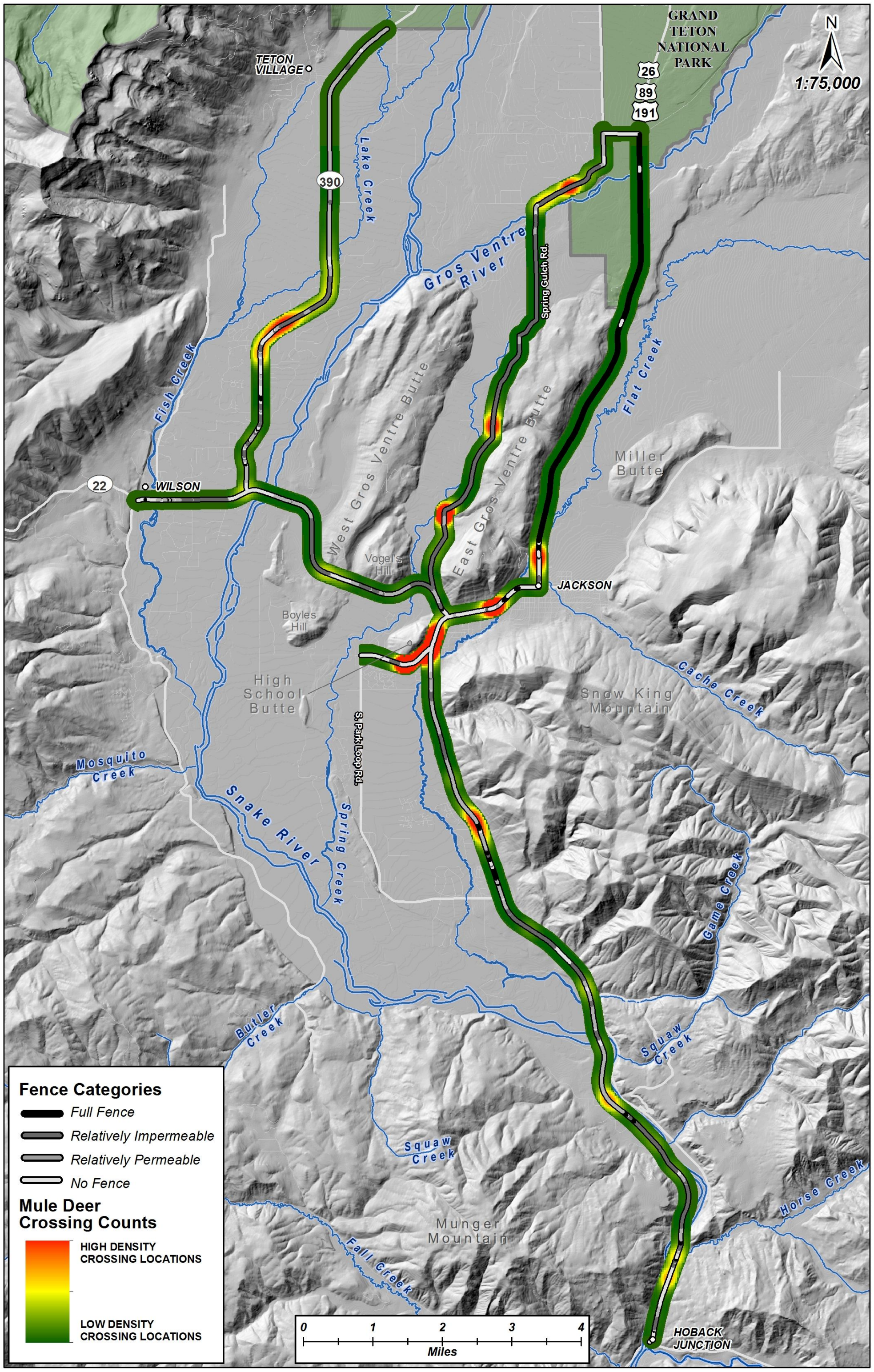


Figure 17. Utilization distribution of deer road crossing locations overlain with fence categories. The UD of crossings was created using a kernel density estimation of road crossing points that was then clipped to the roadways.

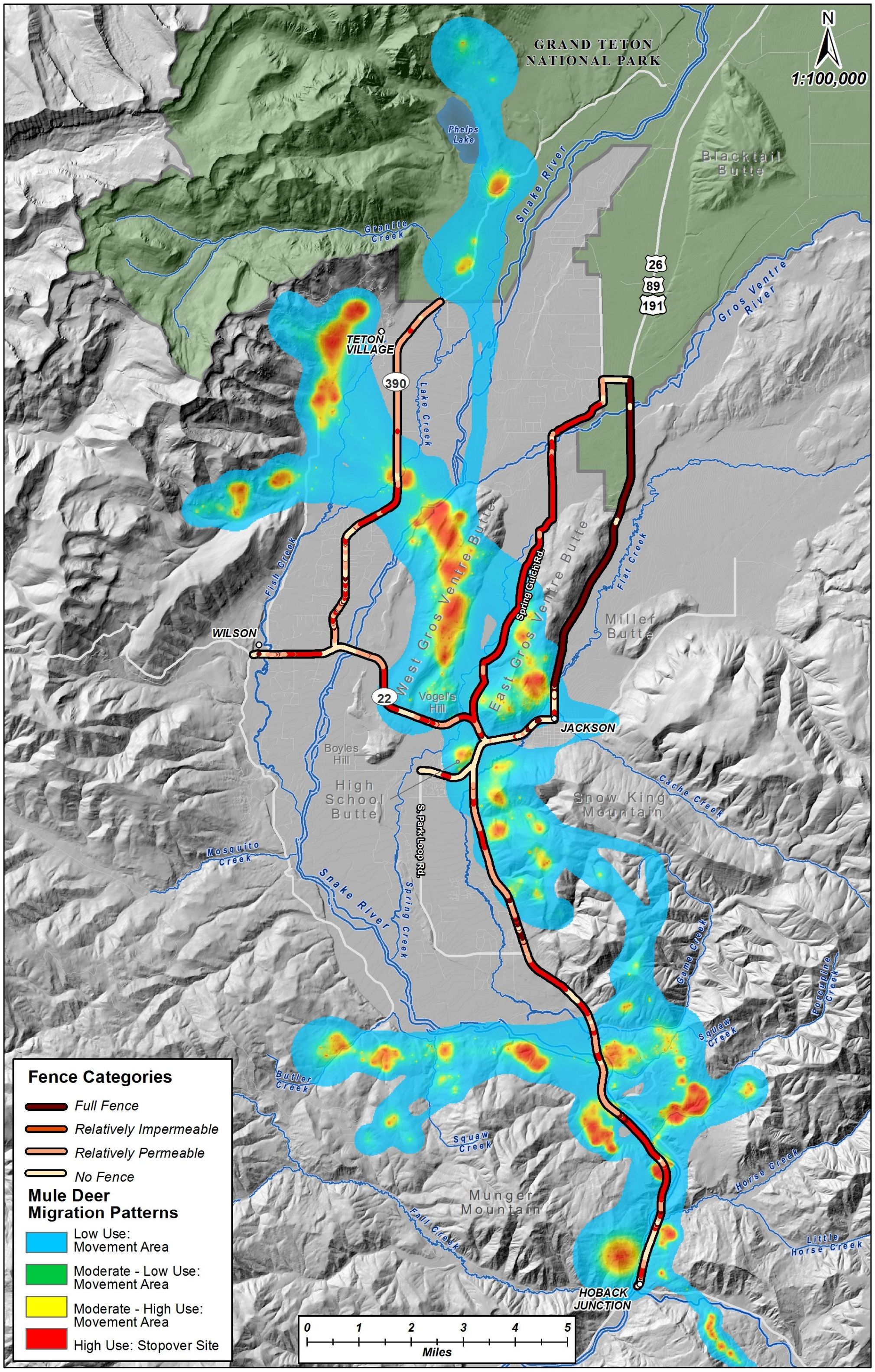


Figure 18. Population-level Brownian bridge movement model utilization distribution overlain with fence categories.

DEER-VEHICLE COLLISIONS

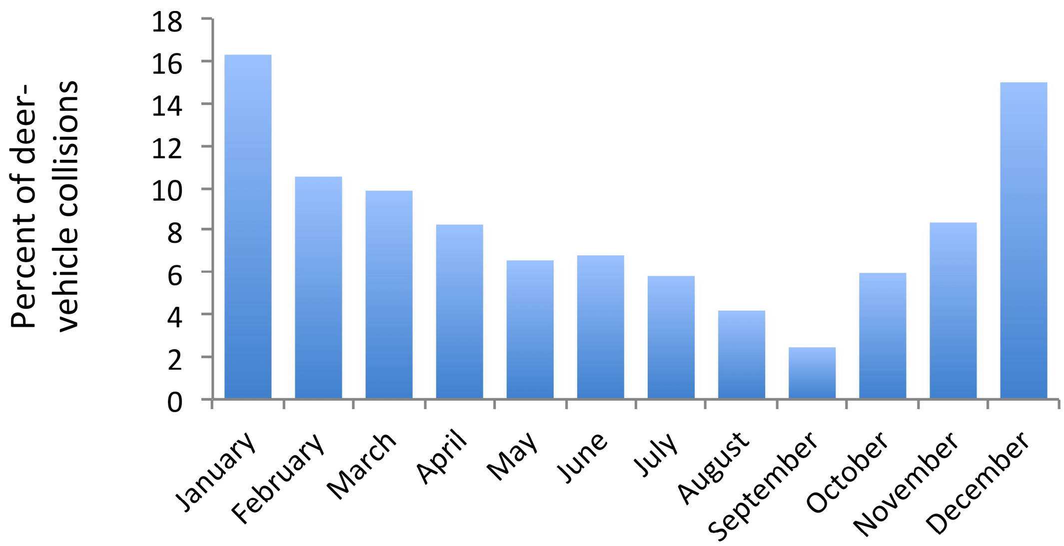
Temporal Patterns of Deer-Vehicle Collisions

Deer-vehicle collisions between 1990 and 2012 were most numerous in the months of December and January and were least numerous during the months of August and September (figure 19a). These seasonal patterns of deer mortality generally match the seasonal patterns of mule deer road crossings, which also peaked during the winter months. Diurnal patterns of deer-vehicle collisions showed a distinct peak between 19:00 and 23:00, with a lesser peak between 06:00 and 07:00 (figure 19b). This differs from diurnal patterns of deer road crossings, which peaked in the middle of the night.

Spatial Patterns of Deer-Vehicle Collisions

Deer-vehicle collisions between 1990 and 2012 were most numerous along Broadway (US-89/191 as it passes through the town of Jackson) (figure 20). Of the estimated 1,984 collisions that occurred during this time, 28 percent took place along the 3 mi (4.8 km) stretch between the northern intersection of US-89/191 with South Park Loop Road and the southern edge of the National Elk Refuge (mile posts 152-154). All in all, 69 percent of reported deer-vehicle collisions were located along US-89/191 south of the National Elk Refuge. By contrast, deer-vehicle collisions were relatively much fewer along US-89/191 north of Jackson, along WY-22, WY-390, and Spring Gulch Road.

a. Seasonal timing of collisions



b. Diurnal timing of collisions

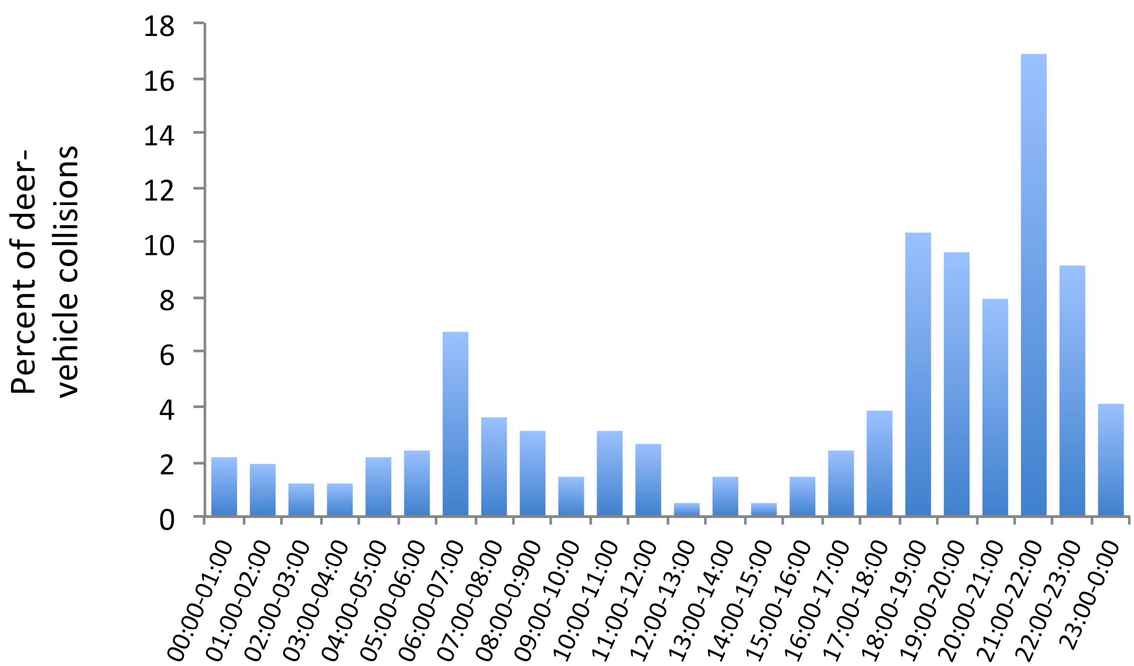


Figure 19. Temporal patterns of deer-vehicle collisions by (a) month and (b) time of day.

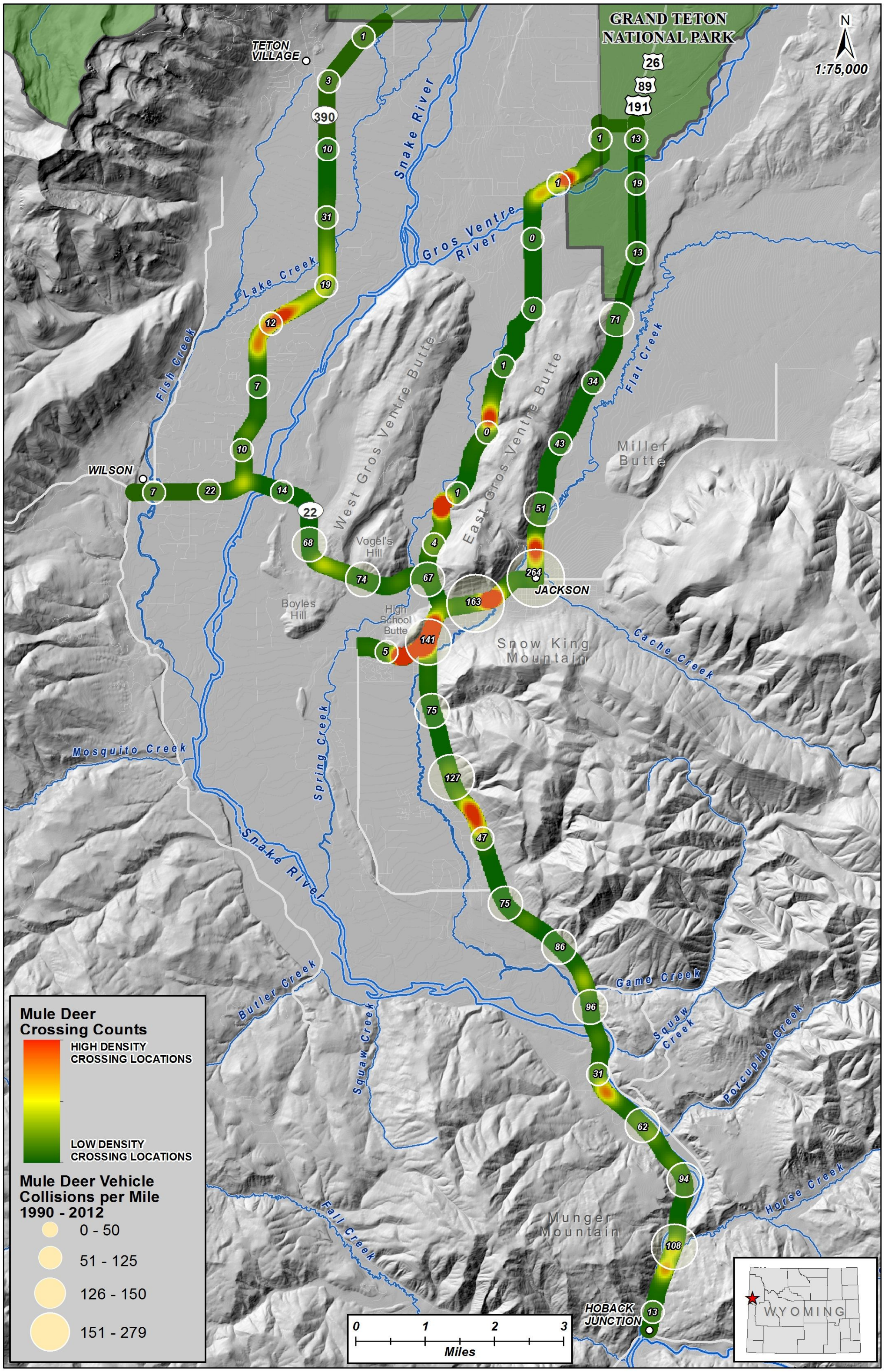


Figure 20. Spatial patterns of deer-vehicle collisions shown with deer road crossing utilization distribution. Vehicle collision data are shown for each mile of road.

CHAPTER 5. DISCUSSION

SEASONAL AND MIGRATORY HABITAT USE

Seasonal Habitat Use

Mule deer used several areas around the town of Jackson intensively during the winter months (December-May) (figure 10). Winter habitat use was particularly concentrated on the mixed shrub, herbaceous, and juniper-dominated south, southeast and southwest facing slopes of East Gros Ventre Butte, High School Butte, the ridge east of the Rafter J development, Boyle's Hill, and the Porcupine Creek, Game Creek and Horse Creek drainages. This affinity for open, hilly habitat dominated by sagebrush and bitterbrush—both of which are important winter forage for mule deer—is consistent with the winter habitat preferences of mule deer elsewhere in the region.[(41-43)] Prevailing winds from the southwest and higher incidence of solar radiation also cause south-facing slopes to have less snow cover than north-facing (typically conifer- and aspen-dominated) slopes or flat land, allowing easier access to forage. Deer also exhibited an affinity for areas dominated by mixed trees (many of which were ornamentals in developed areas) and riparian vegetation—potentially because these cover types afforded them thermal cover or browse.

Seventy-four percent of collared deer were migratory and moved to higher elevation summer ranges for the months of June-October/November. These migratory deer could broadly be separated into two groups: those that spent their winters on the buttes and hills around Jackson and their summers in the Teton Range ("northern group"), and those that spent their winters in the Porcupine Creek and Game Creek areas and summers on the northern and eastern slopes of Munger Mountain ("southern group"). This general pattern of moving to higher elevation meadows and forested areas in summer is consistent with observations of mule deer habitat use elsewhere.[(10)] Migration enables ungulates to access highly nutritious forage throughout the spring and summer, which is closely linked to juvenile survival [(44)] and probability of pregnancy for females in the fall.[(45-46)] Summer habitat use was particularly intense in the area around the Jackson Hole Mountain Resort ski slopes. It is likely that the habitat complexity formed by a mixture of open meadows and closed forest is attractive to deer.

Twenty-six percent of the collared animals were classified as "non-migratory"; these animals stayed in the lower elevation areas of the Jackson Hole valley throughout the year. Several of these animals had home ranges that centered around golf courses (Jackson Hole Golf and Tennis just north of the Gros Ventre River, and Teton Pines west of WY-390). It is likely that the high quality forage of these fertilized, irrigated golf courses attracted the deer and allowed them to maintain a relatively high nutritional condition even in the dry summer months. Other non-migratory individuals' home ranges centered on the slopes of Boyle's Hill, Porcupine Creek, and Game Creek. It appears that these individuals shifted their habitat use somewhat in summer to include the more forested north-facing slopes of these hills.

This pattern, wherein approximately one quarter of the sampled animals exhibited a non-migratory life strategy, has been reported in some ungulate populations elsewhere.[(9,12,43,47)]

However, the benefits of this strategy remain poorly understood. Non-migratory ungulates generally have lower nutritional condition than migratory animals but may, in some cases, benefit from reduced predation rates relative to their migratory counterparts.[9,11,12] Additionally, or alternatively, non-migratory animals may be accruing nutritional benefits from anthropogenic development (as in the case of the deer that appear to live near golf courses) that obviate the benefits of migration. In the case of the Jackson mule deer population, additional study is needed to elucidate the benefits of the non-migratory life strategy.

Although mule deer in other areas have been found to spend considerable amounts of time in fallow agricultural field,[43] we found only low levels of deer use in the agricultural land of the valley floor (figure 10). This could be due to the depth of snow in these flat areas, or due to the fact that most fields in the valley are fenced (though rarely with completely game-proof fencing). Deer did exhibit a significant affinity for the areas close to supplemental feed sites (mostly places where hay, deer pellets, or bird seed were available for regular consumption). Given high energetic costs and low food availability during winter months, such alternative food sources likely provide attractive, nutrient-rich additions to deer diets.

Interestingly, the collared deer in this study did not exhibit intense winter use of West Gros Ventre Butte. Although this butte is a very important stopover area during seasonal migrations (see below), it was not as intensively used by mule deer as other valley buttes with similar habitat characteristics—possibly because of its less steep southeast facing slopes. Moderate to high numbers of mule deer were observed in areas of West Gros Ventre Butte and the adjoining Vogel's Hill in the 1980's.[48] Because of the different ways in which these two sets of data were collected, it is difficult to determine whether deer use patterns have changed over time or not.

Short-Distance Migrations

Three quarters of the deer that we collared moved seasonally in distinct migration paths. "Migration" is typically defined as round-trip movement between distinct seasonal ranges.[14,49] Migrations are often thought of as linear paths taken by large numbers of animals, but recent studies have highlighted more complex dynamics. Particularly, migratory animals may stop over in distinct locations between core seasonal ranges,[15] and individual animals within a given population can take different migration routes between the same general seasonal ranges.[14]

Our collared deer exhibited many of the same patterns as migratory ungulates elsewhere. Deer movements over time followed the classic, periodic wave-pattern expected of migratory animals [31] (figure 5; appendix B). Results of our Brownian bridge movement modeling showed several key stopover sites along migration corridors—particularly for the northern group of deer that migrated between the Teton Range and the hills around Jackson (figure 9). Individual deer's migration routes at times diverged and at other times overlapped with other deer's migration paths.

In contrast to other migrations in the region, however, the migrations we observed were relatively short—averaging just 14.8 km (9.2 mi). Western Wyoming is well-known for having some of the longest ungulate migrations in North America; populations of pronghorn, mule deer, moose, and elk in this region have all been found to migrate over distances of 50-100 km (31-62 mi).[14,49] Relative to these long-distance migrations, Jackson Hole mule deer migrations were both short and rapid—with the average migration lasting only 80 hours. Migrations among the southern group of deer were particularly short, averaging just 8.5 km (5.3 mi) and many taking less than two hours to complete.

Although these mule deer migrations do not cover large distances, they are very likely important to the persistence of the population. Understanding key migration corridors and stopover sites is central to ensuring that mule deer are able to continue moving between seasonal home ranges in the future. Several heavily used stopover sites along the northern group's migration corridor are located near relatively developed areas—including East Gros Ventre Butte, West Gros Ventre Butte, and Teton Village. Migration corridors cross major roadways in several places (see below) and are constrained to relatively narrow passages in other locations, such as where they cross the Snake River. Further constraining movement corridors or stopover sites may impede mule deer's ability to move between seasonal ranges. Deer and other large ungulates have been shown to have a threshold response to development and road networks—moving through areas that have low densities of development or roads but not moving at all through areas that exceed some threshold density of development or roads.[50-52] Thus, it is important to consider that small, incremental constrictions to mule deer movement corridors and stopover sites could have large cumulative effects.

DEER BEHAVIOR IN RELATION TO ROADS

Although mule deer generally did not use developed areas of the landscape, they also did not avoid areas of good habitat (particularly winter habitat) next to roads or near developed areas. In fact, some of the most intensively used areas of winter range were on East Gros Ventre Butte and High School Butte, directly adjacent to residential and commercial areas of Jackson and the stretch of US-89/191 with the highest traffic volume. Studies of mule deer elsewhere have similarly found that animals do not avoid roadways [42,53]

Results from our direct observations of mule deer behavior indicate that deer incur a cost in terms of forage intake rate when they use habitat close to roads. In general, deer spent more time vigilant, standing, and moving—and 10-15 percent less time foraging— when they were close to roads (less than 200 m or 656 ft) compared to when they were far from roads (greater than 200 m or 656 ft). It likely that less time spent foraging translates to a lower rate of forage intake. This, coupled with potentially higher levels of stress associated with proximity to roads [54] may result in lower net nutritional gain for animals that spend a large proportion of their time near roads. However, it is difficult to predict the degree to which these effects translate to reduced nutritional condition among individual deer or the population as a whole.

Our finding that deer were more vigilant when close to roads is consistent with the theory that prey species react to human activities in much the same way as they react to predators.[55] Ungulates typically are more vigilant, move more, and forage less when predators are in the vicinity. For mule deer that spend time close to roadways, vehicles appear to elicit a fear response similar to the response that predators elicit. Elk [56] and big-horn sheep (*Ovis* *canadensis*) [57] have also been found to be more vigilant and to forage less in response to vehicles. Interestingly, however, mule deer behavior was not generally affected by traffic volume. Deer spent more time moving when close to high traffic volume roads relative to low traffic volume roads, but paradoxically, deer spent more time vigilant when the nearest road was a low traffic volume road. It is possible that deer whose home ranges include high traffic volume roads are more habituated to vehicles than deer whose home ranges only include low traffic volume roads.[50]

SPATIAL AND TEMPORAL PATTERNS OF DEER ROAD CROSSINGS

Non-Migration Road Crossings

The overwhelming majority of mule deer road crossings that we observed (95 percent) were made by migratory mule deer on their winter range or by non-migratory deer. The reason for this is clear when one considers the spatial relationship between the network of major, WYDOT-maintained roads and mule deer seasonal habitat use. Major roadways in Jackson Hole follow the valley floor, which is also the lower-elevation winter range for mule deer. Major roads are completely absent in the higher elevation summer range used by migratory deer.

Seventy-six percent of non-migration road crossings took place between 19:00 and 07:00 (figure 14). Crossings peaked in frequency between 00:00 and 05:00 and were infrequent during the middle of the day. Other studies of ungulate road crossing behavior have revealed similar patterns; elk, moose, and mule deer have all been found to cross roads more frequently at night than during the day.[39,58,59]

Spatially, road crossings were highly clustered in a few locations (figure 16 and 17). In general, areas where many crossings occurred were directly adjacent to or in the center of areas that deer used intensively in winter (figure 10). Crossing frequency was also related to a similar set of habitat variables as overall winter use (table 2, table 3). An overwhelming 40 percent of all observed crossings were located on US-89/191 (Broadway) and South Park Loop Road, along the southeastern flanks of High School Butte and East Gros Ventre Butte. Other areas with a high density of crossings were also located adjacent to key winter range areas, such as: US-89/191 along the Snake River (north of Hoback Junction); US-89/191 east of the Rafter J development; WY-390 south of Lake Creek Bridge; and Spring Gulch Road along the Gros Ventre River.

Results of our RSPF analysis of road crossing locations indicate that the probability of road crossings depended strongly on what type of fence was present along the roadway. Deer were significantly more likely to cross segments of roads with no fence compared to segments of road with full fencing. Deer had an intermediate likelihood of crossing roads with fences designated as “relatively impermeable” and “relatively permeable.” In general, fences were absent along roadways in the more developed and urban areas, such as along Broadway (US-89/191 between mile 152-155). This may in part explain why deer crossed the road so frequently in some of these areas. In some cases where road crossing hotspots were located along fenced roadways, the crossing hotspot aligned with places where permanent gaps (such as driveways) are known to occur (for example, at both crossings along the southern end of Spring Gulch Road). A more fine-scale understanding of the specific locations where deer cross the road would help to illuminate the degree to which deer cross different types of fences and/or rely on gaps or breaks in the fence to cross roads.

Our RSPF analysis of road crossing locations also indicated that several habitat variables are related to the likelihood of deer crossing roads. We found a negative relationship between the probability of crossing and the percent cover of agricultural land adjacent to the road. This is likely a reflection of the fact that deer did not utilize agricultural land very intensively. Conversely, there was a positive relationship between probability of crossing and percent cover of herbaceous vegetation, juniper, and mixed trees. These are all habitat types that were generally used intensively by collared mule deer on their winter range. Other cover types that mule deer utilize in the winter, such as riparian cover, were not significantly related to road crossings. This may be a reflection of the small sample size in the road crossing analysis, or may be because those cover types were scarce alongside roads.

In general, areas with many crossings seemed to occur in places where deer could move from steeper, shrubland-grassland areas into flatter areas. Although road crossings were not associated with cover of riparian vegetation, visual inspection of the data shows a pattern of deer crossing major roadways as they move between the hills or buttes and major streams and rivers. For example, the two areas of highest crossing frequency along Broadway (US-89/191) both separate high-use winter habitat on the west side of the road from Flat Creek on the east side of the road. Other areas of high crossing frequency were also located near to streams and rivers (e.g. Snake River east of WY-390; Gros Ventre River south of Spring Gulch Road; Snake River east of US-89/191 in the area north of Hoback Junction). Whether deer were seeking out water, forage, or thermal cover in these riparian areas is not yet clear.

Interestingly, non-migratory deer contributed a much higher fraction of road crossings than migratory deer. Even though non-migratory deer only made up 24 percent of the collared animals, they accounted for 56 percent of the road crossings between January-April. Several individual non-migratory deer crossed roads especially frequently, while some of the migratory deer only crossed roads a handful of times over two years. Why non-migratory deer should cross the road disproportionately is not clear, but may reflect that these animals were more habituated than their migratory counterparts, or that non-migratory deer made greater use of anthropogenic food sources (including, potentially, hay or other livestock feed, fertilized lawns, or ornamental plantings) and crossed roads frequently to access these resources. The behaviors and foraging habits of migratory versus non-migratory deer merit further investigation to understand why non-migratory animals cross roads so much more frequently than migratory ones.

Migration Road Crossings

Migration road crossings accounted for only 5 percent of all road crossings. Although few in number, these crossings are likely very important for sustaining the population. Temporally, most migration crossings (58 percent) occurred in May-June, with another 34 percent occurring in October-December. Most migration crossings took place in the middle of the night (23:00 to 02:00) or early in the morning (06:00 to 09:00). Most road crossings that took place during migrations were part of long steps between sequential GPS collar fixes, indicating rapid movement. Spatially, migration crossings clustered in several key places. Some deer in the northern group crossed US-89/191 near its junction with WY-22, and almost all of the deer in this group crossed WY-390 at or very close to Lake Creek Bridge. It is possible that deer use this bridge as an underpass and do not actually cross the roadway of WY-390. This crossing pattern was distinct from the numerous non-migration crossings that occurred on WY-390 in the two miles south of Lake Creek Bridge. Deer in the southern group generally only crossed US-89/191 once as part of each migration. Crossings were concentrated at two locations along the Snake River. It is possible that these are places where deer can cross the river most easily.

SPATIAL AND TEMPORAL PATTERNS OF DEER-VEHICLE COLLISIONS

The spatial and temporal patterns of deer-vehicle collisions in the study site were similar in some respects to patterns of deer road crossings, but also differed in several important respects. While road crossings were most frequent in January and February, vehicle collisions were most likely to occur in December and January (16 and 11 percent respectively of all deer-vehicle collisions between 1990 and 2012). Both road crossings and deer-vehicle collisions were much less likely to occur in the spring, summer, and fall (May to November) than in the winter (December to April). Thus on a broad seasonal scale, crossings and collisions showed similar patterns. This makes sense, since deer are much more likely to be found near roadways during the winter months than the rest of the year.

On a daily time scale, however, there was less agreement between patterns of deer road crossings and vehicle collisions. Fifty-four percent of reported deer-vehicle collisions took place in the five hours between 18:00 and 23:00, with an additional 7 percent of collisions occurring between 06:00 and 07:00. Collisions were infrequent between 23:00 and 06:00. In contrast, most road crossings occurred in the middle of the night, between 00:00 and 05:00. This difference in the timing of deer road crossings versus vehicle collisions suggests that collisions are most likely to occur in the post-dusk and pre-dawn periods when traffic volumes and the likelihood of deer crossing the road are both moderate. The same pattern of WVCs occurring more frequently in the evenings and early mornings has generally been observed elsewhere.(1)

Spatially, there was also a mismatch between road crossing and vehicle collision patterns (figure 20). Most collisions (69 percent) were located along US-89/191 between Hoback Junction and the northern edge of Jackson (southern edge of the National Elk Refuge). Collisions were most prevalent in the 3 mi (4.8 km) stretch of Broadway that passes directly through Jackson (28 percent of all collisions). This 3 mi (4.8 km) stretch was also the place where deer were most likely to cross the road. However, deer road crossings were much less frequent along most of US-89/191 south of Jackson and were never observed on US-89/191 north of Jackson (possibly because our collared deer did not use the area north of Jackson very intensively). In contrast, deer-vehicle collisions were relatively numerous all along US-89/191 south of town and moderately numerous on the same road north of town. Conversely, deer-vehicle collisions were relatively few along WY-390 and Spring Gulch Road, despite several hotspots of deer road crossings occurring along these roads.

Spatial patterns of deer-vehicle collisions need to be interpreted with some caution, since WYDOT has initiated some WVC mitigation measures in the last several years (e.g. reduced nighttime speed limits) that may have reduced the frequency of deer-vehicle collisions in those places. Nevertheless, it is clear that the spatial patterns of vehicle collisions were, in many cases, different from the spatial patterns of road crossings. In general it appears that collisions reflect traffic patterns—with more collisions occurring on the stretches of road that have highest traffic volume.

Few studies have directly compared patterns of ungulate road crossings with patterns of vehicle collisions. In a study similar to our own, however, Neumann[60] showed that the timing and spatial patterns of moose-vehicle collisions in Sweden were unrelated to patterns of moose road crossings. Collision patterns were instead related to traffic volume, speed limit, and visibility conditions.

Taken together, these results suggest that deer-vehicle collisions in our study area are a function of season, traffic volume, and other road conditions. Nevertheless, understanding where deer are most likely to cross roadways is valuable information for planning future WVC mitigations and for understanding how future changes to the roads or increases in traffic volume might impact mule deer and highway safety.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Two years of data on the movements and habitat use of 40 collared mule deer provide several important insights about the relationships between deer and roads in Jackson Hole and other places like it. One critical finding is that mule deer road crossings in the area are almost all associated with winter habitat use; only 5 percent of all observed road crossings took place during mule deer seasonal migrations. This has important implications for management and mitigation of deer-vehicle collisions—suggesting that mitigation strategies that have worked elsewhere for migration road crossings may not be as effective or desirable in Jackson Hole.

In many other parts of Wyoming, such as Nugget Canyon on US-30 and Trapper's Point on US-191, roadways bisect ungulate migration routes. Ungulates cross these roads infrequently, typically once during their spring migration and once during their fall migration. Groups of migrating ungulates follow narrow and relatively fixed routes, so that the places where they cross roads are predictable, once identified. The Wyoming Department of Transportation has been very successful in reducing vehicle collisions with migrating ungulates in several locations across the State. These successes have largely been achieved through installing crossing structures (underpasses and overpasses) and fencing large stretches of highway to funnel migrating ungulates to the crossing structures.

The relationship between mule deer and roads in Jackson Hole, however, is fundamentally different. The town of Jackson and the major roads surrounding the town are situated in the middle of mule deer winter range. Most of the individual deer that we studied had winter home ranges that straddled major roadways. These animals crossed roads regularly—several times a month, on average—primarily between December and May and primarily at night. It is likely that animals crossed roads to access the suite of resources (e.g. water, forage, cover) that they need as part of their daily existence. Crossing roads, for these deer, was not an exceptional event but rather part of the normal course of their behavior.

Deer road crossings were concentrated in a few general areas, mostly directly adjacent to preferred winter habitat (figures 21-23). Some of the most frequently crossed areas were:

- Broadway (US-89/191) between its northern junction with South Park Loop Road and the southern end of the National Elk Refuge (figure 21; miles 152-155).
- US-89/191 directly east of the Rafter J neighborhood (miles 149.5-150.5).
- US-89/191 north of the Hoback Junction, along the western banks of the Snake River (figure 22; miles 142-145.5).
- WY-390 in the area south of Lake Creek (figure 23; miles 1.5-4.5).

Places where deer most frequently crossed roads were related to proximity to preferred winter habitat and degree of fencing along the road. Deer were more likely to cross the road in places that had no fence on either side of the road compared to places where at least one side of the road was fenced. Deer particularly avoided crossing the road where there was "full" fencing (mesh, chain link, or a wall) but still showed some avoidance of crossing where other types of more permeable fencing were present (e.g. buck-and-rail, barbed wire, post-and rail, or post-and-wire fence). These results indicate that the degree and type of fencing can have strong impacts on how deer move through the landscape and where they choose, or are able, to cross roads.

Patterns of deer-vehicle collisions overlapped partially, but not completely, with patterns of deer road crossings. Deer-vehicle collisions over the last 22 years were most common along US-89/191 between Hoback Junction and the northern end of the town of Jackson. Even in places along US-89/191 where deer crossings were rarely observed, deer-vehicle collision rates were moderate to high. Conversely, we identified areas where deer frequently cross roads but are relatively unlikely to be hit (e.g. Spring Gulch Road, South Park Loop Road, and WY-390). It appears that deer-vehicle collisions are most likely to occur on stretches of road where traffic volumes are high, particularly when those high-volume roads pass by key mule deer winter habitat. Deer-vehicle collisions were also most likely to occur in the first several hours after dark (19:00 to 23:00)—a time when moderate traffic volumes overlap with moderate likelihood of deer crossing the road (compounded, of course, by drivers' reduced ability to see deer at night).

Three quarters of the mule deer that we collared migrated out of the valley floor and spent the months from June to October or November in higher elevation summer ranges. Road crossings and deer-vehicle collisions were much less frequent during these months than during the winter months. Migratory deer did cross major roadways as part of their migration paths. Key migration road crossings were located on WY-390 at or near Lake Creek, on Broadway (US-89/191), and on US-89/191 along the Snake River south of Game Creek. Although migration road crossings only accounted for 5 percent of all road crossings observed, these crossings are likely just as important to the persistence of the deer population as the much more numerous winter road crossings.

These findings may shed light on mule deer relationships with roadways in other areas where roads and human development overlap with mule deer winter range, such as the Thermopolis region. As development in Sublette and Lincoln counties (where many mule deer overwinter) grows, it is likely that interactions between roads and mule deer on their winter range will become more common. Understanding these interactions is important for mitigating deer-vehicle collisions.

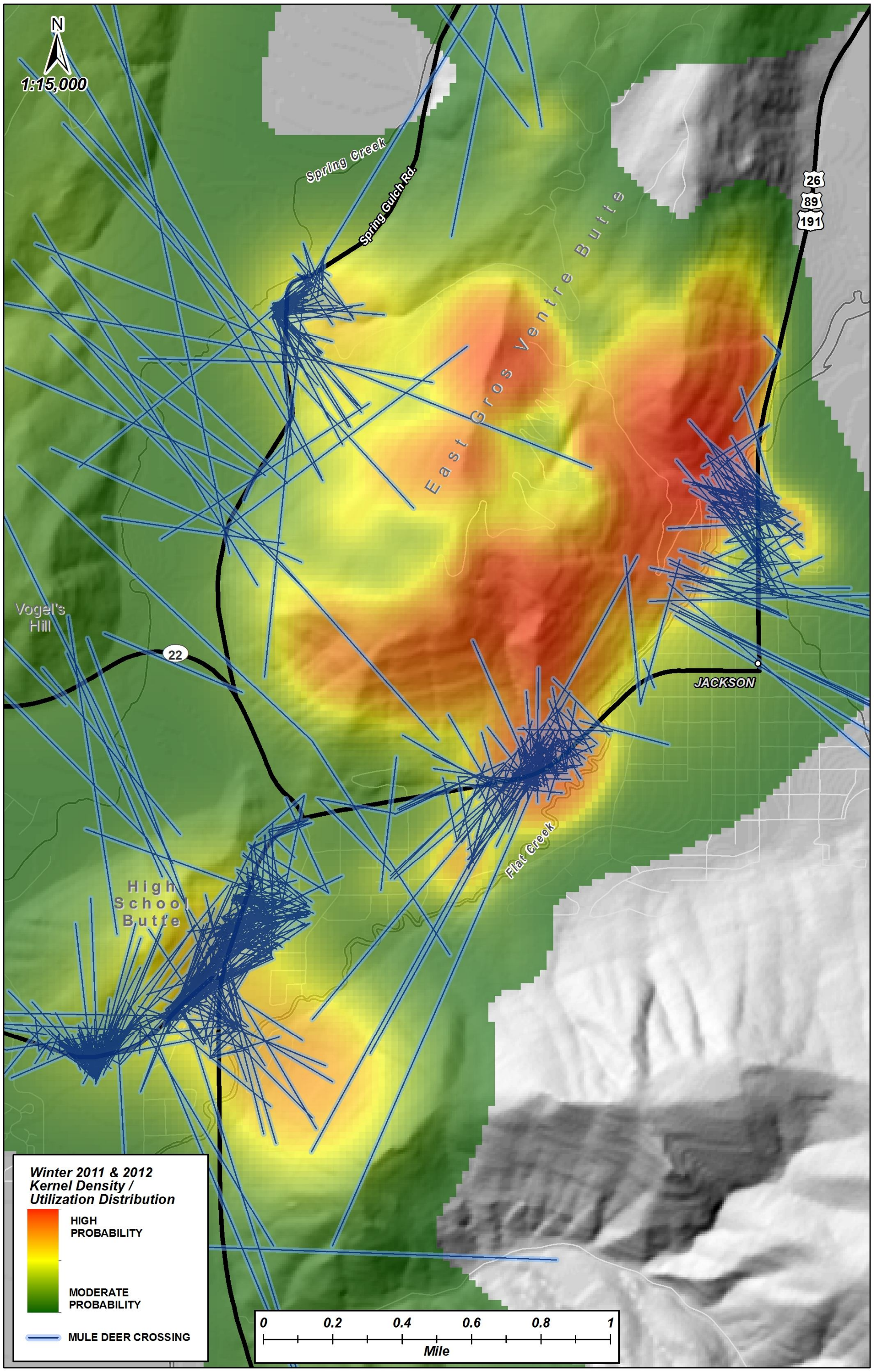


Figure 21. Winter population-level utilization distribution overlain with deer crossing lines (lines connecting consecutive GPS locations that straddled a major roadway), zoomed in for Broadway (US-89/191).

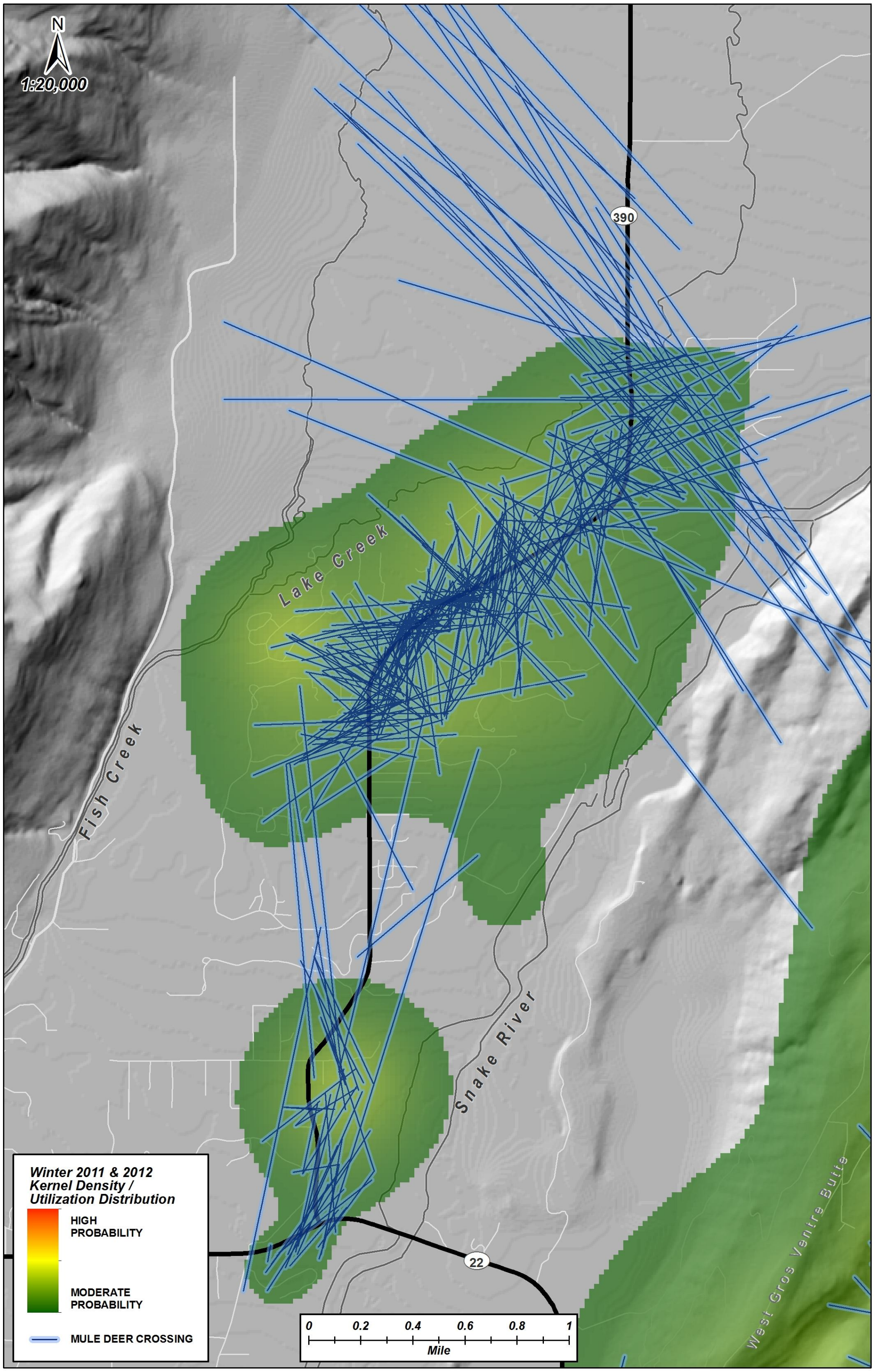


Figure 22. Winter population-level utilization distribution overlain with deer crossing lines, zoomed in for WY-390.

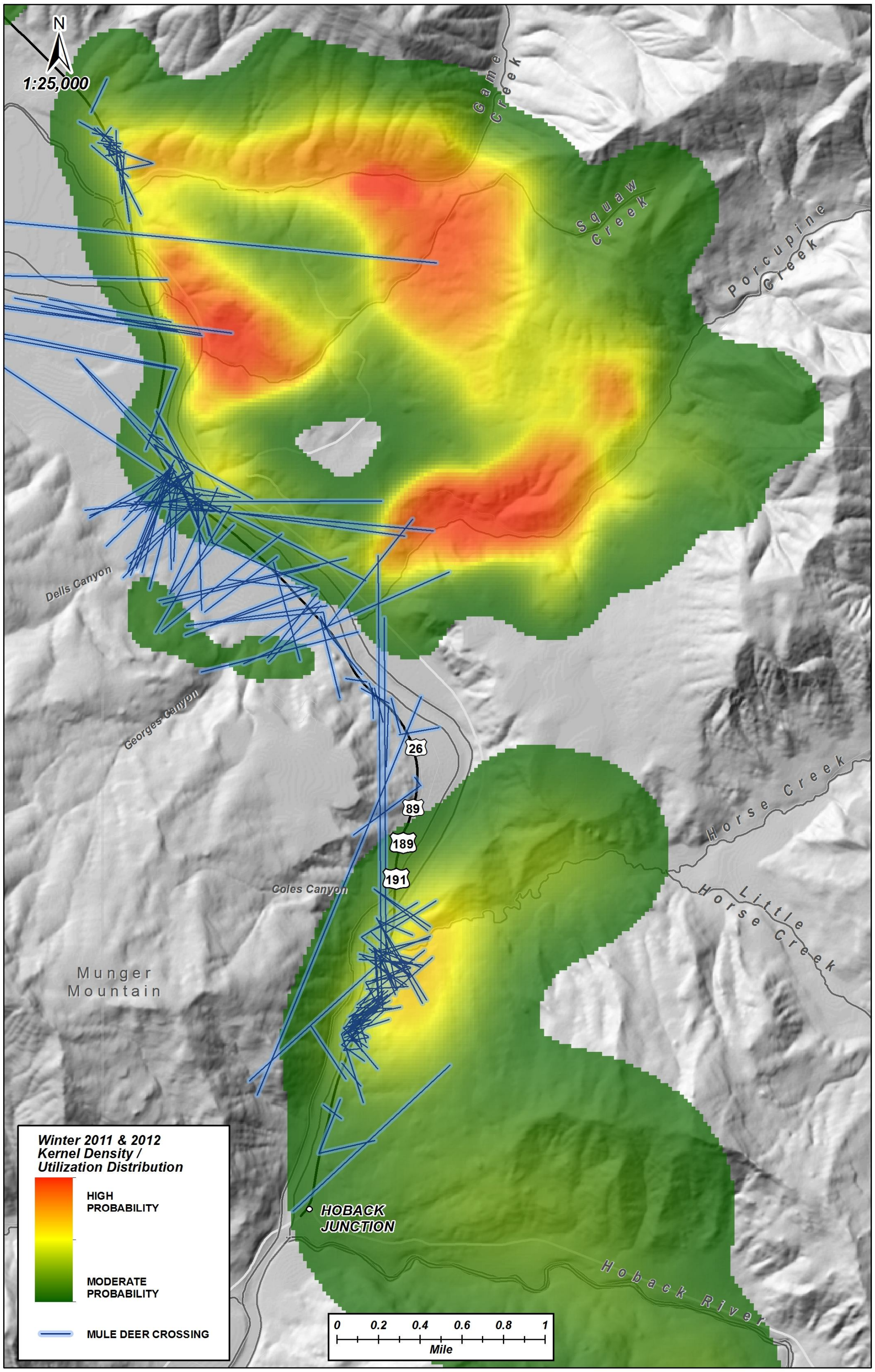


Figure 23. Winter population-level utilization distribution overlain with deer crossing lines, zoomed in for south US-89/191.

RECOMMENDATIONS

Deer-vehicle collisions present a significant highway safety issue. As traffic volumes in Jackson Hole continue to increase, deer-vehicle collisions are likely to become more frequent—incurring rising costs to drivers—without mitigation. At the same time, the community of Jackson Hole places a very high value on wildlife and conservation. People value the high densities of wild ungulates, such as mule deer, that occur in the area. This is evidenced by the prominent focus on accommodating wildlife in the recent revision of the Jackson/Teton County Comprehensive Plan.(61) Ensuring that mule deer continue to use the valley throughout the winter is a high priority for many people in Jackson Hole.

The fact that the roadway infrastructure in Jackson is centered on mule deer winter range and not simply within a migration corridor presents some unique challenges for mitigating deer-vehicle collision rates. Any mitigation effort will need to ensure that deer can cross roads not only safely, but also frequently and in multiple locations. A 2010 report by the Western Transportation Institute(62) concluded that crossing structures (both under- and over-passes) would be suitable mitigation strategies for wildlife-vehicle collisions in Jackson Hole. This conclusion was based on the large reductions in wildlife-vehicle collision rates that have been achieved with crossing structures elsewhere. However, the authors of the report focused primarily on the migration movements of large ungulates; they did not consider that mule deer, in particular, spend the whole winter in Jackson Hole and cross roads frequently as part of their winter habitat use. Therefore, the challenge with roadways in Teton County is to reduce WVCs while simultaneously providing deer frequent access to crucial winter range.

Recommendation 1—Multiple Mitigation Strategies

A suite of mitigation strategies should be considered for each mule deer crossing hotspot. Mitigations such as seasonal or daily speed reductions, driver visibility enhancements, vegetation management (e.g. mowing), traffic signals, message signs, as well as crossing structures with required funnel fencing should be evaluated for each hotspot.

Terrain or other design considerations may limit the practicality of constructing crossing structures. Further, most crossing structures require impermeable funnel fencing to effectively function. In areas where a large number of openings in funnel fences (e.g. driveways or side streets) are required (e.g. Broadway Avenue), a reduction in the funneling function would be expected, rendering the crossing structure ineffective. Therefore, suites of mitigation strategies other than crossing structures may be required to effectively reduce WVCs and provide deer access to their crucial winter habitat.

Recommendation 2—Multiple Crossing Structures

A single crossing structure per area of high crossing likelihood and may not provide sufficient means for non-migratory, wintering deer to exploit all components of their winter habitat. Long sections of impermeable fencing associated with a single crossing structure may reduce WVCs but may be counterproductive to providing these deer access to crucial components of their winter range.

Instead of a single crossing structure, a series of crossing structures at frequent intervals within a crossing hotspot should be considered so as to provide sufficient crossing opportunities to maintain connectivity in mule deer winter habitat. If the presence of a single crossing structure unduly restricts access to various components of winter range, the long-term viability of the deer population may inadvertently be jeopardized.

Recommendation 3—Fencing Design

Since the type of fencing adjacent to the roadway influences crossings by deer, roadside fencing should be considered as a crossing mitigation tool. Impermeable roadside fencing can, on the one hand, funnel animals to cross at safe locations or mitigation sites. On the other hand, roadside fencing, both impermeable and permeable, could inadvertently funnel animals to cross at areas with unsafe characteristics (e.g. high traffic volume, high vehicle speeds, or poor visibility). Since deer preferentially use fence openings, placement of openings should be carefully considered in terms of how it impacts deer crossing behavior.

Recommendation 4—Driver Behavior

Reduced nighttime speed limits and driver awareness campaigns should be considered part of the suite of mitigation tools. Although these mitigation options are not thought to be very effective in reducing wildlife-vehicle collision rates in general, using them to enhance mitigation effectiveness may be warranted. A number of local non-profit organizations have conducted extensive campaigns to raise driver awareness in Teton County. These techniques could be used to increase driver awareness, particularly in the winter when local traffic is prevalent and visitor numbers are low. Reduced speed limits and driver awareness campaigns are much cheaper to implement than crossing structures and would not require altering or closing off the movement pathways used by deer.

Recommendation 5—Monitoring Mitigation Effectiveness

An adaptive approach to reducing WVCs should be considered. This will entail testing and monitoring the effectiveness of specific mitigation measures and adapting them, based on the results obtained, to maximize the effectiveness of these measures to the local situation.

Recommendation 6—Planning for Multiple Species

This study focuses on mule deer. However, elk and moose also frequently cross major roadways in Jackson Hole. In considering any potential mitigation measures, it is important to weigh their effects and effectiveness for all species of large ungulates, based on the best information available. Additional research may be necessary to improve our understanding of where elk and moose are most likely to cross roads and whether mitigations measures planned for mule deer will be effective for these other species.

CHAPTER 7. OUTREACH AND EDUCATION

PRESENTATIONS

Hall, L.E., S. Dwinnell, L. Work, P. Hallsten, G. Fralick, D. Brimeyer, S. Dewey, B. Hammond and S. Fagan. 2011. Understanding mule deer (*Odocoileus hemionus*) movements and responses to roadways in northwest Wyoming. Poster presentation. The Wildlife Society, Wyoming Chapter, 2011 Annual Meeting.

Riginos, C., Hall, L.E., Krasnow, K., Graham, M.G., Sundaresan, S.R., Brimeyer, D., Fralick, G., and Wachob, D. 2013. Mule deer movements and habitat use in relation to roadways. Paper presentation. The Wildlife Society, Wyoming Chapter, 2013 Annual Meeting.

MEDIA COVERAGE

National coverage:

- USA Today.
- Yahoo! News.
- Assignment Earth.

Regional coverage:

- WY Public Radio.
- Casper Star Tribune – Stopping deer-vehicle collisions: Biologist studies the animal's roaming habits in order to prevent accidents (May 15, 2011).

Local coverage:

- Jackson Hole News & Guide.
    - Study starts to reveal where deer cross roads (December 7, 2011).
    - More mule deer will be collared for crash study (November 24, 2011).
    - Biologist studies mule deer to prevent roadkill: Research to better understand animal habits might help reduce roadkill carnage (May 4, 2011).
    - Science Schools, state to track mule deer: Information from 3-year study could help design animal underpasses, overpasses for highways (July 21, 2010).
- Jackson Hole Daily.

EDUCATION AND OUTREACH

During the course of the research process, we engaged with and educated members of the public through a wide variety of means:

- Educated 73 Teton Science Schools Graduate students and AmeriCorps interns on mule deer road relations and telemetry techniques. Through Teton Science Schools' programming, these educators have passed this information to hundreds of students from across the country.

- Demonstrated radio telemetry and field data collection to 107 field education students and families.
- Presented project to 28 community members, including landowners, interested citizens, high school students and WYDOT representatives.
- Collaborated with two high school seniors to develop a capstone film project summarizing project goals, data collection efforts and research outputs.
- Provided carcass data to support a high school math class project.
- Shared research goals and project progress with 25 NPS concession guides as part of a two-day guides' training.
- Educated 15 Wind River Tribal College students on mule deer ecology, field techniques and project objectives.
- Trained citizen scientists in collecting data on collared deer through Nature Mapping Jackson Hole, Jackson Hole Wildlife Foundation and Meg & Bert Raynes Wildlife Fund; developed database for citizen observations of marked deer.
- Educated Jackson Hole Mountain Resort patrons on a weekly basis on project goals and local ungulate ecology (summer 2011 and 2012).
- Developed curriculum materials with TSS graduate student emphasizing mule deer behavior observations and the scientific process.
- Presented to 20 University of Wyoming Environment and Natural Resource undergraduate students on roadway and mule deer ecology and radio-telemetry techniques.
- Collaborated on a Video Blitz project through local nonprofit, 1 Percent for the Tetons, focusing on planning and policy, using mule deer as a case study (2012).

UPCOMING ACTIVITIES

Over the next two months, we are planning the following public education and partner outreach activities:

- Oral presentation of project results, followed by open discussion, for the Jackson office of the Wyoming Game and Fish Department.
- Oral presentation to other project partners.
- Oral presentation of project results to members of the public in Teton County through an open-invitation public seminar, to be held at the Teton County Public Library.

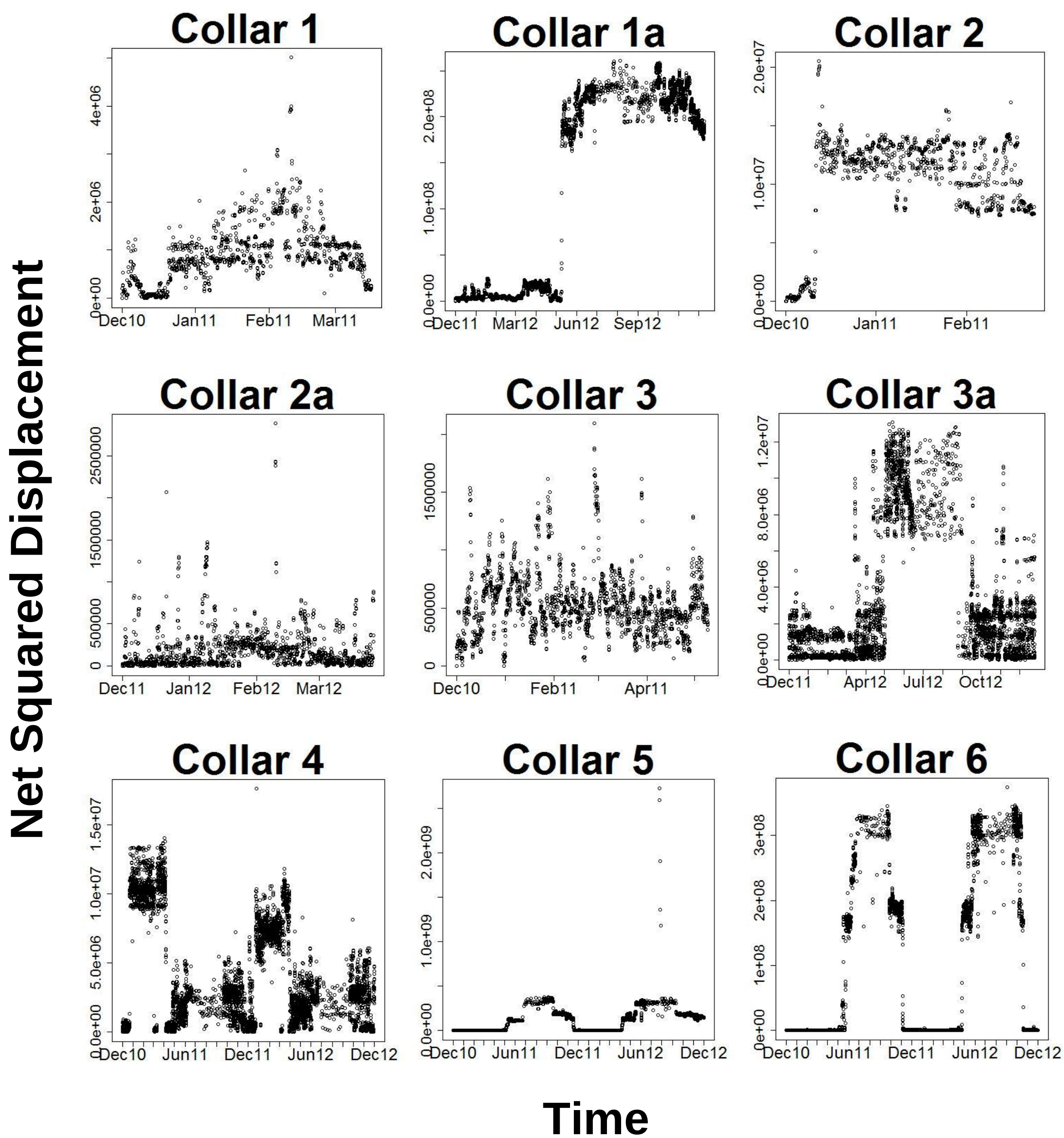
APPENDIX A. METHODS FOR ESTIMATING STATE-WIDE WVC COUNT

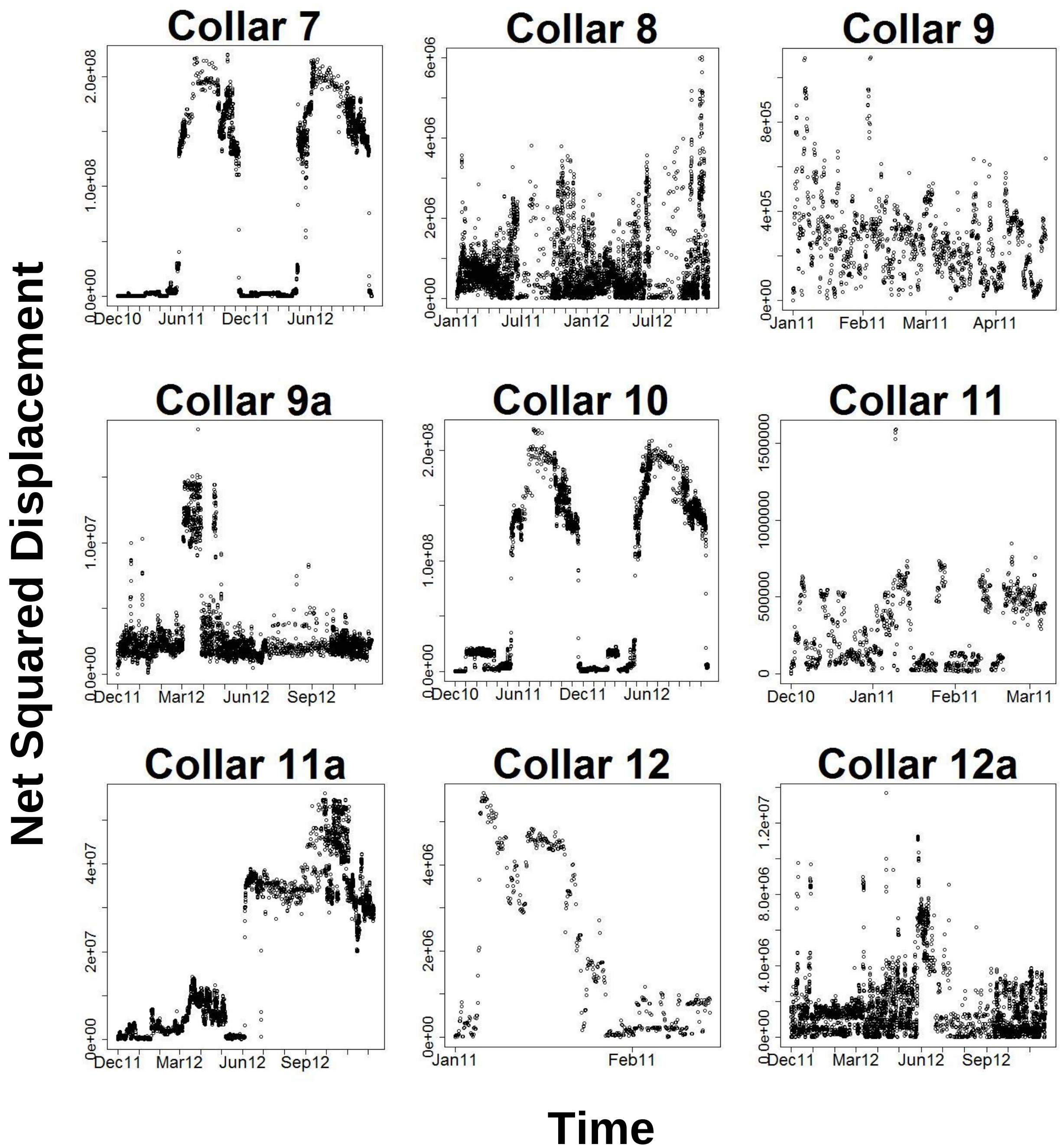
The number and locations of wildlife-vehicle collisions across the State of Wyoming were established from WYDOT Wildlife-Vehicle Collision and Carcass databases. WYDOT's WVC database contains records of collisions reported by State Highway Patrol—usually when the collision has resulted in property damage and/or bodily injuries valued at more than 1,000 dollars. The carcass data are collected by Highway Maintenance crews and capture information about collisions that may not have otherwise been reported.

We merged the records of all collisions and carcasses that were recorded between 1994 and 2012 and converted tabular data into a spatially explicit geo-database. WYDOT maintains spatial datasets for major travel routes and whole mile reference markers. However, WYDOT WVC and carcass records are referenced to a 1/10th mile (0.16 km) marker. In order to join collision and ±±carcass records to WYDOT's whole mile reference system, we created a 1/10th mile (0.16 km) marker reference dataset. Tabular records with route and milepost information were spatially joined to the 1/10th mile (0.16 km) reference dataset. Any data with geographic/projected coordinates without a 1/10th mile (0.16 km) marker reference were snapped spatially to the nearest major travel route, and then to the nearest 1/10th mile (0.16 km) marker. Records located more than 152 m (500 ft) from a major road were removed.

Records with "unknown," "other," or "other wild" were removed. To remove duplicate records, we first identified records that shared the same carcass number and combined their attributes. We then targeted remaining duplicates by flagging records with the same date and within 0.32 km (0.2 mi) of each other. These flagged records were further inspected to see if the sex and age were identical; if so, these records were combined.

APPENDIX B. NET-SQUARED DISPLACEMENT PLOTS FOR ALL COLLARED MULE DEER

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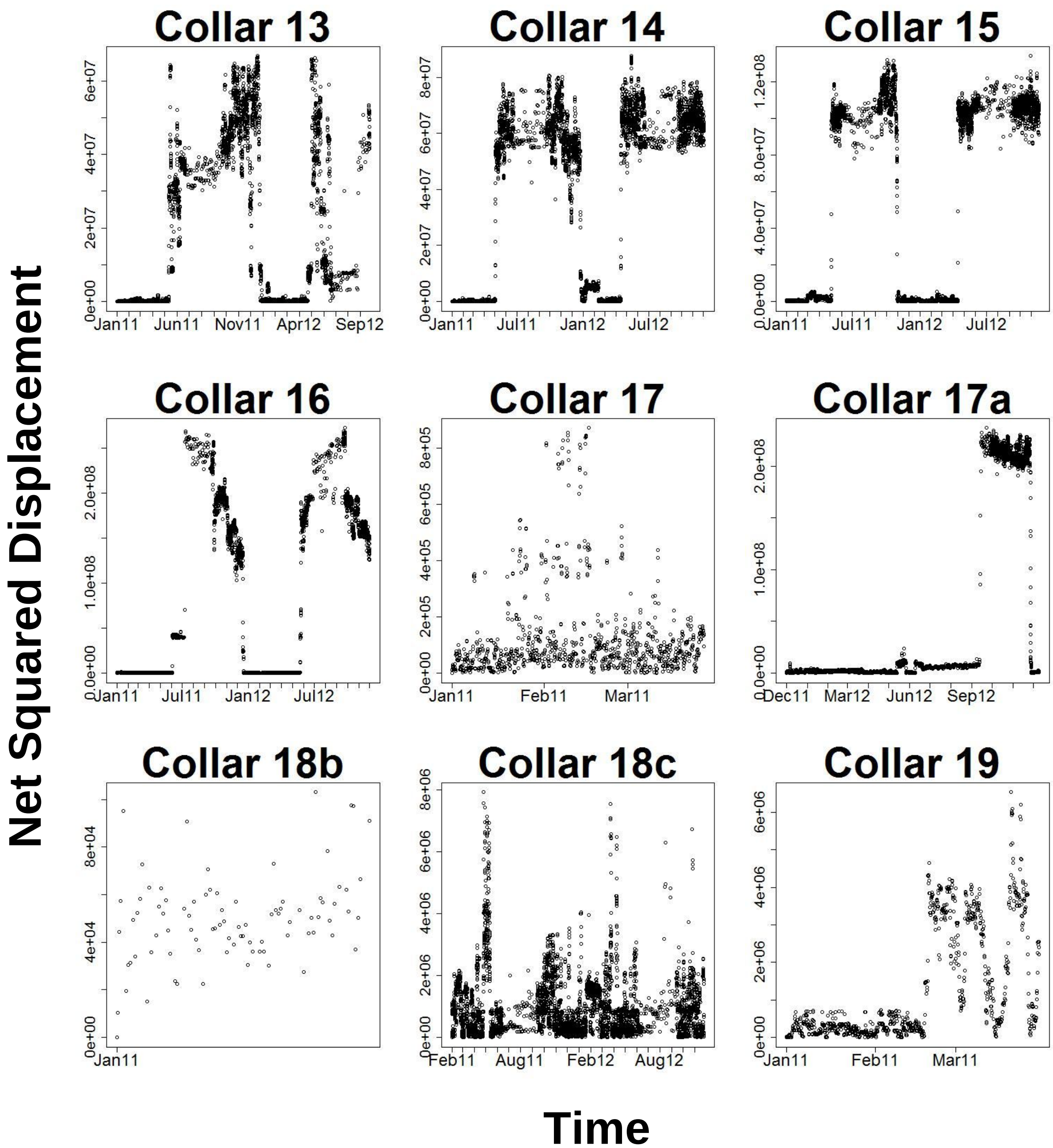
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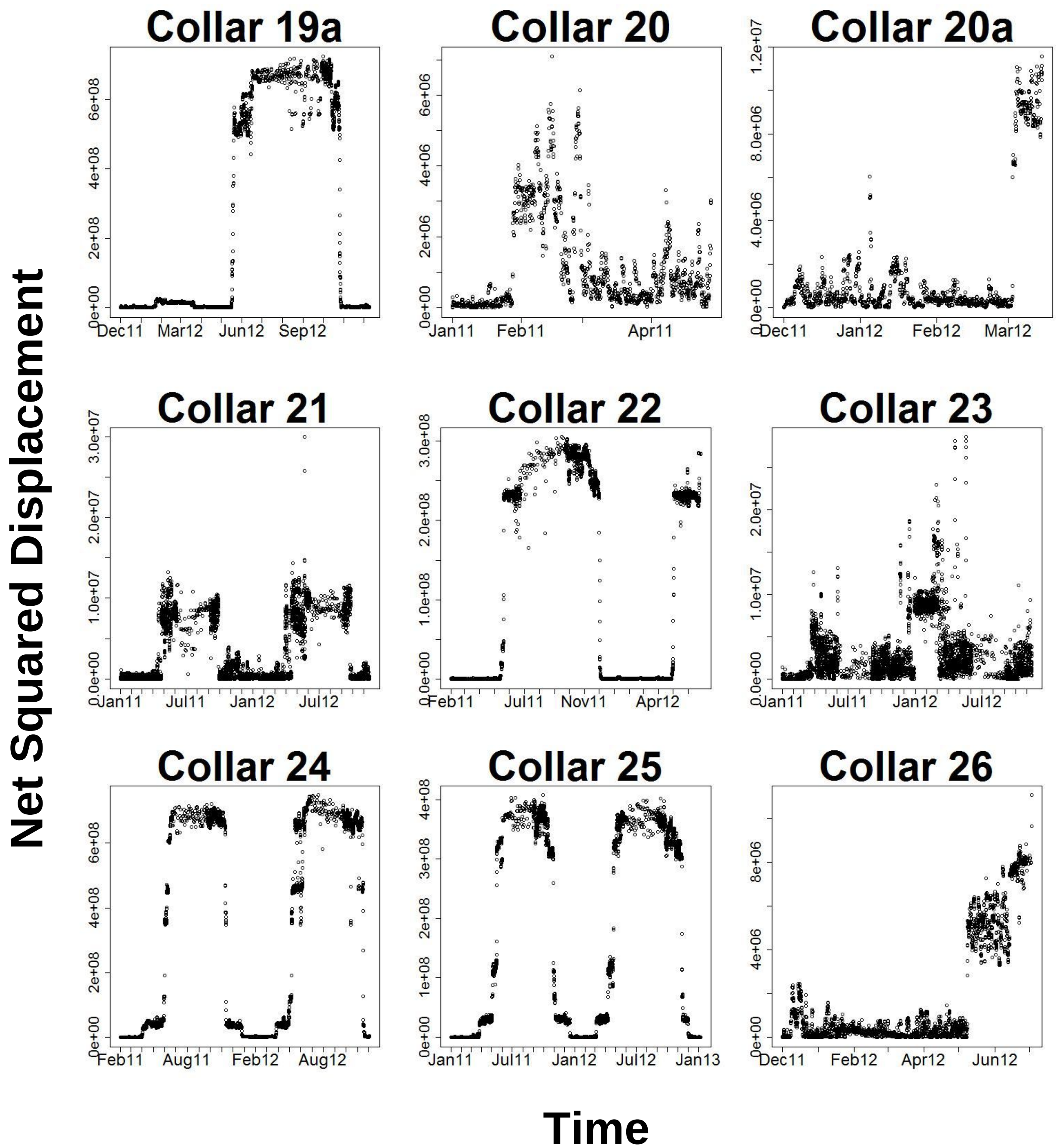
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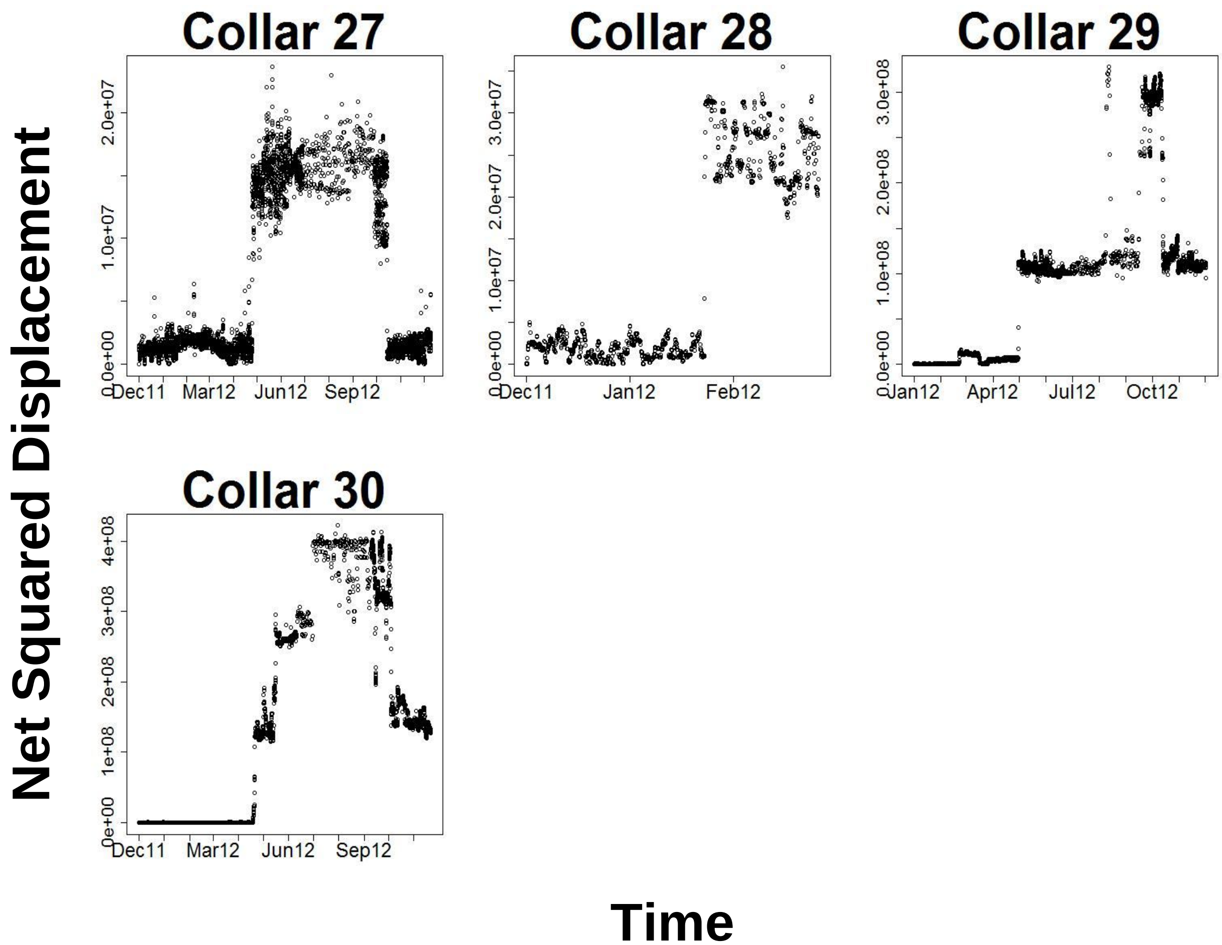
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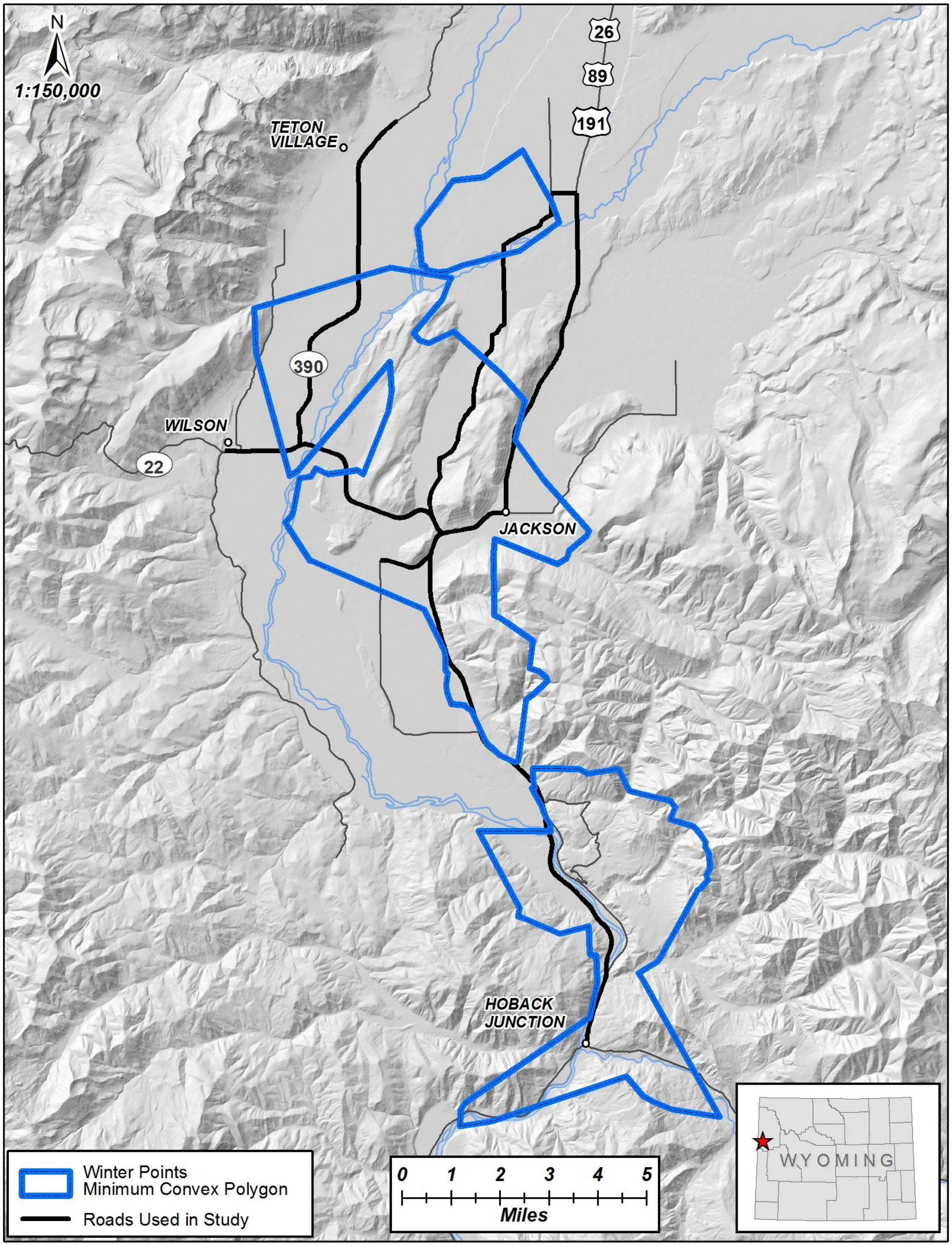
APPENDIX C. WINTER HOME RANGE OVERLAY FOR ALL COLLARED DEER



Winter home range for all deer, derived from overlaying the winter home ranges (minimum convex polygon) of all individual deer. Sampling for winter habitat use and road crossing RSPF analyses was constrained to this overall polygon.

APPENDIX D. MODEL AICc VALUES FOR RSPF ANALYSES

Winter Habitat Models

Maximal model: Number of Locations = Distance to Feed + Distance to Road + Slope + Slope^2 + Aspect + Aspect^2 + Agriculture + Herbaceous + Shrub + Coniferous + Aspen + Mixed + Juniper + Golf/Lawn + Riparian + Development

Best model: Number of Locations = Distance to Feed + Distance to Road + Slope + Slope^2 + Agriculture + Herbaceous + Shrub + Aspen + Mixed + Juniper + Golf/Lawn + Riparian

ΔAICc values and number of parameters (K) for models in which variables that explained the least amount of variation were sequentially dropped:

Model	**ΔAICc**	**K**
Drop Aspect^2	-2.02	15
Drop Aspect	-2.02	14
Drop Coniferous – percent cover	-1.01	13
Drop Developed land – percent cover	-2.01	12

Road Crossings Models

Maximal model: Number of Crossings = Fence Type + Slope + Distance to Feed + Agriculture + Herbaceous + Shrub + Coniferous + Aspen + Mixed + Juniper + Golf/Lawn + Riparian

Best model: Number of Crossings = Fence Type + Agriculture + Herbaceous + Mixed + Juniper

ΔAICc values and number of parameters (K) for models in which variables that explained the least amount of variation were sequentially dropped:

Model	**ΔAICc**	**K**
Drop Riparian – percent cover	-2.27	13
Drop Slope	-2.25	12
Drop Golf / Lawn – percent cover	-2.23	11
Drop Aspen – percent cover	-2.21	10
Drop Coniferous– percent cover	-2.18	9
Drop Distance to Feed	-1.17	8
Drop Shrub – percent cover	-0.15	7

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