FINAL REPORT

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SPATIAL AND TEMPORAL CHARACTERISTICS OF MOOSE HIGHWAY CROSSINGS IN THE BUFFALO FORK VALLEY, WYOMING

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Notice

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Abstract: The purpose of this study was to provide the Wyoming Department of Transportation (WYDOT) and the Wyoming Game and Fish Department (WGFD) with information that could be used to assess the importance of habitat, landscape, and anthropogenic features that are essential determinants in evaluating moose crossing locations in northwest Wyoming.

Approximately 30 moose were captured, tranquilized, and collared using global positioning system (GPS) collars. The collars were programmed to provide a fix every hour from 15 November to 15 June, and every five hours from 16 June to 14 November.

The results of this study demonstrated that models developed to assess adult female moose winter habitat selection could be used at a finer spatial scale to accurately identify areas where moose are most likely to cross U.S. Highway 26/287 in the Buffalo Valley. The moose crossing events were not randomly distributed, but occurred at predictable locations that could be estimated by examining winter habitat selection parameters that contained an abundance of forage provided by aspen and willow-dominated, riparian habitats, on either side of the road.

Key Words		Distribution Statement	
Wyoming, GPS, collar, moose, habitat, vegetation, structure, roadway design, crossing, migration.		Unlimited	
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SI* (Modern Metric) Conversion Factors

Approximate Conversions from SI Units

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	35.71	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	megagrams	1.103	short tons (2000 lbs)	T
Temperature (exact)				
°C	Centigrade temperature	1.8 C + 32	Fahrenheit temperature	°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	pound-force per square inch	psi

Approximate Conversions to SI Units

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 yards	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
Mass				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lbs)	0.907	megagrams	Mg
Temperature (exact)				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°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	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

ACKNOWLEDGMENTS

A project of this magnitude could not have been accomplished alone. Scott Becker would first like to thank the late Dr. Stanley H. Anderson for his belief in my abilities to accomplish this task and for providing me the opportunity to study a fascinating critter, the moose. Scott Becker would also like to thank my three remaining committee members Dr. Fred Lindzey, Dr. Chuck Anderson, and Dr. Tom Thurow for stimulating discussions and for providing helpful edits to this final report. This project would not have been possible without the funding and support provided by the Teton County Conservation District, Wyoming Animal Damage Management Board, Wyoming Department of Transportation (WYDOT), Wyoming Game and Fish Department (WGFD), and the Wyoming Governor's Big Game License Coalition/Wildlife Heritage Foundation of Wyoming.

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EXECUTIVE SUMMARY

To accommodate rises in traffic volume and to address highway safety concerns, transportation managers often need to expand existing travel corridors which may result in an increased risk of wildlife-vehicle collisions. Wildlife-vehicle collisions are not random events and appear to be related to the daily and seasonal activity patterns of animals. By examining the spatial and temporal patterns of wildlife crossings, managers can apply appropriate mitigation to reduce collision risk and maintain highway safety. The U.S. Highway 26/287 reconstruction project provided an opportunity to examine the influence of habitat, landscape, and man-made features that determine moose crossing locations in northwest Wyoming. A previous model developed to assess moose winter habitat selection was used at a smaller spatial scale to determine if it could accurately identify moose crossing locations along a 9.7 km (6.0-mi) section of U.S. Highway 26/287 that bisects a high-density moose winter range in the Buffalo Fork Valley. We used an independent sample of moose crossing locations to validate the predictive highway crossing map. We also examined temporal patterns of moose crossings and the influence of fence types.

The predictive map indicated that areas classified as high or medium-high predicted probabilities of use occurred between mileposts 3.2-4.5, 6.1-6.7, and 7.0-9.0. These areas were characterized by a high proportion of aspen and riparian/deciduous shrub habitat with little coniferous cover, low elevation, relatively flat slope, and moderate distance to cover. Of the 201 moose crossings recorded from the independent sample, 81% (n = 162) occurred in high to medium-high probability of use areas. Moose used high-use areas more than expected, medium-high and medium-low use areas as expected, and low-use areas less than expected. Although we were unable to directly measure the use of the Buffalo Fork and Blackrock Creek bridges, mileposts on either side of these structures were classified as high-use areas which suggest a high likelihood that moose utilized these structures to cross U.S. Highway 26/287. Moose crossed the highway more than expected during afternoon to early evening and less than expected during mid-day. A high proportion of fencing occurred along private lands adjacent to the highway that were not preferred moose habitat, therefore, moose crossed the highway more than expected in areas that contained no fencing and less than expected in areas that contained fencing. Fencing along the highway was not constructed to prevent moose movements and preferred habitat and landscape features appeared to have more influence in determining crossing locations than the presence of fencing.

Because aggregations of moose crossings occurred at predictable locations and the risk of collisions were highest during periods of limited visibility, managers could reduce speed limits and erect temporary warning signs during winter in areas classified as high and medium-high predicted probabilities of use to warn motorists of the increased risk of encountering a moose on the highway. Due to the low number of moose-vehicle collisions during this study (n = 1), major and costly mitigation may not be justified in the Buffalo Fork Valley unless collisions increase following highway reconstruction. Lengthening existing bridges over rivers and streams may facilitate animal movements under these structures. Moose are not the only animals that inhabit the Buffalo Fork Valley, thus, managers could develop mitigation to benefit multiple species while continuing to maintain motorist safety.

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CHAPTER 1

PROBLEM DESCRIPTION

Rising human populations create an increasing need to expand transportation corridors to accommodate the concurrent rise in traffic volume. This can lead to sharp increases in the number of wildlife-vehicle collisions (McDonald 1991, Oosenbrug et al. 1991, Groot Bruinderink and Hazebroek 1996, Farrell and Tappe 2007). In the United States, Conover et al. (1995) estimated that approximately 726,000 deer (*Odocoileus* spp.)-vehicle collisions occurred in 1991 resulting in an estimated 211 human fatalities. In 1991, deer-vehicle collisions cost an estimated $1,500 (U.S.) per accident and human injuries occurred in approximately 4% of collisions (Conover et al. 1995). Because not all accidents are reported, the actual number of deer-vehicle collisions may be much higher (Conover et al. 1995). When collisions occur with larger animals (i.e., moose [*Alces alces*]), the risk of human injury and increased property damage rises significantly (Joyce and Mahoney 2001). Methods to reduce wildlife-vehicle collisions have had mixed results. Mitigation to reduce the number of collisions or prevent animals from entering the roadway (i.e., roadside clearing, fencing, overpasses and underpasses) appear to be the most effective, but maintenance and repair costs often limit their implementation (Bashore et al. 1985, Feldhammer et al. 1986).

Wildlife-vehicle collisions can rarely be associated with a single factor, but the spatial and temporal patterns of accidents are not random events and appear to be related to daily and seasonal activity patterns of animals (Bashore et al. 1985, Belant 1995, Waller and Servheen 2005). In addition, traffic volume, speed limits, driver awareness, and weather conditions have been implicated as influencing the risk of collisions (Lavsund and Sandegren 1991, Modafferi 1991, Joyce and Mahoney 2001, Seiler 2005). Numerous studies have used modeling approaches to identify habitat, landscape, and anthropogenic (i.e., man-made) features that predict high collision risk areas (Hubbard et al. 2000, Nielsen et al. 2003, Malo et al. 2004, Seiler 2005, Dussault et al. 2007). These models aid managers in determining where animal travel corridors occur and where appropriate mitigation can be applied so that collision risk is reduced and habitat linkages are maintained (Clevenger et al. 2002, Ng et al. 2004, Kindall and Van Manen 2007).

Most studies of wildlife-vehicle collisions examined habitat and landscape characteristics once the frequency of accidents became socially unacceptable. Many roads in North America bisect important seasonal ranges of ungulates where few collisions have recently occurred, but the importance of identifying areas of potential increased collision risk can be valuable in addressing possible problem locations before they become chronic. By examining spatial and temporal patterns of animal movements associated with a roadway, proactive engineering can be implemented into existing roadway design or incorporated into the design phase of proposed highway reconstruction projects to reduce the chances that wildlife-vehicle collisions will reach a socially unacceptable level (Groot Bruinderink and Hazebroek 1996, Finder et al. 1999). The U.S. Highway 26/287 reconstruction project from Moran Junction to Dubois, Wyoming (Young and Sawyer 2006) is an example where mitigation can be incorporated into the design phase. A portion of this highway bisects a high-density moose winter range in the Buffalo Fork Valley (Houston 1968, Brimeyer and Thomas 2004) in northwest Wyoming.

Core moose crossing areas have been identified by snow-track surveys in the Buffalo Fork section of the U.S. Highway 26/287 reconstruction project (Young and Sawyer 2006). However, the influence of habitat, landscape, and anthropogenic features in determining crossing locations has not been investigated. We used global positioning system (GPS) collars to collect fine scale movement data for adult ($\geq$ 2 years) female moose that winter adjacent to U.S. Highway 26/287 in the Buffalo Fork Valley during winter 2005-2007. Using habitat and landscape variables that were deemed important predictors of winter habitat use, we developed a model to estimate habitat selection by adult female moose over the entire winter range (Chapter 2). We used this model at a smaller spatial scale to determine whether winter habitat selection patterns of moose could accurately identify crossing locations by moose along a 9.7-km (6.0-mi) section of U.S. Highway 26/287 that bisects winter range in the Buffalo Fork Valley. We also examined temporal patterns of moose crossing events and the influence of fence type in determining crossing locations.

CHAPTER 2

OBJECTIVES

The purpose of this study was to provide the Wyoming Department of Transportation (WYDOT) and the Wyoming Game and Fish Department (WGFD) with information that could be used to assess the importance of habitat, landscape, and anthropogenic features that are essential determinants in evaluating moose crossing locations in northwest Wyoming. The results will assist WYDOT in identifying, evaluating, and implementing highway designs and mitigation that improve safety to moose and motorists by reducing the risk of moose-vehicle collisions while maintaining highway permeability for moose. With an improved understanding of the spatial and temporal characteristics of moose crossings, a more efficient approach to mitigation can be applied to future highway redevelopment projects.

The primary objective of this study was to apply a model developed to estimate winter habitat selection by adult female moose to a 9.7-km (6.0-mi) stretch of U.S. Highway 26/287 in the Buffalo Fork Valley to determine if the model could be used to accurately identify crossing locations for a migratory moose population that winters adjacent to the highway. We also quantified the influence of fence types associated with moose crossing events and estimated the frequency and timing of crossings that occurred along U.S. Highway 26/287 and U.S. Highway 26/89/187 during the study period. To formally address the above objectives, we tested the following hypotheses: (1) moose crossing events are randomly distributed and occur in equal proportions throughout the day, (2) the location of moose crossings occur in equal proportion to the predicted probability of use (i.e., preferred habitat) within the highway study area, and (3) fence types are crossed in proportion to availability by moose.

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CHAPTER 3

TASK DESCRIPTION

Study Area

The study area was located about 50 km (30 mi) north of the town of Jackson, Wyoming and encompassed approximately 1,100 km^2 (425 mi^2; Chapter 2) of predominately public land in northwest Wyoming (Figure 1). It was defined by the winter distribution of GPS-collared adult female moose (Chapter 2) and included portions of Grand Teton National Park (GTNP) and Bridger-Teton National Forest (BTNF). Primary moose winter ranges occurred along the Buffalo Fork River, the Snake River, and Pacific Creek. Major roads within the study area included U.S. Highway 26/287, U.S. Highway 26/89/187, and U.S. Highway 89/287 (Figure 1). All were two-lane highways with speed limits ranging from 88 km/h (55 mi/h) in GTNP to 105 km/h (65 mi/h) outside of Park boundaries. From January 2005 to December 2007, mean daily traffic was estimated to be 952 vehicles/day along U.S. Highway 26/287 with a peak in traffic volume occurring during the tourist season from June through September (WYDOT 2006, 2007, 2008).

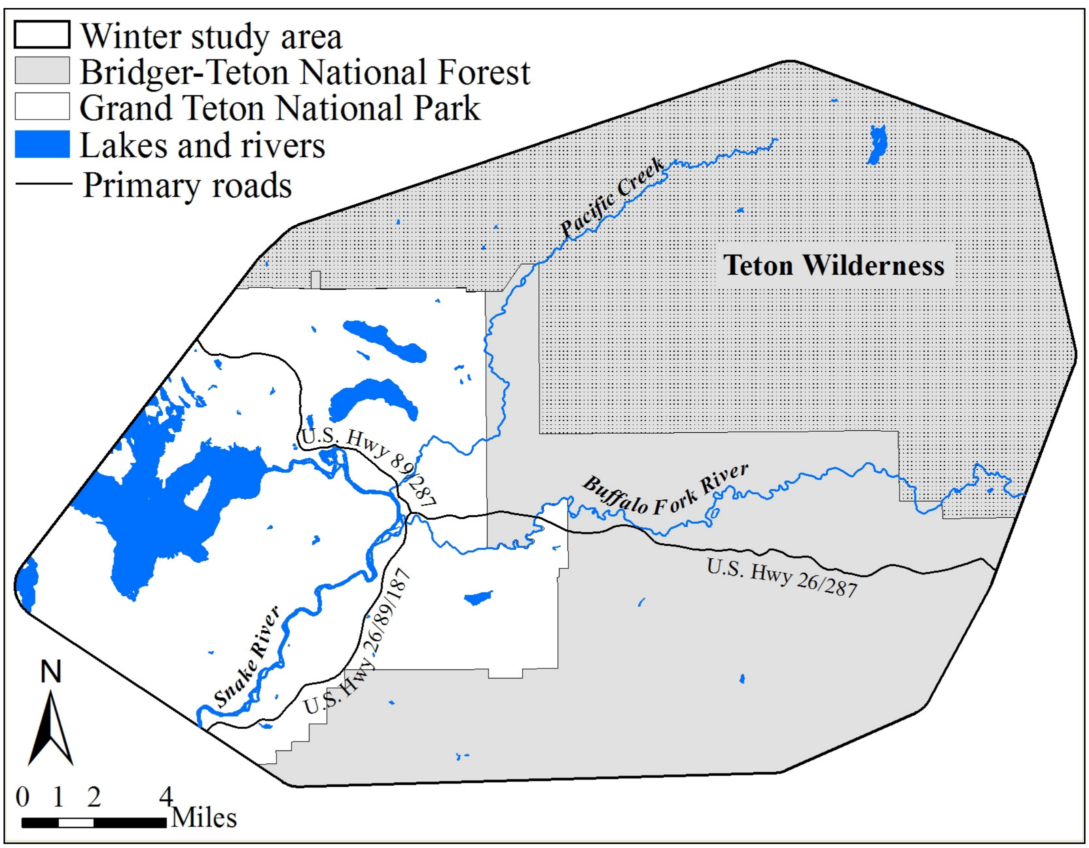

Figure 1. Study area in northwest Wyoming defined by the winter distribution of GPS-collared adult female moose (n = 22), 2005-2007.

Vegetation types occur along an elevational gradient (Whitlock 1993, Knight 1994) within the study area. Lower elevations and many south-facing slopes at higher elevations are dominated by big sagebrush (*Artemisia tridentata*). Mid-elevations are characterized by large stands of lodgepole pine (*Pinus contorta*) intermixed with Douglas fir (*Psuedotsugia menziesii*) and aspen (*Populous tremuloides*). Engelmann spruce (*Picea engalmanni*) and subalpine fir (*Abies lasiocarpa*) are found on north slopes and more mesic sites at lower elevations. Engelmann spruce, subalpine fir, and lodgepole pine intermixed with smaller stands of whitebark pine (*Pinus albicaulis*), limber pine (*Pinus flexilis*), and aspen dominate higher elevations. Alpine tundra occurs at the highest elevations while open forest parks and subalpine meadows dominated by grasses and forbs (i.e., flowering plants) occur at all elevations. Riparian areas are dominated by willows (*Salix* spp.) intermixed with narrowleaf cottonwood (*Populus angustifolia*) and occur in large, flooplain environments at lower elevations and along nearly all streams within the study area (Wigglesworth and Wachob 2004).

The climate is characterized by short, cool summers and cold winters. From 1975-2004, annual precipitation averaged 56.2 cm (22.1 in; range = 37.9 cm [14.9 in] – 79.1 cm [31.1 in]; http://www.cdc.noaa.gov/cgi-bin/Timeseries/timeseries1.pl; accessed 16 October 2005), but most of the annual precipitation falls as snow between November and May. The Teton Mountains to the west and the northern highlands along the Yellowstone National Park (YNP) boundary typically receive the greatest amounts of precipitation (Houston 1968, Cole 1969, Boyce 1989).

Moose Captures and Data Management

Adult female moose were captured from a helicopter on winter range in the Buffalo Fork Valley of northwest Wyoming during February 2005 and 2006. Moose were darted and immobilized with 10-mg thiafentanil oxalate (A-3080, Wildlife Pharmaceuticals, Fort Collins, Colorado, USA; McJames et al. 1994, Arnemo et al. 2003, Kreeger et al. 2005). Once handling was completed, thiafentanil was antagonized with an intramuscular injection of 300-mg naltrexone (Trexonil, Wildlife Pharmaceuticals, Fort Collins, Colorado, USA). All captured moose were fitted with TGW-3700 GPS collars with store-on-board technology (Telonics, Mesa, Arizona, USA) that were programmed to attempt a location fix every hour from 15 November to 15 June and every 5 hours from 16 June to 14 November. Location data were collected until 1 March 2007 when the collars were programmed to release from the moose. Upon retrieval of GPS collars, location data were examined and all unsuccessful fixes and obvious location errors were removed (D'Eon et al. 2002, D'Eon and Serrouya 2005). Data were not corrected for fix-rate bias because of the high fix-rate success observed (Chapter 2; D'Eon 2003, Friar et al. 2004, Hebblewhite et al. 2007). Three-dimensional fixes accounted for a high proportion of winter locations (Chapter 2), therefore, data were not differentially corrected because 3-dimensional locations generally have < 20 m error (Di Orio et al. 2003). Captures were performed in accordance with approved University of Wyoming Animal Care and Use Committee protocols.

Frequency and Timing of Highway Crossing Events

To estimate the number of highway crossing events during winter within the study area, we mapped winter locations of moose from 2005 to 2007 in ArcMap 9.2 (Environmental Systems Research Institute, Redlands, California, USA) and used the HOME RANGE TOOLS extension for ArcGIS (Rodgers et al. 2007) to create movement paths for each individual. We determined that a crossing occurred when the straight line between 2 consecutive locations crossed either U.S. Highway 26/287 or U.S. Highway 26/89/187. We did not investigate crossings that occurred along U.S. Highway 89/287 between Moran Junction and YNP because of limited traffic volume due to seasonal road closures within GTNP.

Because winter locations were collected every hour, the timing of crossing events were estimated to have occurred within the time period between 2 consecutive locations. The timing of moose crossings were grouped into 4 distinct time periods to reflect when moose-vehicle collisions were most likely to occur. These time periods were 0300 – 0859 hrs (early to mid-morning), 0900 – 1459 hrs (mid-day), 1500 – 2059 hrs (afternoon to early evening), and 2100 – 0259 hrs (night). A chi-square test ($P \leq 0.05$) was used to determine if crossing events occurred at random during each time period throughout the day.

Predicting Moose Crossing Locations in the Buffalo Fork Valley

To create the highway study area, we used a hand-held GPS unit to mark the location of mileposts 3 through 9 and plotted these in ArcGIS. We digitized a 9.7-km (6.0-mi) stretch of U.S. Highway 26/287 from a U.S. Geological Survey 1:24,000 scale digital orthophoto quarter quadrangle map and divided each 1.6-km (1.0-mi) section into 10 equal segments that represented secondary mile markers to the nearest 0.16-km (0.1-mi). The highway study area was defined as that area within a 1.5-km (0.9-mi) buffer around the highway, which represented the average daily distance moved by radio-collared adult female moose during winter (Chapter 2).

The final population-level model developed to estimate adult female moose winter habitat selection included coefficients for the proportion of riparian/deciduous shrub, mixed/other conifer, and aspen habitats, elevation, habitat diversity, slope, and distance to coniferous cover (Chapter 2). To measure these variables, we created circular sample units with 25-m (82-ft) radii that were systematically distributed across the highway study area. We extracted vegetation data from each sample unit with HAWTHs ANALYSIS TOOLS (Beyer 2004) and calculated the proportion of each vegetation type that occurred within each unit. We used SPATIAL ANALYST to estimate slope from a 26 x 26-m digital elevation model (U.S. Geological Survey 1999) and to create a distance to cover layer from the existing vegetation map. Cover was defined strictly as coniferous habitats that could potentially provide thermal cover during winter. Estimates for elevation, slope, and distance to cover were extracted from the midpoint of each sample unit. We used 250-m (820-ft) radii circular units centered on the midpoint of each sample unit to calculate a Shannon-Weiner habitat diversity index based on the proportion of spruce/fir, lodgepole pine, mixed/other conifer, aspen, riparian/deciduous shrub, and other habitat types that occurred within each circular sample unit.

We used the R statistical software package (R Core Development Team 2006) to estimate resource selection probability functions (RSPF; Manly et al. 2002) for each sample unit using population-level coefficients developed to assess winter habitat selection by adult female moose (Table 1; Chapter 2). The RSPF predictions were mapped across 50 x 50-m pixels for the highway study area. The RSPFs were assigned to 1 of 4 categories based on the quartiles of the distribution of predictions (Sawyer et al. 2006, Sawyer et al. 2007). Pixels were assigned values from 1 to 4 representing the highest to lowest estimated use probabilities in 25% increments (i.e., highest use probability = 1 [highest 25%], lowest use probability = 4 [lowest 25%]).

To determine the validity of the predictive map in delineating moose crossing locations in the highway study area, we used an independent sample of 201 crossing events collected during winter 2003-2004 and 2004-2005 that were recorded to the nearest 0.16-km (0.1-mi) marker (Young and Sawyer 2006). Since it was unknown exactly where the moose crossed the highway relative to the nearest mile marker, we created 80-m buffers around each 0.16-km (0.1-mi) marker and estimated an average RSPF class from all the predicted probability-of-use classes within each buffer. The 80-m buffer represented the mean probability-of-use for each mile marker given that a moose could have crossed anywhere within that buffer and still be classified as having crossed at the mile marker. Markers with mean RSPF classes from 1.00 to 1.50 were assigned to class 1 and were classified as high-use areas, markers with mean RSPF classes from 1.51 to 2.50 were assigned to class 2 and were classified as medium-high-use areas, markers with mean RSPF classes from 2.51 to 3.50 were assigned to class 3 and were classified as medium-low-use areas, and markers with classes from 3.51 to 4.00 were assigned to class 4 and were classified as low-use areas. We joined the RSPF class and the number of crossing events associated with each secondary mile marker from the independent sample and calculated the proportion of crossing events that occurred within each RSPF class. We estimated a chi-square statistic ($P \leq 0.05$) for each RSPF class to determine if moose selected highway crossings associated with preferred habitat.

Table 1. Coefficients (β) and standard errors (SE) for a population-level winter habitat selection model developed from global-positioning system (GPS)-collared adult female moose in northwest Wyoming, 2005-2007.

	Winter		
Variable	β	SE	*P*
Intercept	11.204	3.775	0.007
Riparian	3.559	0.173	<0.001
Elevation (m)	-0.011	0.002	<0.001
Habitat diversity	0.856	0.143	<0.001
Slope (°)	0.105	0.034	0.005
Slope^2 (°)	-0.006	0.002	<0.001
Mixed conifer	-2.251	0.995	0.034
Dist. to cover (m)	-0.002	0.001	0.051
Aspen	0.590	0.384	0.139

Fence Types and Moose Crossings

To determine if fence type influenced moose movement across U.S. Highway 26/287 in the Buffalo Fork Valley, we created a GIS layer that depicted three different fence types that occurred within the highway study area: (1) bighorn fence, (2) four-strand, barbed wire fence, and (3) buck-and-rail fence. The bighorn fence was a two-pole, two-wire fence that stands approximately 1.1 m (43 in) in height (Figure 2). Sections of four-strand, barbed-wire fence were primarily located along stretches with permanent standing water. A small section of buck-and-rail fencing was located west of the GTNP boundary (Figure 3). No fencing occurred within GTNP, from the bridge over Blackrock Creek (milepost 8.45) to milepost 9 on the north side of the highway, and from mileposts 8 to 9 on the south side of the highway.

Because fence types differed on either side of the roadway in a number of locations, we examined the north and south side of the highway separately then combined both sides for analysis. We assumed that the straight line used to depict moose movements accurately reflected the fence type that was crossed by moose. Only those crossing events that occurred between mileposts 3 and 9 were used to assess the possible effects of fence type. We used a chi-square test ($P \leq 0.05$) to estimate if moose crossed fences in proportion to what was expected throughout the study area.

Figure 2. Bighorn fence (view facing west). This was the primary type of fence found east of the Grand Teton National Park boundary within the highway study area.

Figure 3. Radio-collared adult female moose crossing buck-and-rail fencing. This type of fence was found west of the Buffalo Fork bridge and the Grand Teton National Park boundary in the highway study area.

CHAPTER 4

RESULTS

Frequency and Timing of Highway Crossing Events

Twenty-two adult female moose were monitored to estimate the frequency and timing of crossing events within the winter study area. A total of 257 crossing events were recorded with 19 moose crossing U.S. Highway 26/287 or U.S. Highway 26/89/187 at some point during the study period. Only 8 moose crossed the highway ≥ 10 times and these moose accounted for 84% of all crossing events ($n = 217$). Adult female moose crossed the highway more than expected during afternoon to early evening ($\chi^2 = 10.32$, df = 1, $P = 0.001$), less than expected during mid-day ($\chi^2 = 18.26$, df = 1, $P < 0.001$), and as expected during the night ($\chi^2 = 0.52$, df = 1, $P = 0.473$) and early to mid-morning ($\chi^2 = 0.12$, df = 1, $P = 0.732$; Table 2).

Table 2. Comparison of observed and expected moose highway crossings by time of day in the Buffalo Fork Valley, Wyoming, winter 2005-2007.

Time	Observed number of highway crossings	Expected number of highway crossings	χ^2	P	Observed/ expected[a]
Afternoon to early evening	90	64.25	10.32	0.001	>
Night	70	64.25	0.52	0.473	=
Early to mid-morning	67	64.25	0.12	0.732	=
Mid-day	30	64.25	18.26	<0.001	<

[a] “>”: use greater than expected; “=”: use equal to expected; “<”: use less than expected.

Predicting Moose Crossing Locations in the Buffalo Fork Valley

The highway study area covered approximately 34 km^2 (13 mi^2; Figure 4) within the Buffalo Fork Valley moose winter range. Private land encompassed approximately 11 km^2 (4 mi^2) with the remaining area managed by GTNP and BTNF. The predictive map indicated that areas classified as high or medium-high probabilities of use occurred between mileposts 3.2 and 4.5, 6.1 and 6.7, and 7.0 and 9.0 (Figure 5). These areas were characterized by a high proportion of aspen and riparian/deciduous shrub habitat with little coniferous cover, low elevation, relatively flat slope, and moderate distance to cover. Private land used for cattle and horse grazing occurred between mile markers 4.5 and 6.1, while private land held in conservation easements occurred between mile markers 6.1 and 6.9. The predictive map indicated that moose were less likely to cross private land that was used for grazing, but were more likely to cross on private land that was held in a conservation easement (Figure 5). Mileposts that occurred on either side of the Buffalo Fork bridge and the Blackrock Creek bridge were each classified as high-use areas. This indicates a high likelihood that moose may have utilized bridges to cross U.S. Highway 26/287 because preferred habitat occurred on either side.

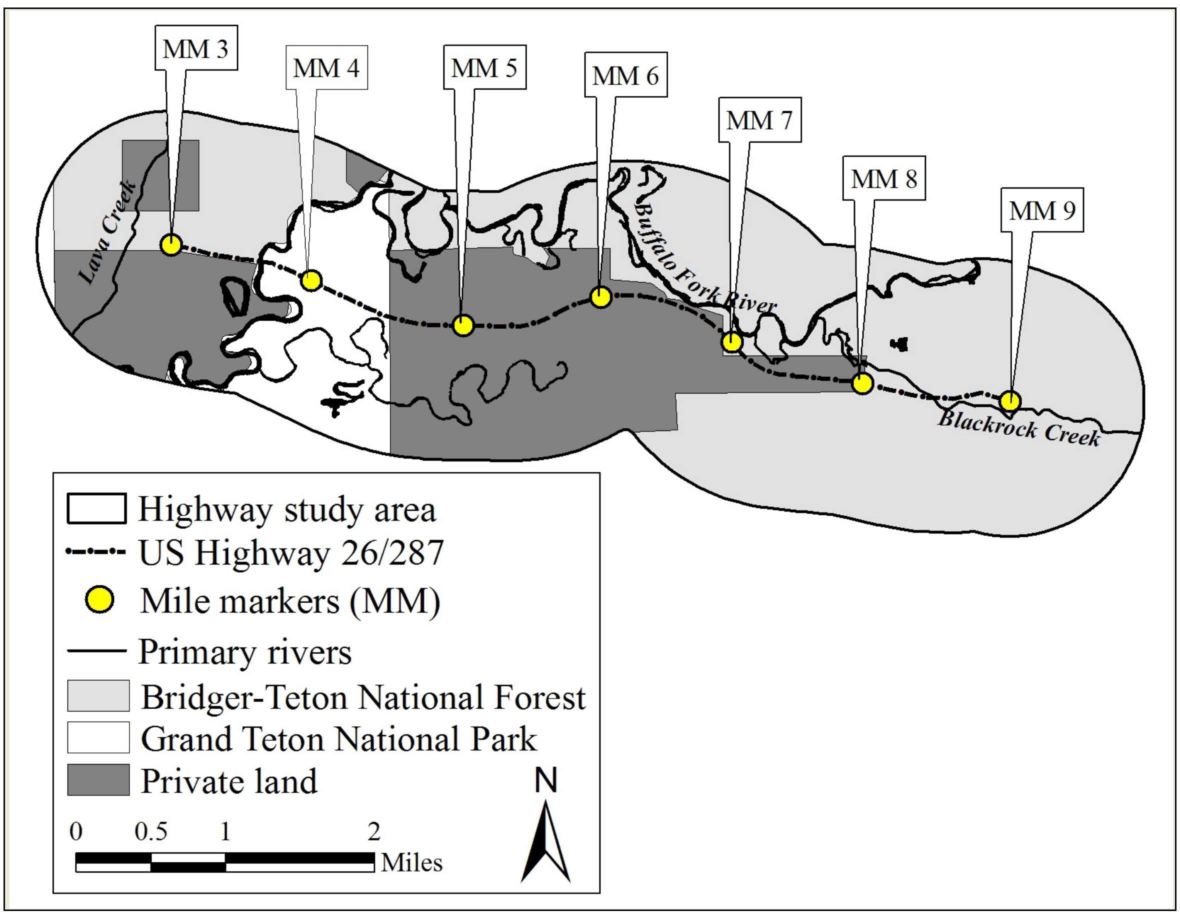

Figure 4. Highway study area in the Buffalo Fork Valley, Wyoming, used to measure habitat and landscape variables when creating a predictive map of winter habitat selection along a 9.7-km (6.0-mi) stretch U.S. Highway 26/287 during winter 2005-2007.

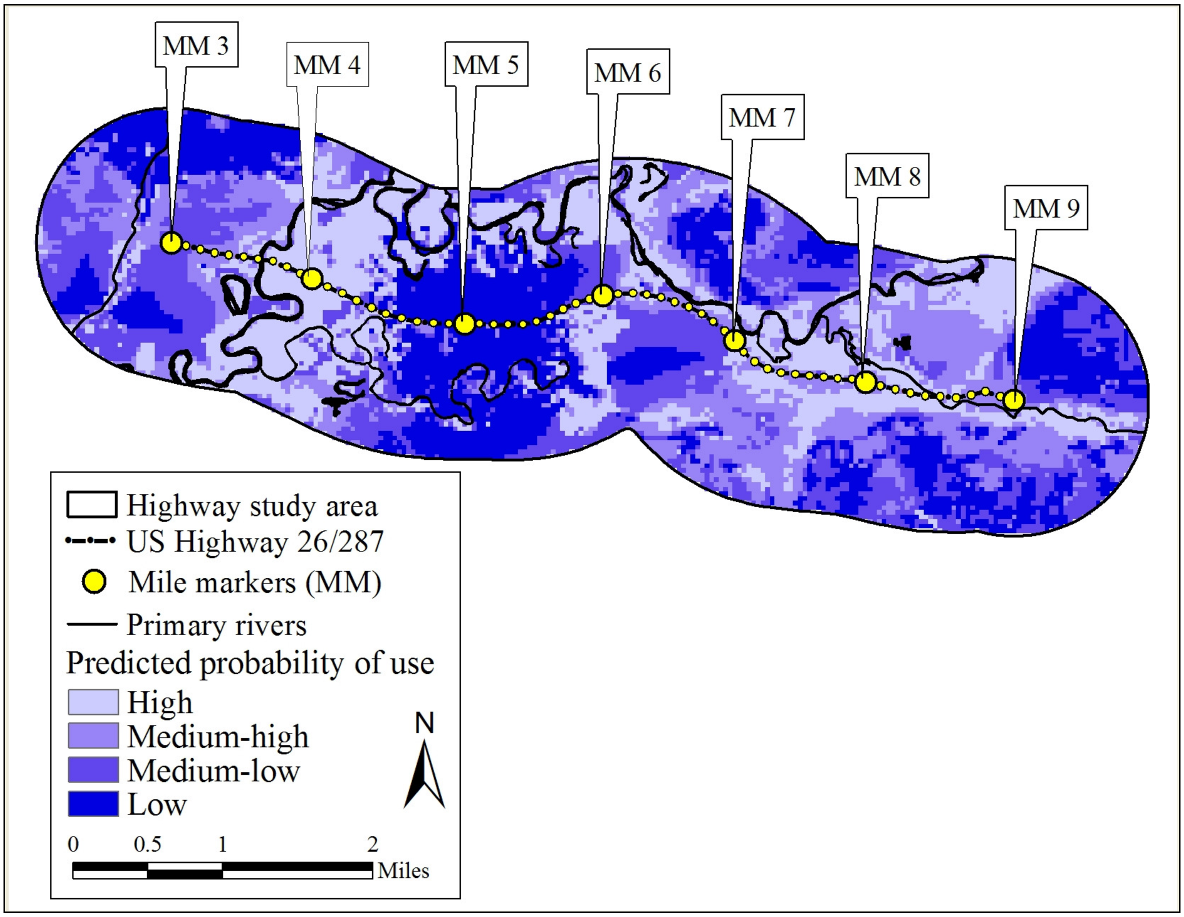

Figure 5. Relative predicted probabilities and associated categories (low = 0-25%, medium-low = 26-50%, medium-high = 51-75%, high = 76-100%) of habitat use for the highway study area developed from a model of winter habitat selection for adult female moose in northwest Wyoming during winter 2005-2007.

Of the 201 moose crossings recorded from the independent sample, the highest proportion of crossing events occurred in areas classified as high or medium-high predicted probabilities of use (81%, $n = 162$), while fewer crossings occurred in areas classified as medium-low or low predicted probabilities of use (19%, $n = 39$; Table 3). Moose crossed the highway in areas categorized as high-use areas more than expected ($\chi^2 = 6.92$, df = 1, $P = 0.009$), as low-use areas less than expected ($\chi^2 = 5.40$, df = 1, $P = 0.020$), and in proportion to what was expected in medium-high-use ($\chi^2 = 0.36$, df = 1, $P = 0.550$) and medium-low-use ($\chi^2 = 3.64$, df = 1, $P = 0.056$) areas (Table 3). Although areas classified as medium-low were used approximately as expected, the actual number of crossings ($n = 22$) were lower than the number of expected crossings ($n = 33$).

Table 3. Comparison of observed and expected moose highway crossings associated with the mean predicted probability of use for each 0.16-km (0.1-mi) mile marker along U.S. Highway 26/287 in the Buffalo Fork Valley, Wyoming, winter 2005-2007. The predicted probability of use was calculated by extracting RSPF class values from an 80-m buffer around each milemarker and averaging these values. Markers with mean RSPF classes from 1.00 to 1.50 were classified as high-use areas, markers with mean RSPF classes from 1.51 to 2.50 were classified as medium-high-use areas, markers with mean RSPF classes from 2.51 to 3.50 were classified as medium-low-use areas, and markers with classes from 3.51 to 4.00 were classified as low-use areas.

Predicted probability of use	Proportion of mile markers	Number highway crossings[a]	Proportion of highway crossings	χ^2	*P*	Observed/ expected[b]
High	0.23	64	0.32	6.921	0.009	>
Medium-high	0.46	98	0.49	0.357	0.550	=
Medium-low	0.16	22	0.11	3.639	0.056	=
Low	0.15	17	0.08	5.401	0.020	<
Total	1.00	201	1.00			

[a] Data from an independent sample collected during winter 2003-2005 (Young and Sawyer 2006).
[b] “>”: use greater than expected; “=”: use equal to expected; “<”: use less than expected.

Fence Types and Moose Crossings

Along the 9.7-km (6.0-mi) stretch of U.S. Highway 26/287, there was approximately 6.4 km (4.0 mi) of fencing on the north and the south side of the highway for a total of 12.9 km (8.0 mi). About 6.6 km (4.1 mi) of highway was fence free with most occurring within GTNP and east of Blackrock Creek. One section of barbed-wire fence that was less than 0.16 km (0.1 mi) in length was assumed to be bighorn fence in this analysis. Bighorn fence was the primary fence type within the study area while buck-and-rail fence and barbed-wire fence each occurred along equal proportions of highway (Table 4).

A total of 311 fence crossings were recorded with 19 of 22 moose crossing fences along U.S. Highway 26/287 at some point during the study period. Only 9 moose crossed fences ≥ 10 times and these accounted for 87% of all crossing events ($n = 269$). Adult female moose crossed sections of highway that contained no fencing more than expected ($\chi^2 = 41.55$, df = 1, $P < 0.001$) and crossed less than expected along sections with bighorn ($\chi^2 = 11.47$, df = 1, $P < 0.001$), buck-and-rail ($\chi^2 = 5.87$, df = 1, $P = 0.004$), and barbed-wire ($\chi^2 = 8.33$, df = 1, $P = 0.015$) fence types (Table 4).

Table 4. Comparison of observed and expected moose highway crossings by fence type crossed in the Buffalo Fork Valley, Wyoming, winter 2005-2007. The number of fence crossings were calculated for the north and south side of U.S. Highway 26/287 separately and then combined to estimate significance.

Fence type	Proportion fence type	Number of fence crossings	Proportion fence crossings	χ^2	*P*	Observed/ expected[a]
No fencing	0.34	171	0.55	41.548	<0.001	>
Bighorn	0.56	129	0.41	11.477	<0.001	<
Buck and rail	0.05	6	0.02	5.865	0.015	<
Barbed wire	0.05	5	0.02	8.330	0.004	<
Total	1.00	311	1.00			

[a] “>”: use greater than expected; “<”: use less than expected.

CHAPTER 5

DISCUSSION AND RECOMMENDATIONS

Discussion

This study demonstrated that models developed to assess adult female moose winter habitat selection can be used to identify areas where moose are most likely to cross U.S. Highway 26/287 in the Buffalo Fork Valley. Moose crossing events were not randomly distributed along the highway. Aggregations of moose crossings occurred at locations that could be predicted by examining winter habitat selection parameters. Similarly, the number of grizzly bear (*Ursus arctos*) highway crossings in Alaska (Graves et al. 2006) and Montana (Waller and Servheen 2005) were clustered at specific locations while most wildlife-vehicle collisions typically occur along a relatively small proportion of the roadway (Bashore et al. 1985, Joyce and Mahoney 2001, Malo et al. 2004, Seiler 2005). The spatial aggregation of crossings may increase the risk of collisions between motorists and moose in areas identified as high or medium-high predicted probabilities of use. Mitigation that may potentially increase highway safety for motorists, as well as maintain highway permeability for moose, can be applied to sections of highway where crossing locations are most likely to occur.

Moose crossings were aggregated in areas where preferred habitat and landscape features occurred on either side of the highway. In northwest Wyoming, adult female moose selected for low-elevation habitats during winter that contain an abundance of forage provided by aspen and willow-dominated, riparian habitats (Chapter 2). Other studies have noted the importance of preferred habitat and landscape features in predicting crossing locations and collision risk for moose (Gundersen et al. 1998, Seiler 2005), elk (*Cervus elaphus*; Dodd et al. 2007), white-tailed deer (*Odocoileus virginianus*; Carbaugh et al. 1975, Feldhammer et al. 1986, Finder et al. 1999, Hubbard et al. 2000), and black bear (*Ursus americanus*; Clevenger et al. 2002, Kindall and Van Manen 2007). Dussault et al. (2007) indicated that the proportion of forage was greatest where moose crossed roads in Quebec, Canada, yet moose selected crossing locations that provided abundant cover rather than food resources. However, snow accumulations during their study were some of the highest in the world (Dussault et al. 2007) and it has been well documented that, when the availability of forage decreases and the energetic cost of locomotion increases due to increased snow depths, moose generally seek cover provided by mature coniferous forests (Matchett 1985, Hundertmark et al. 1990, MacCracken et al. 1997, Stephenson et al. 2006). In northern Sweden, snow depth influenced the availability of food which in turn influenced the peak in moose-vehicle collisions during winter (Lavsund and Sandegren 1991). In Norway and Alaska, a similar trend was observed concerning moose-train collisions (Modafferi 1991, Andreassen et al. 2005). In the Buffalo Fork Valley, snow accumulations may not have been severe enough to cause a shift in use to closed canopy coniferous forests. Additionally, the Buffalo Fork Valley provided abundant winter forage and moose may have utilized tracks of other individuals to reduce the cost of locomotion in deep snow (Ball et al. 2001), thus crossing locations may be consistent among years even with varied degrees of winter severity. Nonetheless, in years of deep snow, increased monitoring of moose crossing locations may be warranted to determine if there is a shift in preferred habitat and, consequently, highway crossing locations.

Although moose crossings typically occurred in low elevation areas that contained a high proportion of aspen and riparian habitats, moose selected for areas with high habitat diversity. This suggests that moose require a mix of riparian, aspen, and coniferous habitats to meet forage and cover requirements and that the distribution of all habitat types across the landscape likely influenced the probability that a crossing event occurred in a specific location. Private lands used for grazing adjacent to the highway were composed primarily of herbaceous cover and contained little habitat diversity or preferred forage, thus very few moose crossings occurred in these areas. In contrast, private lands held in conservation easements were composed of a mix of riparian and coniferous habitats and, not surprisingly, moose use and crossing events associated with these areas were relatively high. Areas of high habitat diversity have also been implicated with the increased risk of vehicle collisions for white-tailed deer in Illinois (Finder et al. 1999), Iowa (Hubbard et al. 2000), and Minnesota (Nielsen et al. 2003) and roe deer (*Capriolus capriolus*), wild boar (*Sus scrofa*), and red deer (*Cervus elaphus*) in Spain (Malo et al. 2004). However, in areas where preferred habitat is common and habitat diversity is relatively low, highway crossings, and thus wildlife-vehicle collisions, were more randomly distributed (Allen and McCullough 1976, Bashore et al. 1985, Feldhammer et al. 1986).

Bridges over the Buffalo Fork River and Blackrock Creek were both identified as having a high probability of use suggesting that moose may utilize these structures to cross beneath the highway. Young and Sawyer (2006) documented and photographed several moose crossing the highway underneath these structures. Bridges may facilitate wildlife crossings which could ultimately reduce the risk of wildlife-vehicle collisions along short sections of highway near these structures (Seiler 2004, Seiler 2005). However, Hubbard et al. (2000) indicated that bridges acted as “major edge-creating landscape features” that increased the risk of collisions with white-tailed deer in Iowa. Furthermore, low to intermittent traffic volume caused a reduction in passage rates for elk using wildlife underpasses in Arizona that was possibly caused by the sudden auditory and visual stimuli created by a vehicle crossing over the underpass during an otherwise quiet period (Gagnon et al. 2007*a*). Even though moose relocations were obtained every hour during the winter period, this location frequency was insufficient to confirm whether or not a moose actually used bridges to cross the highway. All that could be determined is that habitat and landscape features on either side of the bridges were classified as high use areas and the probability that a moose used these habitats, and thus the bridges, was also high.

Moose crossed the highway more frequently in areas that were not fenced when compared to areas that contained any of the three other fence types. Although fences within the Buffalo Fork Valley were not designed to prevent moose from crossing the highway, these results concur with those of Seiler (2005) who described the risk of moose-vehicle collisions being greatest along sections of road that did not contain moose-proof fencing. Furthermore, in South Africa, the ratio of total accidents to animal-related accidents was significantly less along sections of highway that had a higher proportion of fencing (Eloff and Van Niekerk 2005). In contrast, fencing along an interstate highway in Pennsylvania reduced the number of deer observed in the right-of-way, but it did little to reduce the number of deer-vehicle collisions (Feldhammer et al. 1986). We suggest that preferred habitat and landscape features had much more influence in determining moose crossing locations given that the fence-types present in the Buffalo Fork Valley were not high enough to prevent moose crossings. The predictive map indicated that the unfenced section of highway, located within GTNP, contained a high proportion of preferred habitat on either side of the roadway. Likewise, from mile marker 7 to approximately 8.5 (i.e., Blackrock Creek), preferred habitat can be found on both sides of the highway even though the majority of this area primarily contains bighorn fence. Approximately 8.1 km (5.0 mi) of fence, nearly two-thirds of the total length of fencing along the highway, was along private land that was not preferred moose winter habitat. Thus, the likelihood that a moose would cross a fence in these areas was significantly reduced due to habitat features rather than fence presence. Lack of fence structures in areas of quality moose habitat may have inhibited our assessment of the influence of fence type on moose movements associated with U.S. Highway 26/287.

Approximately 88% of all moose crossing events in the Buffalo Fork Valley occurred from afternoon to mid-morning (i.e., 1500 – 0859 hours), which coincided with peaks in daily moose activity patterns (Renecker 1986). Light conditions during these time periods are relatively poor or non-existent which can increase the risk of moose-vehicle collisions. In Newfoundland, approximately 75% of all moose-vehicle collisions were observed between sunset and sunrise while severe injuries or death to motorists were twice as likely to occur after dark (Joyce and Mahoney 2001). Similarly, other studies have demonstrated that highway crossings and the potential of collisions increased significantly from dusk to dawn for ungulates (Carbaugh et al. 1975, Belant 1995, Groot Bruinderink and Hazebroek 1996) and grizzly bears (Waller and Servheen 2005, Graves et al. 2006). In contrast, caribou (*Rangifer tarandus*) were observed to cross roads more frequently during the day (Dyer et al. 2002), which may minimize collision-risk due to increased motorist visibility.

Concurrent with increased highway crossings during evening and early morning hours is a reduction in traffic volume during these time periods. Grizzly bears have been observed to cross more frequently at night when traffic volume was low (Waller and Servheen 2005, Graves et al. 2006). Elk shifted use away from highways during the day when traffic volume was high and returned to areas near the highway at night when traffic volumes decreased (Gagnon et al. 2007*b*). Furthermore, research along the Trans-Canada Highway in Banff National Park, Canada, has shown reduced permeability of the highway for all wildlife due to very high traffic volume (Alexander and Waters 2000, Alexander et al. 2005). Increased traffic volume has also been implicated in preventing bighorn sheep (*Ovis canadensis*) from reaching important mineral sites in Rocky Mountain National Park, Colorado (Keller and Bender 2007) and with an increased risk of deer-vehicle collisions in Arkansas (Farrell and Tappe 2007). Although traffic volume was not analyzed within the context of moose crossing probabilities in our study, when compared to other studies, the relatively low number of vehicles on U.S. Highway 26/287 during winter does not appear to impede moose movements across the road at the present time. However, the risk of moose-vehicle collisions is likely increased at night due to reduced motorist visibility and a concurrent increase in moose crossing events.

Recommendations

Application of the winter habitat selection model developed for moose in northwest Wyoming should be used with caution if applied to other sections of highway in the state. The model worked well to identify areas along U.S. Highway 26/287 that have a high risk of moose-vehicle collisions, but the model may not work well if habitats available to moose differ from those found in the Buffalo Fork Valley. If the model is to be used in other areas, it should be tested using an independent sample of crossing locations for validation prior to making assumptions concerning potential mitigation. Snow-track surveys, similar to those conducted by Western Ecosystems Technology, Inc. (Young and Sawyer 2006), would work well in determining the efficacy of the model for other locations. If this is done and model performance is not satisfactory, the results of the snow-track survey may be used because areas identified as core moose crossing locations in the Buffalo Fork Valley by Young and Sawyer (2006) were basically the same as those identified in the present study. However, if a more complete understanding of habitat, landscape, and anthropogenic features used by moose to select highway crossings is needed, a new study utilizing GPS technology may be warranted if the risk of moose-vehicle collisions is high.

Although numerous moose crossing events were observed in the Buffalo Fork Valley, only one moose-vehicle collision was recorded during the study. This occurred near milepost 7.4 which was classified as a high probability of use area. The collision occurred on 12 June 2005 and involved an uncollared, adult female moose that died as a result of the accident. While some accidents may go unreported, moose-vehicle collisions are relatively rare events in the Buffalo Fork Valley with only 5 collisions reported from 1995 to 2004 (Young and Sawyer 2006). All radio-collared moose that wintered in the Buffalo Valley were migratory and most summered at higher elevations to the north (Chapter 2). Thus, the greatest risk of collisions occurred during winter when traffic volume was much lower than during summer.

Within the Buffalo Fork Valley, speed limits could be reduced and seasonal use of large, temporary warning signs with flashing lights could be erected in areas classified as high or medium-high predicted probabilities of use during winter to warn motorists of the increased risk of encountering moose on the highway (Groot Bruinderink and Hazebroek 1996, Gordon et al. 2004, Sullivan et al. 2004). Speed limits have been identified as an important determinant in the number and severity of moose-vehicle collisions, especially during night when motorist visibility is reduced (Joyce and Mahoney 2001, Seiler 2004, Seiler 2005), but they have also been difficult to enforce (Lavsund and Sandegren 1991, Joyce and Mahoney 2001). Since local residents primarily drive the road during winter, a public awareness program could be implemented to educate people about the risk of moose-vehicle collisions (Joyce and Mahoney 2001) if traffic volume increases and the number of moose-vehicle accidents concurrently rise following highway reconstruction. The message could be conveyed to the public by hosting informational workshops or conducting essay or poster contests at local schools (Del Frate and Spraker 1991). Bumper stickers and information packets describing moose and their behavior could also be distributed to local residents and offered to patrons at gas stations and shops throughout the area. Many tourists come to northwest Wyoming to observe moose, so the packets could also be used to show areas where they are most likely to see moose. Public service announcements could be broadcast over the radio to inform motorists of areas where the risk of collisions is highest (Del Frate and Spraker 1991).

Major and costly mitigation may not be justified in the Buffalo Fork Valley at the present time unless moose-vehicle collisions increase following highway reconstruction. Vegetation removal along the highway right-of-way to increase motorist visibility may be the most easily-applicable and socially-acceptable form of large-scale mitigation (Jaren et al. 1991, Gundersen et al. 1998, Rea 2003, Andreassen et al. 2005). However, this type of mitigation must be maintained routinely because of moose preference for early seral vegetation (Loranger et al. 1991, Peek 1997). Moose-proof fencing has proven effective, but may only be justified in areas where traffic volume is high due to the high costs associated with construction and maintenance (Lavsund and Sandegren 1991, McDonald 1991, Groot Bruinderink and Hazebroek 1996). Caution must be used though because dependent upon where fences terminate, new high-collision-risk areas may be created due to animal movements along fence lines. In extreme cases, electric fencing has proven effective in reducing moose-vehicle collisions (Leblond et al. 2007). When used in conjunction with fencing to funnel animals to areas where they are most likely to cross a highway (Ng et al. 2004), the use of overpasses and underpasses that facilitate animal movements has also proven successful (McDonald 1991, Foster and Humphrey 1995, Clevenger and Waltho 2005, Gagnon et al. 2007*a*). Crossing structures that greatly improved rates of passage for large animals are high, wide, and short in length (Clevenger and Waltho 2005) and provide suitable habitat at the crossing points (Ng et al. 2004). Similar to the expansion of the Buffalo Fork Bridge in 2007, lengthening of existing bridges over rivers and streams that act as natural travel corridors may be a cheaper way of facilitating animal movements across the highway rather than erecting costly underpasses and overpasses at important crossing locations (Hubbard et al. 2000, Ng et al. 2004, Sawyer and Rudd 2005, Seiler 2005).

Moose are not the only animals that inhabit the Buffalo Fork Valley or cross U.S. Highway 26/287. A suite of large and small carnivores, ungulates, and small rodents have also been documented to cross the highway (Young and Sawyer 2006). Hence, potential crossing aggregations should be identified for all wildlife that may cross the highway and mitigation that benefits multiple species should be employed (Sawyer and Rudd 2005). For example, within the Buffalo Fork section of U.S. Highway 26/287, core elk crossing areas were similar to those identified for moose (Young and Sawyer 2006). Thus, mitigation to prevent moose-vehicle collisions will also assist in preventing elk-vehicle collisions in the Buffalo Fork Valley. Mitigation for multiple species will certainly increase the difficulty in planning appropriate, and potentially expensive, mitigation, but it will ultimately benefit motorists by increasing highway safety and wildlife by maintaining habitat linkages (Ng et al. 2004).

Numerous studies have demonstrated the effects of transportation corridors on wildlife, but some animals appear to have a higher tolerance of traffic than others. Alexander et al. (2005) noted that highway permeability was much lower for large carnivores than ungulates along the Trans-Canada Highway in Banff National Park, Canada. They indicated that 300-500 vehicles/day decreased highway permeability for large carnivores whereas ungulates demonstrated a higher tolerance to increased traffic volume. They also suggested that mitigation should be implemented at the threshold for carnivores to maintain habitat linkages and reduce habitat fragmentation for all wildlife (Alexander et al. 2005). Carnivores may be impacted by current traffic volume along U.S. Highway 26/287 during all seasons while ungulates may be affected during the summer months. Coordination with state and federal land and wildlife management agencies should continue after highway reconstruction so the impacts of the traffic corridor on wildlife can be determined and appropriate mitigation can be implemented to maintain motorist safety and highway permeability for wildlife.

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