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

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ABSTRACT: To accommodate increases in traffic volume and to address highway safety concerns, transportation managers often need to expand existing travel corridors which may result in increased risk of wildlife-vehicle collisions. By understanding the spatial and temporal characteristics of wildlife crossings, managers can apply appropriate mitigation techniques to reduce collision risk while maintaining habitat linkages. The U.S. Highway 287/26 reconstruction project in northwest Wyoming provided an opportunity to examine the influence of habitat, landscape, and anthropogenic features that influence highway crossing locations of Shiras moose (*Alces alces shirasi*). A model developed to estimate adult (≥ 2 years) female 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 section of U.S. Highway 287/26 that bisects a high-density moose winter range in the Buffalo Fork Valley. To test our model's predictive capability, we used 201 moose crossing locations collected previously by independent researchers using snow-track survey techniques. The majority (81%) of moose crossing events occurred in areas classified as high or medium-high relative probability of use. We also examined temporal patterns of moose crossings and the influence of fence types in influencing crossing location. Moose crossed the highway more frequently during early to mid-evening and less frequently during mid-day. Our findings indicate that preferred habitat and landscape features such as relatively flat, low elevation habitats dominated by deciduous shrubs/trees interspersed with conifers had a stronger influence on crossing location than fences.

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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, 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 costing an estimated $1,500 (U.S.) per accident. Approximately 4% of these collisions resulted in human injuries with an estimated 211 human fatalities. When collisions occur with larger animals (e.g., moose [*Alces alces*]), the risk of human injury and increased property damage rises significantly (Joyce and Mahoney 2001). Methods aimed at reducing wildlife-vehicle collisions have been marginally successful. Mitigation to reduce the number of collisions or prevent animals from entering the roadway (e.g., roadside clearing,

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fencing, overpasses, and underpasses) appear to be most effective, but maintenance and repair costs often limit their implementation and long-term effectiveness (Bashore et al. 1985, Feldhammer et al. 1986).

Wildlife-vehicle collisions can rarely be linked to 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, Gunderson et al. 1998, Waller and Servheen 2005, Dodd et al. 2007). Moreover, traffic volume, speed limits, driver awareness, and weather conditions have been implicated as factors influencing the risk of collisions (Lavsund and Sandegren 1991, Joyce and Mahoney 2001, Seiler 2005). Numerous studies have used modeling approaches to identify habitat, landscape, and anthropogenic features related to collision risk (Hubbard et al. 2000, Nielsen et al. 2003, Malo et al. 2004, Seiler 2005). Oftentimes these models are presented with coefficients in tabular form and a description of the characteristics where wildlife are most likely to cross a road (e.g., Waller and Servheen 2005, Dussault et al. 2007). By expanding on these models and mapping probabilities across a desired study area, transportation and wildlife managers can more easily interpret the likelihood that an animal will cross in a specific location.

Studies of wildlife-vehicle collisions often examine habitat and landscape characteristics after the frequency of accidents becomes socially unacceptable (Finder et al. 1999, Seiler 2005, Dussault et al. 2006). By examining spatial and temporal patterns of animal movements associated with roadways, proactive engineering can be implemented into roadway design to reduce the likelihood of wildlife-vehicle collisions (Groot Bruinderink and Hazebroek 1996, Finder et al. 1999, Dodd et al. 2007).

The purpose of this study was to evaluate the efficacy of using a winter habitat selection model (Becker 2008) for adult (≥2 years) female Shiras moose (*A.a. shirasi*) to predict highway crossing locations in northwest Wyoming. The U.S. Highway 287/26 reconstruction project in northwest Wyoming presented an opportunity to assess this technique because a 9.7-km section of this highway bisects a high-density moose winter range in the Buffalo Fork Valley (Houston 1968). Previous research that identified core crossing areas from snow-track surveys (Young and Sawyer 2006) provided independent data to validate our predictions of moose crossing locations. Understanding spatial and temporal characteristics of moose crossings should improve mitigation efforts associated with highway improvement and construction.

STUDY AREA

The winter study area was located approximately 50 km north of Jackson, Wyoming and was defined by the winter distribution of adult (≥2 years) female moose fitted with global positioning system (GPS) collars (Fig. 1; Becker 2008). The area encompassed roughly 1,100 km^2 of predominately public land which included portions of Grand Teton National Park (GTNP) and Bridger-Teton National Forest (BTNF). All roads within the study area were 2 lane highways with speed limits ranging from 88 km/h in GTNP to 105 km/h outside of GTNP boundaries. From 2005-2007, mean daily traffic volume along U.S. Highway 287/26 averaged 509 vehicles/day during winter (November-April) and 1251 vehicles/day during summer (May-October; Wyoming Department of Transportation [WYDOT] 2006, 2007, 2008). From 1975-2004, annual precipitation averaged 56.2 cm (range = 37.9-79.1 cm) with nearly 75% falling as snow from November-May (National Oceanic and Atmospheric Administration 2005).

Vegetation types occurred along an elevational gradient. Riparian areas dominated by willows (*Salix* spp.) intermixed with narrowleaf cottonwood (*Populus angustifolia*)

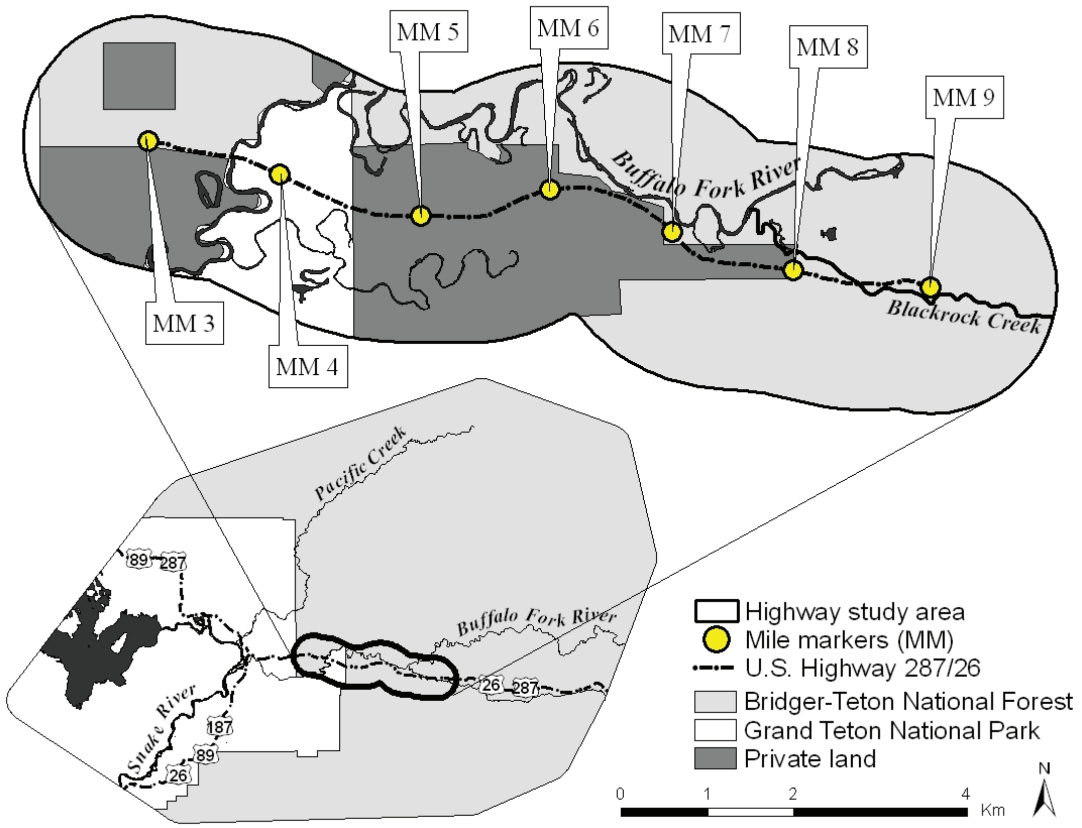

Fig. 1. The winter and highway study areas in northwest Wyoming, 2005-2007. We used the winter study area to evaluate the frequency and timing of adult female moose crossing events along U.S. Highway 287/26 and U.S. Highway 26/89/187. The highway study area was located along a 9.7-km section of U.S. Highway 287/26 in the Buffalo Fork Valley. We used the highway study area to create and validate a predictive map of moose crossing locations and to evaluate the influence of fence types on moose crossing locations.

were located in large, relatively flat floodplain environments at lower elevations and along nearly all drainages within the study area. Engelmann spruce (*Picea engalmanni*) and subalpine fir (*Abies lasiocarpa*) were found on some mesic sites while big sagebrush (*Artemisia tridentata*) occurred in more xeric locations at lower elevations. Higher elevations were dominated by lodgepole pine (*Pinus contorta*), Douglas fir (*Psuedotsugia menziesii*), subalpine fir, and Engelmann spruce interspersed with aspen (*Populous tremuloides*) (Knight 1994).

The highway study area was approximately 34 km^2 within the moose winter range in Buffalo Fork Valley (Fig. 1; see Methods for descriptive definition of the study area) where moose density was estimated at 4.0 moose/km^2 in 2005 (D. Brimeyer, Wyoming Game and Fish Department, unpublished data). Private land encompassed roughly 11 km^2 with the remaining area managed by GTNP and BTNF. The majority of private land was maintained for livestock grazing (i.e., herbaceous cover) and tourist accommodations; smaller areas were held in conservation easements to preserve natural vegetative communities.

METHODS

Moose Captures and Tracking

We darted and immobilized adult female moose from the ground or helicopter on winter range in the Buffalo Fork Valley during February 2005 and 2006. We used 10 mg of thiafentanil (A-3080, Wildlife Pharmaceuticals, Fort Collins, Colorado, USA; Kreeger et al. 2005) for capture, and an intramuscular injection of 300 mg naltrexone (Trexonil, Wildlife Pharmaceuticals, Fort Collins, Colorado, USA) as an antagonist after handling. Capture and handling procedures were performed in accordance with approved University of Wyoming Animal Care and Use Committee protocols (Approved 2005, 2006).

Moose were fitted with TGW-3700 global positioning system (GPS) collars with store-on-board technology (Telonics, Mesa, Arizona, USA) programmed to release on 1 March 2007. The collars were set to fix hourly locations during winter (15 November-15 June). The high fix-rate success (Becker 2008) negated correction for fix-rate bias (Nielson et al. 2009).

Frequency and Timing of Highway Crossings

To estimate the number of highway crossing events occurring within the study area, we mapped winter locations of moose from 2005-2007 in ArcGIS 9.2 (Environmental Systems Research Institute, Redlands, California, USA), and used the HOME RANGE TOOLS extension (Rodgers et al. 2007) to create movement paths for each individual. We assumed that a crossing occurred when the straight line between 2 consecutive locations crossed either U.S. Highway 287/26 or U.S. Highway 26/89/187.

Because locations were collected every hour, a crossing event was assumed to occur within the time period between 2 consecutive locations. The time of crossings was categorized into 4 distinct time periods reflecting daily activity patterns (Renecker 1986): 1) 0300-0859 hr (early to mid-morning), 2) 0900-1459 hr (mid-day), 3) 1500-2059 hr (early to mid-evening), and 4) 2100-0259 hr (night). We used the R statistical software package (R Core Development Team 2006) to run 200 bootstrap samples of individual moose (Manly 2007) and estimated the mean proportion of moose crossings with 95% confidence intervals within each time period. The bootstrap results were plotted against the expected proportion of crossings to determine if moose crossed in proportion to expected in a given time period. We assumed that a difference existed if the expected proportion of crossings fell outside the range of the 95% confidence intervals. This method treats the marked animal as the experimental unit, thereby eliminating issues related to pooling data across individuals and the potential for spatial or temporal correlation in animal movement (Thomas and Taylor 2006).

Predicting Crossing Location

Development of the predictive map - A resource selection function (RSF) was developed (see Becker 2008) to estimate winter habitat selection characteristics of moose following methods outlined by Sawyer et al. (2009). This modeling effort identified 7 variables as potentially important predictors of winter habitat selection by adult female moose. These included the proportion of riparian/deciduous shrub, mixed conifer, and aspen habitats, as well as elevation, habitat diversity, slope, and distance to coniferous cover. Using population-level coefficients from the RSF, we developed a predictive map of possible moose crossing locations along a 9.7-km section of U.S. Highway 287/26 in the Buffalo Fork Valley.

We first recorded the GPS location of mile markers 3.0-9.0 along U.S. Highway 287/26 and plotted these in ArcGIS. We then digitized the 9.7-km section between these mile markers from a U.S. Geological Survey (USGS) 1:24,000 scale digital orthophoto quarter quadrangle map, and divided each 1.6-km section into 10 equal segments representing secondary mile markers to the nearest 0.16 km. The highway study area was defined as that area within a 1.5 km buffer around the highway. The buffer distance represented the approximate, average daily distance moved by GPS-collared adult female moose during winter (Becker 2008).

To measure the 7 variables that were potentially important predictors of moose crossing locations, we created circular sample units with 25-m radii that were systematically distributed across the study area. Using a 30 x 30-m vegetation layer, we extracted vegetation data from each sample unit using Hawths Analysis Tools (Beyer 2004) and calculated the proportion of each vegetation type occurring within each unit. We used Spatial Analyst to estimate slope from a USGS 26 x 26-m digital elevation model, and the existing vegetation layer to create a distance to cover layer. Cover was defined strictly as coniferous habitats that could potentially provide thermal cover during winter. Estimates for elevation (m), slope (°), and distance to cover (m) were extracted from the midpoint of each sample unit. We considered a quadratic term to estimate slope in addition to the linear form of the variable. The habitat diversity coefficient in our winter habitat selection model was estimated using a 250-m radii circular sampling unit to capture diversity at a biologically relevant scale (Becker 2008). This distance represented the average distance an adult female moose traveled in a 4-hr period during winter. Because this was the scale used in the original model, we created 250-m radii circular units centered on the midpoint of each 25-m radii sample unit. We extracted vegetation data from each circular unit and calculated a Shannon-Weiner diversity index based on the proportion of 6 vegetation classes (i.e., spruce-fir, lodgepole pine, mixed conifer, aspen, riparian/deciduous shrub, and burn/other) within each unit.

We used the R statistical software package (R Core Development Team 2006) to estimate the relative probability of use for each sample unit using population-level (adult female) winter habitat selection coefficients (Becker 2008). The model predictions were assigned values from 1-4 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%]; Sawyer et al. 2009). These predictions were mapped across 50 x 50 m pixels in the highway study area.

Validating the predictive map - Young and Sawyer (2006) recorded 201 moose crossing events from snow-track surveys along the 9.7-km section during winter 2003-2004 and 2004-2005. They recorded the location of each crossing event to the nearest 0.16-km mile marker rather than with a GPS location. These crossing data were used to validate our predictive map and assess its accuracy in identifying crossing locations.

Since we did not know exactly where moose crossed the highway relative to the nearest secondary mile marker, we created 80-m buffers around each 0.16-km marker, extracted relative probability of use class information from each buffer, and estimated a mean relative probability of use class for each secondary mile marker. The 80-m buffer size covered the entire area between each 0.16-km marker without overlap, so each secondary mile marker could be uniquely associated with the number of crossings that were recorded at that location. Markers with mean relative probability of use of 1.00-1.50 were assigned as class 1 (high-use area), means 1.51-2.50 were assigned as class 2 (medium-high-use area), means 2.51-3.50 were assigned as class 3 (medium-low-use area), and means 3.51-4.00 were assigned as class 4 (low-use area).

We joined the relative probability of use class and the number of crossing events associated with each secondary mile marker from the independent sample. We used the R statistical software package (R Core Development Team 2006) to run 200 bootstrap samples (Manly 2007) to estimate the mean proportion of moose crossings with 95% confidence intervals that occurred within each relative probability of use class. We expected that the proportion of moose crossings would equal the proportion of mile markers classified within each relative probability of use class. The bootstrap results were plotted against the expected proportion of crossings within each relative probability of use class. We assumed that a difference existed if the expected proportion of crossings did not fall in the range of the 95% confidence intervals.

Fence Type and Moose Crossings

To evaluate if fence type influenced moose movement, we created a GIS layer depicting 3 different fence types found on both sides of the highway: 1) bighorn fence, 2) four-strand, barbed wire fence, and 3) buck-and-rail fence. The bighorn fence was a 2-pole, 2-wire fence that stood approximately 1.1 m high. Sections of 4-strand, barbed-wire fence were located mostly along stretches with permanent standing water and were approximately 1.1 m high. A small section of buck-and-rail fencing about 1.5 m high was located west of the GTNP boundary. No fencing occurred within GTNP near the western end of the study area. At the eastern end, no fencing occurred between (approximately) milepost 8.5 and 9.0 on the north side of the highway, and from mileposts 8.0-9.0 on the south side.

We assumed that the straight line used to depict moose movement accurately reflected the fence type that was crossed. Only those crossing events that occurred within the 9.7-km section were used to assess the effect of fence type; 19.4 km of fenced or unfenced area (both sides of highway) could potentially be crossed by moose. We used the R statistical software package (R Core Development Team 2006) to run 200 bootstrap samples of individual moose (Manly 2007) and estimated the mean proportion of moose crossings with 95% confidence intervals that occurred at each fence type (including those areas not fenced). We expected that the proportion of moose crossings would equal the proportion of each fence type that occurred within the highway study area. The bootstrap results were plotted against the expected proportion of crossings for each fence type. We assumed that a difference existed if the expected proportion of crossings did not fall in the range of the 95% confidence intervals.

RESULTS

A total of 257 crossing events were recorded; 19 of 22 collared moose crossed the 9.7-km section during the study period. Only 8 moose crossed the highway ≥10 times and these moose accounted for 84% of all crossing events (n = 217). Because the 4 time periods represented an equal proportion of a 24-h period, we expected an equal proportion of crossings during each time period (0.250). The bootstrapped proportion of crossing events was more than expected during early to mid-evening ($\bar{x}$ = 0.351; 95% CI = 0.299-0.401), less than expected during mid-day ($\bar{x}$ = 0.119; 95% CI = 0.088-0.151), and as expected during night ($\bar{x}$ = 0.272; 95% CI = 0.234-0.311) and early to mid-morning ($\bar{x}$ = 0.258; 95% CI = 0.215-0.311; Fig. 2).

The predictive map indicated that areas classified as high or medium-high relative probability of use occurred on both sides of U.S. Highway 287/26 between mileposts 3.2

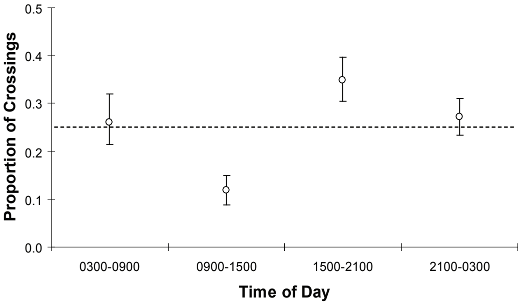

Fig. 2. Bootstrapped mean proportion of crossing events with 95% confidence intervals plotted against the expected proportion of crossings (dashed line) by time of day for adult female moose in northwest Wyoming, winter 2005-2007. Time periods represent early to mid-morning (0300-0900 hr), mid-day (0900-1500 hr), early to mid-evening (1500-2100 hr), and night (2100-0300 hr).

and 4.5, 6.1 and 6.7, and 7.0 and 9.0 (Fig. 3). The model predicted that these areas were characterized by a high proportion of riparian/deciduous shrub and aspen habitat with a lower proportion of coniferous cover. Landscape attributes indicated these sections of highway also had greater amounts of habitat diversity, were at lower elevations, had relatively flat slopes, and were moderate distance to cover. Mileposts that occurred on either side of the bridge over the Buffalo Fork River and the bridge over Blackrock Creek were each classified as high-use areas which indicate a high likelihood that moose utilized these structures to cross U.S. Highway 287/26.

Analysis of the 201 moose crossings documented previously (Young and Sawyer 2006) indicated that the highest percentage of crossing events occurred in areas classified as high or medium-high relative probability of use (81%, *n* = 162); fewer crossings occurred in areas classified as medium-low or low relative probability of use (19%, *n* = 39; Fig. 3). The proportion of mile markers classified within the 4 use classes (high, medium-high, medium-low, low) was 0.229, 0.459, 0.164, and 0.148, respectively. Moose crossed the highway in proportion to expected for all use classes (high: $\bar{x}$ = 0.323; 95% CI = 0.199-0.454; medium-high: $\bar{x}$ = 0.476; 95% CI = 0.339-0.612; medium-low: $\bar{x}$ = 0.108; 95% CI = 0.045-0.179; low: $\bar{x}$ = 0.092; 95% CI = 0.040-0.151), although the general trend was that frequency of crossing increased with higher probability of use (Fig. 4).

There was approximately 6.5 km of fencing

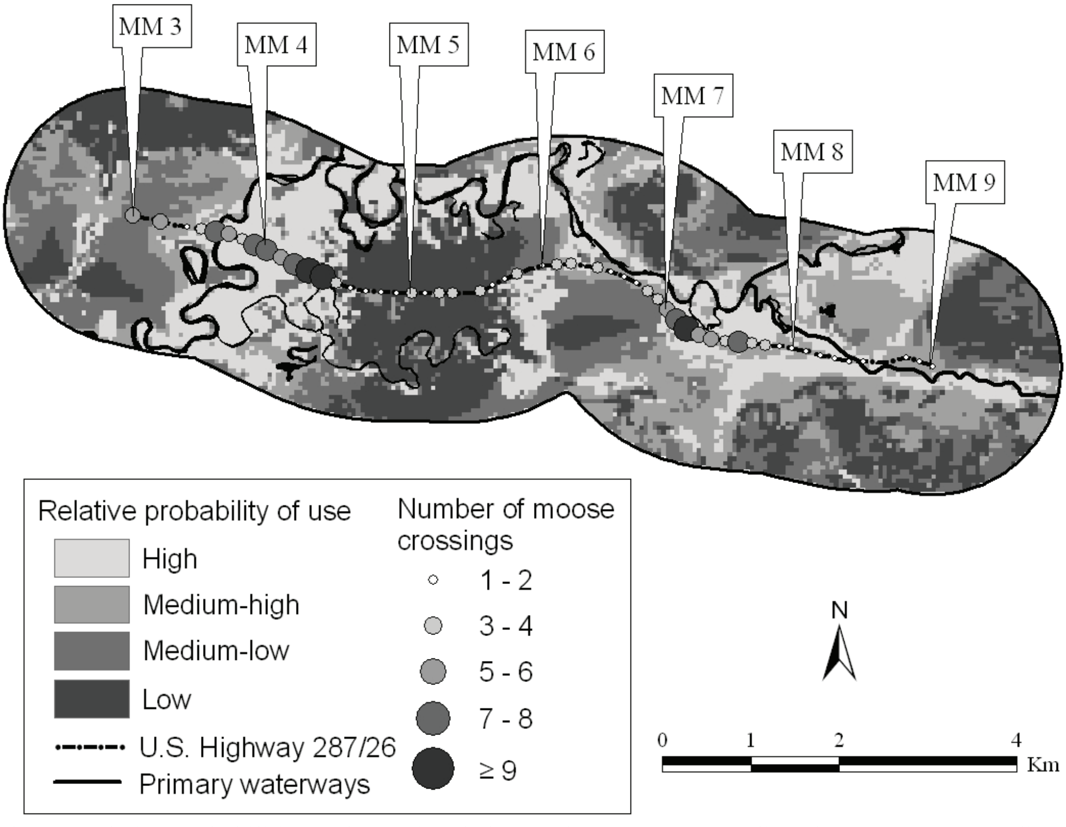

Fig. 3. Relative probabilities and associated classes (low = 0-25%, medium-low = 26-50%, medium-high = 51-75%, high = 76-100%) of habitat use for the highway study area developed from a model of winter habitat selection for adult female moose in northwest Wyoming, 2005-2007. The circles along the highway represent the number of moose crossings recorded to the nearest 0.16-km mile marker during winter 2003-2004 and 2004-2005 (data provided by Young and Sawyer 2006).

on the north and 6.3 km on the south side of the highway. The primary type was bighorn fence that was along 6.3 km and 4.5 km of the north and south sides, respectively. About 6.5 km (north = 3.2 km, south = 3.3 km) of highway was unfenced, most occurring within GTNP and east of Blackrock Creek. Because buck-and-rail fence and barbed wire fence occurred in relatively small proportions, these fence types were grouped into a combined category of "other" for analysis.

A total of 311 fence crossings by 19 of 22 moose were recorded during the study period. Only 9 moose crossed fences ≥ 10 times and these accounted for 87% of all crossing events (*n* = 269). Bighorn fence occurred along the greatest proportion of highway (0.558) and unfenced (0.338) and "other" fence less (0.104). Crossings occurred at unfenced areas in greater proportion than expected ($\bar{x}$ = 0.547; 95% CI = 0.341-0.702), in proportion to expected at bighorn fence ($\bar{x}$ = 0.417; 95% CI = 0.264-0.615), and less than expected in areas with "other" fence ($\bar{x}$ = 0.035; 95% CI = 0.013-0.068; Fig. 5).

DISCUSSION

Frequency and Timing of Highway Crossing Events

Approximately 88% of all moose crossing events in the Buffalo Fork Valley occurred from early evening to mid-morning (1500-0859 hr), coinciding with peaks in daily moose activity patterns (Renecker 1986). Although traffic volumes generally decrease at night, low light conditions at dawn, dusk, and night increase the risk of collision. In Newfoundland, approximately 75% of all moose-vehicle collisions occurred between sunset and sunrise and severe human injury and death were twice as likely to occur after dark (Joyce and Mahoney 2001). Similarly, Dussault et al. (2006) noted that moose-vehicle collisions were 2-3 x higher at night.

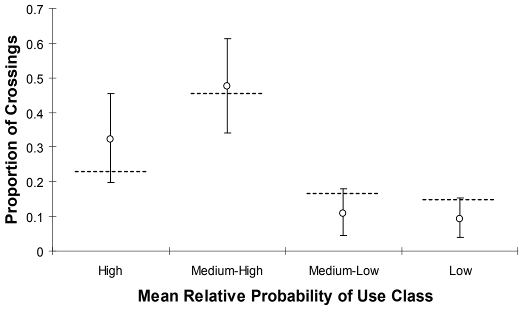

Fig. 4. Bootstrapped mean proportion of crossing events with 95% confidence intervals plotted against the expected proportion of crossings (dashed lines) by mean relative probability of use class along a 9.7-km section of U.S. Highway 287/26 in the Buffalo Fork Valley, Wyoming, winter 2005-2007.

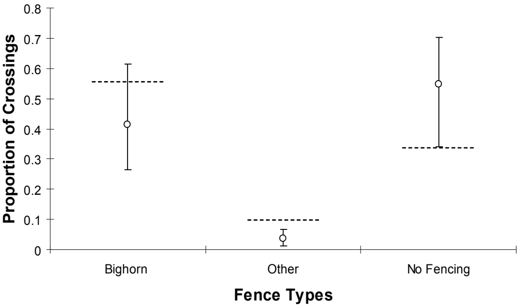

Fig. 5. Bootstrapped mean proportion of crossing events with 95% confidence intervals plotted against the expected proportion of crossings (dashed lines) by fence type along a 9.7-km section of U.S. Highway 287/26 in the Buffalo Fork Valley, Wyoming, winter 2005-2007.

It is unlikely that the relatively low winter traffic volume on U.S. Highway 287/26 (WYDOT 2006, 2007, 2008) impedes highway crossings by moose; however, animals often avoid roadways during periods of high traffic volume. For example, elk (*Cervus elaphus*) shifted use away from an Arizona highway when diurnal traffic volume was high, yet returned at night when traffic volume declined (Gagnon et al. 2007*a*). Increased traffic volume was implicated in preventing bighorn sheep (*Ovis canadensis*) from reaching important mineral sites in Rocky Mountain National Park, Colorado (Keller and Bender 2007). Although many moose crossing events were documented in the Buffalo Fork Valley, only 1 moose-vehicle collision was recorded during the study; it occurred at dusk near milepost 7.4 that was classified as a high probability of use area. While some accidents may go unreported, moose-vehicle collisions are relatively rare events in the Buffalo Fork Valley with only 5 documented from 1995-2004 (Young and Sawyer 2006).

Predicting Moose Crossing Locations in the Buffalo Fork Valley

Moose crossings were not randomly distributed along the 9.7-km section of U.S. Highway 287/26 in the Buffalo Fork Valley; rather, aggregations of moose crossings occurred at locations that could be predicted by estimating winter habitat selection characteristics. The spatial aggregation of crossings demonstrated that collision risk was greatest in areas identified as high or medium-high relative probability of use. Mitigation could be applied where crossings are most likely to occur in an attempt to reduce moose-vehicle collision risk.

Moose crossings were aggregated in areas where preferred habitat (deciduous shrubs/trees) and landscape features occurred on both sides of the highway. Adult female moose in northwest Wyoming select for low-elevation, riparian habitats that contain abundant deciduous forage in winter (Houston 1968, Becker 2008). This relationship suggests that location of highway crossings was related to the spatial distribution of available forage; the same relationship was identified for moose in Scandinavia (Gundersen et al. 1998, Seiler 2004, 2005).

Although moose crossings typically occurred in areas that contained abundant forage, crossing locations also had higher habitat diversity suggesting that the distribution of habitat types across the landscape likely influenced crossing locations. Private lands used for livestock grazing adjacent to the highway were composed mostly of herbaceous cover and contained little habitat diversity or preferred forage; few moose crossings occurred in these areas (mile markers 4.5-6.1; Fig. 3). In contrast, private lands held in conservation easements were composed of a mix of riparian and coniferous habitats and, not surprisingly, more crossings occurred in these areas (mile markers 6.1-7.0; Fig. 3). In other areas of North America where preferred habitat was common and habitat diversity was relatively low, highway crossings and wildlife-vehicle collisions were more randomly distributed (Bashore et al. 1985, Feldhammer et al. 1986).

Bridges over the Buffalo Fork River and Blackrock Creek were identified as having a high probability of use suggesting that moose may utilize these structures to cross beneath the highway. Although location frequency (hourly) was insufficient to confirm whether a moose actually used a bridge to cross underneath the highway, snow-track surveys and remotely triggered cameras documented numerous moose crossing under these bridges (Young and Sawyer 2006). Lengthening existing bridges may facilitate wildlife crossings which should reduce the risk of wildlife-vehicle collisions along short sections of highway (Seiler 2004, 2005). However, bridges can act as "edge-creating landscape features" that increase the risk of collisions (e.g., white-tailed deer [*Odocoileus viginianus*]; Hubbard et al. 2000). Moreover, the low-intermittent traffic volume during winter in the Buffalo Fork Valley (WYDOT 2006, 2007, 2008) might cause moose to flee from the infrequent, yet sudden auditory and visual stimuli of a vehicle crossing a bridge; this may increase the potential for collision if they cross in a less suitable location (Gagnon et al. 2007*b*).

Fence Type and Moose Crossings

Moose tended to cross the 9.7-km section of U.S. Highway 287/26 more frequently in unfenced than fenced areas; however, fences within the Buffalo Fork Valley were not designed to prevent moose crossings. Seiler (2005) described the highest risk of moose-vehicle collisions along sections of road without moose-proof fencing. Although fencing along an interstate highway in Pennsylvania reduced the number of deer observed in the right-of-way, it did little to reduce the number of deer-vehicle collisions (Feldhammer et al. 1986). The lack of fencing in areas of preferred moose habitat limits our assessment of the influence of fence type on moose crossings. Nonetheless, we believe that preferred habitat and landscape features were most influential in determining where moose crossed the highway because fencing was not high enough to physically deter moose.

MANAGEMENT IMPLICATIONS

Our study suggests that models of moose habitat selection and associated probability of use maps can be used to identify areas with an increased risk of moose-vehicle collisions. Moreover, if time constraints created by highway construction projects prevent data collection and analysis of wildlife crossings, existing habitat-based models can be used to locate areas where mitigation techniques may be most appropriate (Clevenger et al. 2002). Using a habitat-based model, our results indicate that existing and proposed mitigation in the Buffalo Fork Valley may be adequate unless moose-vehicle collisions increase following highway reconstruction. For example, the expansion of the Buffalo Fork Bridge in 2007 created a wider corridor for moose to travel underneath the highway between high probability use areas, reducing the likelihood that moose would cross the road surface. Plans to lengthen existing bridges over rivers and streams that act as natural travel corridors may facilitate additional animal movements under the highway between high use areas (Hubbard et al. 2000, Ng et al. 2004, Sawyer and Rudd 2005, Seiler 2005); if so, transportation managers might avoid more costly mitigation such as underpasses and overpasses. If further improvements are needed in the Buffalo Fork Valley, vegetation removal along the highway right-of-way to increase motorist visibility may be the most easily applicable and socially-acceptable form of mitigation (Gundersen et al. 1998, Rea 2003, Andreassen et al. 2005).

A suite of other ungulates, large and small carnivores, and rodents also cross highways (Young and Sawyer 2006), hence, prominent wildlife crossings should be identified and mitigation techniques should benefit multiple species (Sawyer and Rudd 2005). For example, core elk crossing areas (Young and Sawyer 2006) were similar to those identified for moose in the study area, thus, appropriate mitigation could reduce collision frequency for both species. Implementing mitigation efforts that benefit multiple species will likely require detailed scientific data, such as used in our model, but it will ultimately benefit wildlife by maintaining important habitat linkages and reducing highway-related mortality (Ng et al. 2004).

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