Title
Effects of highways on grizzly bear movement in the Bow River Watershed, Alberta, Canada

Authors
Gibeau, Michael L.
Clevenger, Anthony P.
Herrero, Stephen
et al.

Publication Date
2001-09-24

EFFECTS OF HIGHWAYS ON GRIZZLY BEAR MOVEMENT IN THE BOW RIVER WATERSHED, ALBERTA, CANADA

Michael L. Gibeau, Resources and the Environment Program, University of Calgary, 2500 University Drive N.W., Calgary, Alberta, Canada. T2N 1N4. Phone: 403-220-8075

Anthony P. Clevenger, Wildlife Section, Banff National Park, Box 900, Banff, Alberta, Canada. T0L 0C0. Phone: 403-760-1371

Stephen Herrero, Faculty of Environmental Design, University of Calgary, 2500 University Drive N.W.,Calgary, Alberta, Canada. T2N 1N4

Jack Wierzchowski, Geomar Consulting Ltd., Box 1843, Grand Forks, British Columbia, Canada. V0H 1H0

Abstract: Previous research on response by grizzly bears to roads has been confined to interactions with tertiary or unimproved road systems. To our knowledge no information exists to evaluate the potential of high-speed, high-volume highways to disrupt or prevent grizzly bear movement. We know of no other area within occupied grizzly bear habitat in North America that has such an extensive network of high-speed, high-volume highways. Between 1994 and 1998 we captured and radio-marked grizzly bears in the Bow River Watershed, Alberta, and monitored their movements. Using radio telemetry data we documented the permeability of several highways to grizzly bear movement in a landscape where human presence is widespread. One highway with 24-hour, year-round high traffic volumes served as an effective barrier for adult female movement. Traffic volume appeared to be a key variable in the permeability of highways for grizzly bears. Highway crossings by grizzly bears were concentrated in specific locations and occurred during night as well as day. Our analysis demonstrates grizzly bears cross some highways in very site-specific locations, enabling us to predict crossing zones. Zones of high frequency road crossings in this study area were characterized by lower than average total access density, closer to a major drainage, more rugged terrain and higher quality habitat. Significant potential currently exists for permanent habitat and population fragmentation to occur along the Trans Canada Highway. An adaptive management approach will be crucial, with population connectivity being of paramount importance, as we continue to gain knowledge of grizzly bear response to highways.

Introduction

The ecological effects of roads have been the focus of many conservation biologists in the last decade (see Evink et al. 1996, Forman and Alexander 1998, for reviews). Studies show that roads affect mammal populations in numerous ways, from causing habitat loss and habitat alienation (i.e., sensory disturbance) to presenting physical barriers and causing road mortality (Adams & Geis 1983, Woodward 1990, Van der Zee et al. 1992, Belden and Hagedorn 1993, Brandenburg 1996, Romin and Bissonette 1996). Among these effects, habitat fragmentation and physical barriers pose what many conservation ecologists consider the greatest risk to maintaining species diversity, with demographic and genetic effects upon many species including grizzly bears (Wilcox and Murphy 1985, Ralls et al. 1986, Servheen and Sandstrom 1993, Dale et al. 1994, Mills and Smouse 1994, Forman and Alexander 1998).

Transportation routes cut across landscapes, fragmenting large areas for species such as grizzly bears. Vegetative hiding cover is always removed from the transportation corridor surface and along some portion of the right-of-way, thus making the corridor inhospitable or dangerous to grizzly bears. Previous research on response by grizzly bears to roads has been confined to interactions with tertiary or unimproved road systems (Archibald et al. 1987, Mattson et al. 1987, McLellan and Shackleton 1988, McLellan and Shackleton 1989, Kasworm and Manley 1990, Mace et al. 1996). To our knowledge no information exists to evaluate the potential of high-speed, high-volume highways to disrupt or prevent movement within occupied grizzly bear habitat.

We document the permeability of several highways to grizzly bear movement in a landscape where human presence is widespread. In mountainous terrain throughout the world, valley bottoms are the preferred habitats for both humans and wildlife. The Bow River Watershed is no exception, with several high speed, high volume highways bisecting major valley systems. Using radio telemetry information, we tested the hypothesis that grizzly bear crossing rates do not differ between highway configurations, and that grizzly bears do not differentiate between crossing areas and random. We address the potential effects of avoidance of highways, as well as the implications of road and total access density on grizzly bears.

Study Area

The study area encompassed the Bow River Watershed from its headwaters to approximately where it meets the prairies. This is 11,400 km^2 of mountainous terrain 50-180 km west of Calgary, in southwestern Alberta. This area includes a portion of Banff National Park (BNP) and adjacent Alberta Provincial lands known as Kananaskis Country. Differing agency mandates oversee preservation, industrial tourism, recreation, forestry, oil and gas extraction, mining and stock grazing. Native councils, towns and municipalities, commercial developers and residential owners diversify land administration even further.

Human presence is widespread both within and outside of BNP. Three towns, Banff, Lake Louise and Canmore are international tourist destinations that attract approximately four million visitors annually. Developments in addition to the towns that support the tourism industry include numerous hotels, campgrounds and picnic areas, five golf courses, five downhill ski facilities and an extensive network of hiking, biking and equestrian trails.

We know of no other area within occupied grizzly bear habitat in North America that has such an extensive network of high-speed, high-volume highways (figure 1).

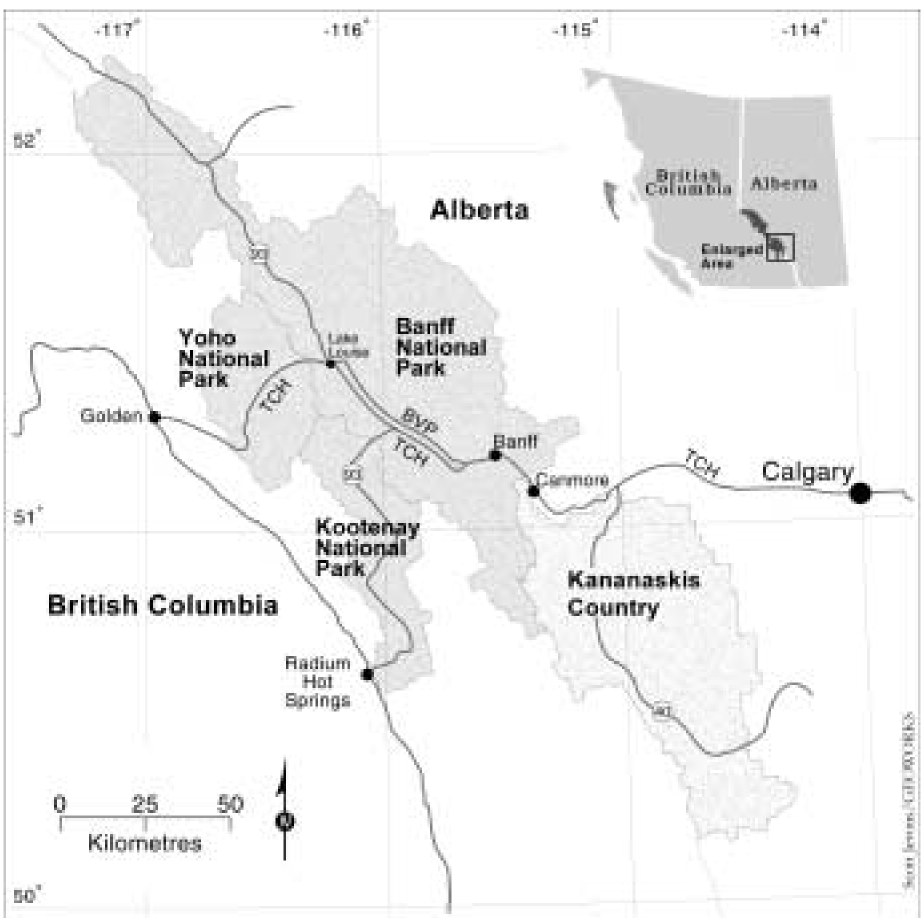

Fig. 1. Network of high-speed, high-volume highways in the Central Canadian Rocky Mountains.

People access the region using primarily the Trans Canada Highway (TCH), a major transcontinental transportation route that bisects the study area east to west. It is a four-lane divided highway through most of the study area with a summer (June - September) average traffic volume of 21,000 vehicles per day (Parks Canada, unpubl. data) and an observed average speed of 110-115 km/hr (Royal Canadian Mounted Police pers. comm). Thirty-five kilometers of this busy freeway have not yet been upgraded to a four-lane divided highway along the western edge of the study area. Forty-five km of the TCH through BNP have been fenced to keep wildlife off the roadway. Wildlife crossing structures have been placed throughout the fenced section to facilitate movement across the highway (Clevenger and Waltho 2000). The remaining 40 km of the TCH along the eastern portion of the study area is a four-lane divided highway but without a wildlife fence.

Several high-speed, two-lane paved highways serve as arterial transportation routes in the study area (figure 1). Highway 40 intersects the TCH along the front range of the Rocky Mountains dissecting Kananaskis Country from north to south. It has a summer average traffic volume of 3,075 vehicles per day with an observed traffic speed of 105-110 km/hr (Royal Canadian Mounted Police pers. comm.). Highway 93 North intersects the TCH west of the town of Lake Louise paralleling the continental divide range north to Jasper. Highway 93 North has a summer average traffic volume of 3,530 vehicles per day with an observed traffic speed of 110-115 km/hr (Banff Highway Patrol pers. comm.). The Bow Valley Parkway (BVP) parallels the TCH on the opposite side of the valley between the towns of Banff and Lake Louise. Although this highway has no paved shoulders it is similar to other two lane highways with a summer average traffic volume of 2,230 vehicles per day with an observed traffic speed of 80-85 km/hr (Banff Highway Patrol pers. comm.). Numerous two-lane paved secondary roads complete the transportation system through most of the low elevation valleys. There are very few gravel roads in the study area.

Topographic features include rugged mountain slopes, steep-sided ravines and flat valley bottoms. The climate is continental with long, cold winters and short, cool summers. The aspect and elevation of the mountainous topography modifies climate somewhat. Topography, soil, and local climate strongly influence plant communities.

Methods

Between 1994 and 1998 we captured and radio-marked grizzly bears in the Bow River Watershed, Alberta (Stevens et al. 1999), and monitored their movements. We searched for collared bears at least once per week, weather permitting, from fixed-wing aircraft or helicopter. Bears were also searched for from the ground opportunistically on a daily basis using standard techniques (Kenward 1987, Samuel and Fuller 1996). In addition to systematic radio tracking, we conducted periodic 24-hour monitoring of individual animals at hourly intervals to obtain detailed information on fine-scale movement patterns in the vicinity of roads. Through testing with radio collars placed in known locations, we recorded an average telemetry error of 150 m. We supplemented radio locations by occasional direct observation reported by the public. Locations were plotted on 1:50,000 topographic maps, assigned a Universal Transverse Mercator (UTM) coordinate and later converted to digital Geographic Information System (GIS) maps using MapInfo Professional® software (MapInfo Corporation, Troy, New York, USA). For this analysis we used several subsets of the telemetry data (described below) to avoid biases of over sampling and to maximize independence between telemetry locations (Hurlbert 1984) required for some analyses.

Highway Crossings

To determine the minimum number of highway crossings by grizzly bears we used data from weekly aerial relocations because the sampling intensity was the same for all bears. We obtained a minimum estimate of crossing frequency by counting the number of times bears crossed the four highways in the study area.

The entire telemetry data set, including 24-hour monitoring, was used to identify areas on the highway where bears chose to cross. we identified highway crossings by plotting consecutive radio locations that were obtained within 24 hours and were $\leq$1 km from the highway. We selected radio locations within this distance in order to provide greater accuracy in determining the estimated crossing location. An estimated crossing location was identified as an intersection of a straight line between 2 consecutive radio locations and the highway.

To identify whether there was a pattern in highway crossings we created a crossing density map using a moving window technique with a 1.5 km radius. To facilitate statistical analysis we categorized the crossing density map into zones of high (>4) crossings and low ($\leq$4) crossing frequencies because the density map revealed crossing locations were either highly clustered or solitary.

The time of highway crossing was estimated by interpolating time from distance calculations following Brandenburg (1996). Assuming a straight line and constant rate of travel, highway crossing time (hct_i) was determined using the following formula:

$$hct_i = (r_i / d_i /) (et_i) + (t_i)$$

where ri is the distance from the highway to the location occurring before the bear crossed the highway, di is the distance between sequential locations, eti is the time elapsed between sequential locations, and ti is the time of the location before the bear crossed the highway.

We obtained traffic volumes for each estimated time of highway crossing from hourly traffic counter data collected for each highway in the study area (Alberta Transportation and Utilities, and Parks Canada unpublished. data). There were no traffic volume data for Highway 40 in 1994; therefore, we used 1995 volume data for the same date and time as the 1994 crossings (n=6). For analysis, hourly traffic volume assigned to each crossing location was categorized into either high volume (_ = 111 for BVP and 117 for Highway 40) or low volume (_ = 13 for BVP and 11 for Highway 40). Categories were based on the inflection point where significant change was observed in traffic volumes.

Using one radio location per day and program CALHOME (Kie et al. 1996), we constructed 99 percent minimum convex polygon (MCP) home ranges (Gibeau and Herrero 1999). We grouped individual bear home ranges into composite home ranges for male and female bears. Both road and total access density were calculated for each of the composite home ranges. Roads were defined as those passable by motor vehicle. Trails were restricted to non-motorized travel. Total access density was defined as all roads and trails.

Crossing Location Attributes

Attributes associated with crossing zones were analyzed at two scales: 1) a fine site level scale within a 150-m radius of the highway crossing site location and, 2) a broader habitat scale within a 1-km radius of the crossing site location. We compared characteristics of high and low frequency crossing zones to the overall characteristics along the total length of the highway by stratified random sampling to extract landscape attributes in the two areas. Landscape attributes for the observed crossing zones and the random highway points (expected) were analyzed using Idrisi® (Clark Univ., Worcester, MA) GIS map layers of: 1) proximity to high quality habitat, 2) proximity to nearest major drainage, 3) terrain ruggedness, and 4) total human access density.

In the absence of a habitat suitability map for the study area we derived surrogate habitat values using Landsat Thematic Mapper satellite images transformed into a greenness band using the tasseled cap transformation (Crist and Cicone 1984, Manley et al 1992). Mace et al. (1999) showed a strong selection by grizzly bears for areas of high greenness. We categorized the image into 12 classes of increasing greenness as an indicator of grizzly bear habitat. Use and expected values for each greenness class calculated from our aerial telemetry data set indicated that the four highest classes were used more than expected based on availability (P = 0.0002). These four classes were combined into a single map layer to represent preferred or high habitat quality.

Proximity to nearest drainage measurements used digital hydrology data for the Bow River Watershed (Parks Canada and Alberta Environmental Protection). We eliminated the Bow and Kananaskis Rivers to focus the analysis on the drainage elements that, given their orientation with respect to the highways, might be conducive to the crossings of highways. A drainage was defined as a permanent watercourse mapped at a scale of 1:50,000.

Terrain ruggedness (Tr), an index capturing the level of complexity of terrain (Nellemann and Fry 1995), was calculated using the following formula:

$$Tr = (De^{x}Ac)/(De+Ac)$$

where De = the density of contour lines within a given window, and Ac = an index of aspect variability (defined as the frequency of cardinal aspect change) within a given window. We used a circular window of 1.5 km radius that roughly corresponds to an average female daily movement distance. The resulting map of terrain ruggedness classified the landscape where the higher the value the greater the topographic diversity.

Both road (motorized roads) and total (roads and trails) human access density maps were produced using a moving window technique (Pereira and Itami 1991, Mace et al 1996, 1999) with a 1.5-km radius window. The moving window technique calculated linear road or total access kilometers per square kilometer. All unsuitable lands (rock, bare soil, and water bodies) were excluded in the density calculations.

Analysis

An unbalanced multivariate analysis of variance (MANOVA) was used to test for the differences in landscape attributes between zones of high and low frequency crossing and the average conditions found along the highways. We used post hoc, multiple comparisons to identify differences in crossing zones for both the immediate vicinity (150 m) and broad scale (1 km) buffers around highways. Significance was accepted at $P < 0.05$. The assumption of equal variances was met for the telemetry data set.

We used discriminant function analysis to distinguish the relative importance of landscape characteristics. Mahalanobis distances criterion was used in a step-wise fashion for variable entry and removal. We estimated the overall power of the model by scrutinizing the eigenvalues, Wilk’s lambda, canonical correlation coefficients, and the percentage of correctly classified cases. To improve power, we opted for a binary model contrasting zone of high frequency crossing with the entire highway. We judged the relative contribution of the variables by analyzing the order in which the variables were entered or removed from the analysis, combined with the analysis of the structure matrix and the magnitude of the standardized canonical function coefficients.

Results

We collected 7,380 telemetry locations from 54 grizzly bears (16 adult male, 11 subadult male, 19 adult female, 8 subadult female) between 1994-98. Twenty-one of those 54 bears had home ranges in the same valley as a high-speed highway (6 adult male, 2 subadult male, 10 adult female, 3 subadult female). Using the aerial telemetry data as a sample of equal-intensity monitoring, we recorded differences in permeability between highways (table 1). Small sample size precluded meaningful statistical testing.

Highway Crossings

Three adult males, 2 subadult males, and 1 subadult female crossed the TCH during the five-year period. Both subadult males were habituated and ultimately removed from the population. The subadult female was also habituated but was not removed. In Kananaskis Country, 3 adult males, 5 adult females, 1 subadult male, and 2 subadult females crossed Highway 40. Two adult males, 2 adult females, 1subadult male and 1subadult female crossed the BVP. Both subadults are the bears that also crossed the TCH. One adult female and 1 subadult male crossed Highway 93, although these were the only bears in our sample in that vicinity.

There was a total of 33 crossings by six bears on the TCH, for a median of 1.5 crossings per bear. Two bears crossed Highway 93, 17 times, for a median of 8.5 crossings per bear. On Highway 40 there was a median of 12.0 crossings per bear, while on the BVP the median was 6.0. One adult male accounted for 66 percent of all TCH crossings. Of the four highways, the TCH formed a home range boundary for six adult females, while Highway 93 bordered the home range of one adult female.

Table 1
Minimum number of recorded grizzly bear highway crossings in the Bow River Watershed, Alberta, 1994-1998.

	Highway			
Bear ID	TCH	93	40	BVP
10	22	-	-	22
13	-	-	20	-
14	-	-	1	-
15	6	-	-	14
34	-	-	6	-
54	1	-	-	-
Subadult male				
16	1	1	-	8
23	1	-	1	-
Adult female				
24	-	-	36	-
26	B	-	14	-
30	B	B	-	4
31	-	-	12	-
32	B	-	-	1
36	B	16	-	-
37	-	-	10	-
40	B	-	-	-
46	B	-	-	-
47	-	-	1	-
Subadult female				
35	-	-	16	-
39	-	-	13	-
56	2	-	-	2
N bears	6	2	11	6
No. crossings	33	17	130	51
Median No. crossing/bear	1.5	8.5	12.0	6.0
No. border home ranges	6	1	0	0

- Bear's home range was not in the same valley as the highway, thus no interaction.
B Bear's home range was in the same valley, but did not cross the highway constituting a home range boundary.

Road density within the composite female home range was 0.16 km/km^2. Total access density within the composite female home range was 1.30 km/km^2. Road density within the composite male home range was 0.44 km/km^2. Total access density within the composite male home range was 1.54 km/km^2.

Only the BVP and Highway 40 had sufficient data that met our established criteria of telemetry locations within 24 hours and 1 km of the highway to analyze highway crossing zones. Three male grizzly bears crossed the BVP 18 times and 2 females crossed 13 times for a total of 31 crossings. Two male grizzly bears crossed Highway 40, 12 times and 6 females crossed 28 times for a total of 40 times. Discrete areas of high frequency grizzly bear crossing were identified for both the BVP (figure 2) and Highway 40 (figure 3).

Timing of highway crossing varied over the 24-hour period. There was no clear pattern of any nocturnal or crepuscular activity crossing roads as most crossings took place between 23:00-07:00 hours (38 percent) and between13:00-18:00 (38 percent) (figure 4). The limited amount of data precluded analysis of each highway separately.

Fig. 2. Grizzly bear highway crossing zones along the Bow Valley Parkway, Alberta, 1994-1998

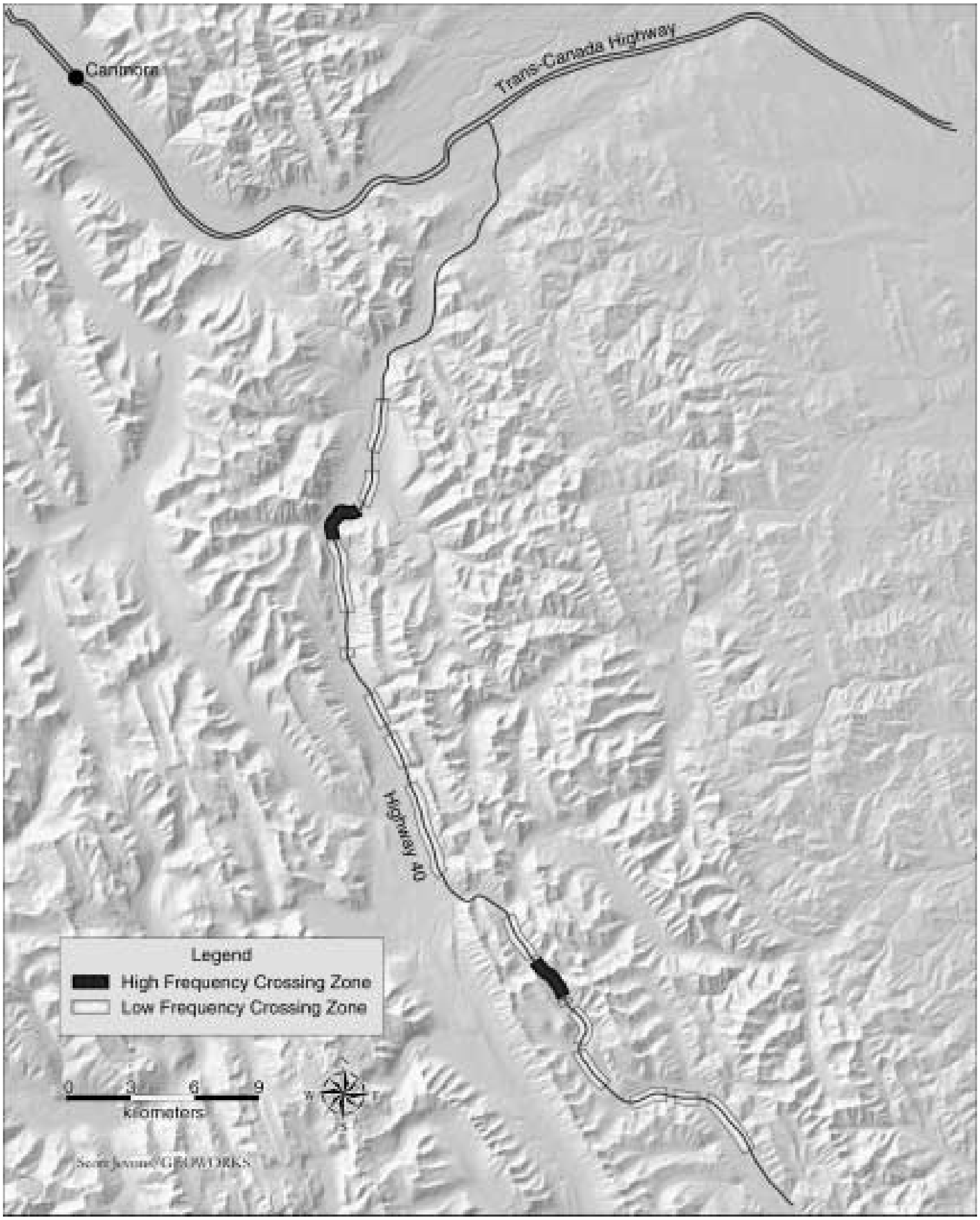

Fig. 3. Grizzly bear highway crossing zones along Highway 40, Alberta, 1994-1998.

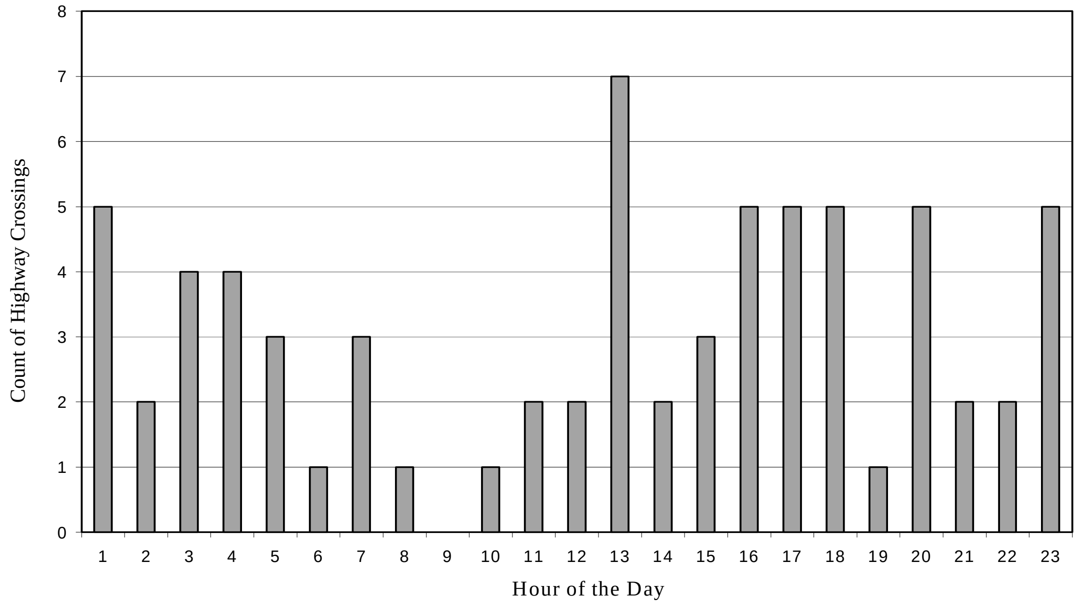

Fig. 4. Timing of grizzly bear highway crossings for the Bow Valley Parkway and Highway 40, Alberta, 1994-1998.

The number of grizzly bear highway crossings varied in relation to traffic volume and intensity of highway use. Most single event crossing areas (identified as zones of low frequency crossing) were made during periods of high traffic volume. In contrast, areas of multiple crossings (zones of high frequency crossing) were used equally during periods of both high and low traffic volumes (table 2).

Table 2
Number of grizzly bear highway crossings for different traffic volumes in the Bow River Watershed, Alberta, 1994-1998.

	Bow Valley Parkway			Highway 40		
	Low traffic volume	High traffic volume	Total n	Low traffic volume	High traffic volume	Total n
Low intensity crossing area	2	7	9	3	10	13
High intensity crossing area	11	11	22	12	15	27
Total n	13	18	31	15	25	40

Crossing Location Attributes

The distribution of distance measurements of crossing location attributes was found to be non-normal. However, the similar shapes of the distributions (symmetric to slightly right-skewed) resulted in the variables having similar variances (verified by the Levene's tests of the homogeneity of variance). Results of statistical tests were the same with both the original values and transformed values to normalize the data. Given the robustness of the chosen statistical tool (MANOVA) to the departures from normality and the need to maintain a clarity of presentation, we present results of original values.

High quality habitat was closer to zones of high frequency crossing than the entire highway in the 150 m buffer for both the BVP ($F_{2, 560} = 6.92$, $P < 0.001$) and Highway 40 ($F_{2, 862} = 8.61$, $P < 0.001$) but was not significantly closer within a 1 km buffer for either highway. No significant differences were detected in proximity to high quality habitat between zones of high and low frequency crossing in the immediate vicinity of either highway.

Significant differences were detected in the distance to a major drainage between zones of high frequency crossing, and both zones of low frequency crossing and the entire highway in the 150 m buffer for the BVP ($F_{2, 560} = 51.16$, $P < 0.001$) and Highway 40 ($F_{2, 862} = 26.61$, $P < 0.001$). Similar results were found for the 1 km buffer for both the BVP ($F_{2, 1103} = 22.70$, $P < 0.001$) and Highway 40 ($F_{2, 2552} = 158.85$, $P < 0.001$). In all cases, major cross-drainages were closer to zones of high frequency crossing than to either zones of low frequency crossing or the entire highway.

Significant differences in terrain ruggedness were evident along the BVP between zones of high frequency crossing, and both zones of low frequency crossing and the entire highway in the immediate vicinity of the highway ($F_{2, 560} = 28.08$, $P < 0.001$) and 1 km buffer ($F_{2, 1103} = 14.84$, $P < 0.001$). Significant differences in terrain ruggedness were also observed along Highway 40 between zones of high frequency crossing, and both zones of low frequency crossing and the entire highway in the immediate vicinity of the highway ($F_{2, 862} = 143.86$, $P < 0.001$) and 1 km buffer ($F_{2, 2552} = 136.34$, $P < 0.001$). In all cases, terrain ruggedness values were higher in zones of high frequency crossing than either zones of low frequency crossing or the entire highway.

Significant differences in total human access density were evident only for the BVP between zones of high frequency crossing, and both zones of low frequency crossing and the entire highway in both the immediate vicinity of the highway ($F_{2, 560} = 126.54$, $P < 0.001$) and 1 km buffer ($F_{2, 1103} = 62.37$, $P < 0.001$). Total access density in zones of high frequency crossing were 2.34 km/km2 compared to 3.01 km/km2 along the entire highway in the 150 m buffer. When analyzing both highways together, significance was detected between zones of high frequency crossing, and both zones of low frequency crossing and the entire highway in the immediate vicinity of the highway ($F_{2, 1425} = 15.57$, $P < 0.001$), but not for the 1 km buffer.

Discriminant function analysis for the BVP produced a 88.3-percent cross-validated correct classification rate. Wilk's Lambda was low (0.51) denoting relatively high discriminating power. The high canonical correlation coefficient (0.69) indicated the model discriminated well between the groups. The Highway 40 analysis had an 83.1-percent cross-validated correct classification rate. Wilk's Lambda was again low (0.60) denoting relatively high discriminating power. The high canonical correlation coefficient (0.63) indicated the model discriminated well between the groups.

Some differences between the structure matrix and the standardized canonical function coefficients were evident due to a correlation between terrain ruggedness and distance to a major drainage. We report the standardized coefficients because of our desire to use discriminant function analysis as a predictive tool.

The most important contributors to calculating the discriminant score for the BVP were: 1) total access density (0.790), 2) terrain ruggedness (-0.694), 3) distance to a major drainage (0.654), and 4) proximity to high quality habitat (0.176). As the canonical discriminant functions evaluated at group means placed the group centroid for the zone of high frequency crossing on the negative side from the grand means, the negative sign on terrain ruggedness indicates higher ruggedness levels within zones of high frequency crossing.

The most important contributors to calculating the discriminant score for Highway 40 were: 1) terrain ruggedness (1.227), 2) total access density (0.789), and 3) distance to a major drainage (-0.213). As the canonical discriminant functions evaluated at group means placed the group centroid for the zone of high frequency crossing on the positive side from the grand means, the positive sign on terrain ruggedness indicates higher ruggedness levels within zones of high frequency crossing.

Discussion

The relative crossing index of bears along the four highways indicated that the TCH was the least permeable for grizzly bears (table 1). Between 1994 and 1998 none of the radio-collared adult female bears crossed the TCH and only two radio-collared males regularly crossed (Gibeau 2000). During 1999 and 2000 a new radio-collared adult female did cross in the fenced section of the TCH using the wildlife crossing structures. Additionally, two highly habituated young females also crossed an unfenced section of the TCH in the vicinity of the town of Lake Louise (Gibeau unpubl. data). Black bears responded similarly to a high-speed highway in North Carolina by crossing only 14 times (n = 9 bears) in four years, and one bear was killed while attempting to cross (Beringer et al. 1990). Highway 40 had the highest number of crossings per bear. This can be partially explained by the fact that the recorded Highway 40 traffic volume is most likely overestimated as a large proportion of the vehicles do not constitute through-traffic (P. Kilburn, Alberta Transportation and Utilities pers. comm.).

Road density has been proposed as a broad index of the ecological effects of roads in a landscape (Forman and Hersperger 1996, Forman et al. 1997, Forman and Alexander 1998). Besides constituting a source of mortality, roads can disrupt movements, cause habitat fragmentation and increase human access, the latter ultimately leading to increased mortality (Brody and Pelton 1989, Beringer et al. 1990). The reported threshold density for functioning landscapes with large carnivores is approximately 0.6 km/km^2 (Forman et al.1997) and is based on field studies of wolves, cougars and brown bears (Thiel 1985, Jensen et al. 1986, Mech et al. 1988, Van Dyke et al. 1986, Clevenger et al. 1997). Previous studies have emphasized that roads themselves are not the problem but rather the human access created by roads. This access can lead to greater disturbance, vulnerability to legal and illegal killing, and management removal due to conflicts (Mech et al. 1988, Brody and Pelton 1989, Beringer et al. 1990, Clevenger et al. 1997).

In the Bow River watershed, road density by itself does not encapsulate the overall effect of humans. We feel a better measure is total access density of roads and trails, which in combination contribute to sensory disturbance. Composite female and male grizzly bear home ranges in this study area were well below the Forman et al. (1997) proposed threshold road density of 0.6 km/km^2, but well above that threshold when considering total access density. Brody and Pelton (1989) indicated that the threshold density for high traffic volume roads (e.g., interstate highways) in bear ranges is extremely low and will be much lower than 0.6 km/km^2. Contrary to other studies of road effects on large carnivores, we documented how one highway with 24-hour, year-round high traffic volumes can serve as an effective barrier for adult female movement and a filtered barrier for males.

Our results, in part, support earlier findings that as traffic volumes increase, crossings by bears decrease (Brody and Pelton 1989, Beringer et al. 1990, Brandenburg 1996). Major highways such as the Trans-Canada in the Bow River Valley can severely disrupt movements by adult female grizzly bears and to a lesser extent, male bear movements. Most of the TCH crossings were by one adult male, suggesting that successfully traversing a major highway is likely a learned behavior that some individuals become adept at over time.

No literature exists on grizzly bear response to roads with traffic volumes in the order of magnitude we have documented. Brandenburg (1996) reported on how roads with traffic volumes between 100-10,000 vehicles per day affected movements of black bears. An interstate highway bisected black bear study areas in North Carolina (Brody and Pelton 1989, Beringer et al. 1990), however, the timing, frequency or distribution of crossings were not reported. Road crossings by black bears at another North Carolina study area were primarily nocturnal and/or during times of low traffic volume (Brandenburg 1996). We found that highway crossings by grizzly bears were concentrated in specific locations (figures 2 and 3) and occurred during night as well as day (figure 4). The rugged topography of this study area, characterized by glacier-carved valleys and steep-walled side drainages, probably limits the number of possible cross-valley and cross-highway locations. The relatively high number of daytime crossings by grizzly bears was surprising and difficult to explain. Bears had a strong tendency to use zones of high frequency crossings during low traffic volumes, however, during periods of high traffic volume, bears used zones of low frequency crossing as much as the zones of high frequency crossings. The scattered distribution of crossing areas during heavy traffic (single events) we attribute to random crossing site selection by bears, i.e., attempting to cross anywhere possible.

Zones of high frequency road crossing for grizzly bears in our study area were characterized by lower total access density, close proximity to a major drainage, more rugged terrain, and higher quality habitat. While these results are for the most part intuitive and consistent with our knowledge, this first attempt to characterize highway-crossing zones identifies specific parameters that can be applied in an adaptive management approach.

Management Implications

Managers have known for some time the direct effect of high-speed roads (mortality) and indirect effect of unpaved or secondary road densities (disturbance, human access) on many wildlife species. However, major transportation systems pose problems that have been virtually disregarded in the past, the most serious being habitat fragmentation and barrier effects to wildlife movement. To date much of our experience related to grizzly bears and roads can be summarized, arguably, into management of human access (IGBC 1998). The effect of high speed, high volume highways on grizzly bears has not been addressed until now.

Permeability was significantly compromised for grizzly bears along the TCH even though this highway had three different configurations in the study area (40 kilometers of four-lane no wildlife fence, 45 kilometers of four-lane with a wildlife fence, and 35 kilometers of two-lane). This leads us to believe that traffic volume appears to be a key variable in the permeability of highways for grizzly bears. The higher the traffic volume the less likely a bear will cross the highway. Management agencies in the Bow River Watershed now find themselves in a particularly difficult position with respect to maintaining a contiguous grizzly bear population in the Central Canadian Rocky Mountains. Our results, along with other analyses form this bear population (Gibeau 2000, Gibeau et al. 2001), lead us to conclude that the TCH is a barrier to adult female grizzly bear movement. The implications of a movement barrier are unknown, however it certainly points to the initial stages of islandization. Given grizzly bear’s large home ranges, significant potential currently exists for permanent habitat and population fragmentation to occur. Management agencies must maintain access to high quality habitat, especially for adult females.

Our analysis demonstrates grizzly bears cross some highways in very site-specific locations, enabling us to predict crossing zones. This will be useful to managers contemplating crossing structures for wildlife passage in an attempt to mitigate the adverse effects of the TCH. While a significant amount of time, energy, and money has gone into the design, placement and construction of these crossing structures (Leeson 1996), the question remains as to how grizzly bears will travel through human access zones to get to the mouth of these structures in order that they may cross the highway. Further, is it possible to mitigate highway effects for grizzly bears if they are repelled by highways and fail to even get close to them? Currently, the combination of intense sensory disturbance from high traffic volumes and overall high human access density precludes most grizzly bears from being in the vicinity of the TCH. For bears to have the possibility of using these crossing structures overall human access density must be reduced, especially in areas identified as potential crossing zones. An adaptive management approach will be crucial as we continue to gain knowledge of grizzly bear response to highways.

National Parks by themselves cannot sustain a regional grizzly bear population (Herrero 1994). Some of the best chances for grizzly bear persistence come from outside National Parks (McLellan et al. 1999) and hence a cooperative and coordinated management approach is critical, with population connectivity being of paramount importance.

Biographical Sketch: Mike Gibeau is the grizzly bear research specialist for Parks Canada and principle researcher for the Eastern Slopes Grizzly Bear Project. His work involves investigating the impacts of human activity on grizzly bears in the Central Canadian Rocky Mountains. He has undergraduate degrees in both forestry and resource conservation, a master's in wildlife biology from the University of Montana, and a Ph.D. in conservation biology from the University of Calgary. Mike has spent 24 years working in National Parks, originally as a park warden and now a biologist. He has extensive experience in the ecology and management of large carnivores including research on coyotes, wolves, black bears, and grizzly bears.

References

Adams, L. W., and A. D. Geis. 1983. Effects of roads on small mammals. Journal of Applied Ecology 20: 403-415.

Archibald, W. R., R. Ellis, and A. N. Hamilton. 1987. Responses of grizzly bears to logging truck traffic in the Kimsquit River Valley, British Columbia. International Conference on Bear Research and Management 7:251-257.

Belden, R. C., and B. W. Hagedorn. 1993. Feasibility of translocating panthers into northern Florida. Journal of Wildlife Management 57:388-397.

Beringer, J. J., S. G. Seibert, and M. R. Pelton. 1990. Incidence of road crossings by bears on PisgahNational Forest, North Carolina. International Conference on Bear Research and Management 8:85-92.

Brandenburg, D.M. 1996. Effects of roads on behavior and survival of black bears in coastal North Carolina. M.Sc. thesis. University of Tennessee, Knoxville.

Brody, A. J., and M. R. Pelton. 1989. The effects of roads on black bear movements in western North Carolina. Wildlife Society Bulletin 17:5-10.

Clevenger, A. P. and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14: 47-56.

Clevenger, A. P., F. J. Purroy, and M. A. Campos. 1997. Habitat assessment of a relict brown bear *Ursus arctos* population in northern Spain. Biological Conservation 80:17-22.

Crist, E. P., and R. C. Cicone. 1984. Application of the tasseled cap concept to simulated thematic mapper data. Photogrammetric Engineering and Remote Sensing 50:343-352.

Dale, V. H., S. M. Pearson, H. L. Offerman, and R. V. O'Neill. 1994. Relating patterns of land-use change to faunal biodiversity in the Central Amazon. Conservation Biology 8:1027-103.

Evink, G., D. Ziegler, P. Garrett, and J. Berry. 1996. Highways and movement of wildlife: improving habitat connections and wildlife passageways across highway corridors. Proceedings of the FLDOT/FHA transportation-related wildlife mortality seminar. Florida Department of Transportation, Tallahassee, Florida.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207-231.

Forman, T. T. and A. M. Hersperger. 1996. Road ecology and road density in different landscapes, with international planning and mitigation solutions. *in* G. L. Evink ed. Proceedings of the International Conference on Ecology and Transportation, Florida Dept. of Transportation, Talahassee, Florida, USA.

Forman, T. T., D. S. Friedman, D. Fitzhenry, J. D. Martin, A. S. Chen, and L. E. Alexander. 1997. Ecological effects of roads: Toward three summary indices and an overview for North America. *in* Proceedings habitat fragmentation and infrastructure. Ministry of Transport, Public Works and Water Management, Directorate-General for Public Works and Water Management, Road and Hydraulic Engineering Division, Delft, The Netherlands.

Gibeau, M. L. 2000. A conservation biology approach to management of grizzly bears in Banff National Park. Ph.D. thesis, Resources and the environment program, University of Calgary, Calgary, AB, Canada. 129 pp.

Gibeau, M. L. and S. Herrero. 1999. Year 5 progress report. Eastern Slopes Grizzly Bear Project. University of Calgary, AB, Canada.

Gibeau, M. L., A. P. Clevenger, S. Herrero, and J. Wierchowski. 2001. Grizzly bear response to human development and activities in the Bow River watershed, Alberta. Biological Conservation. In Press.

Herrero, S. 1994. The Canadian National Parks and grizzly bear ecosystems: The need for interagency management. International Conference on Bear Research and Management 9:7-21.

Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54:187-211.

Interagency Grizzly Bear Committee (IGBC). 1998. Grizzly bear/motorized access management taskforce report. USDI Fish and Wildlife Service, Missoula, Montana, USA.

Jensen, W. F., T. K. Fuller, and W. L. Robinson. 1986. Wolf *Canis lupus* distribution on the Ontario-Michigan border near Sault Ste. Marie. Canadian Field-Naturalist 100:363-366.

Kasworm, W. F., and T. L. Manley. 1990. Road and trail influences on grizzly bears and black bears in northwest Montana. International Conference on Bear Research and Management 8:79-84.

Kenward, R. 1987. Wildlife radio tagging: equipment, field techniques and data analysis.Academic Press, New York, N.Y., USA.

Kie, J. G., J. A. Baldwin, and C. J. Evans. 1996. Calhome: a program for estimating animal home ranges. Wildlife Society Bulletin 24:332-344.

Leeson, B. F. 1996. Highway conflicts and resolutions in Banff National Park, Alberta, Canada. *in*: Evink, G. L., P. Garrett, D. Zeigler and J. Berry (editors.) Trends in addressing transportation related wildlife mortality. Proceedings of the transportation related wildlife mortality seminar, State of Florida DOT, Environmental Management Office, Tallahassee, FL., USA.

Mace, R. D., J. S. Waller, T. L. Manley, L. J. Lyon, and H. Zuuring. 1996. Relationships among grizzly bears, roads, and habitat in the Swan Mountains, Montana. Journal of Applied Ecology 33:1395-1404.

Mace, R. D., J. S. Waller, T. L. Manley, K. Ake, and W. T. Wittinger.1999. Landscape evaluation of grizzly bear habitat in western Montana. Conservation Biology 13:367-377.

Manley, T. L., K. Ake, and R. D. Mace. 1992. Mapping grizzly bear habitat using Landsat TM satellite imagery. Pages 231-240 *in* Remote sensing and natural resource management. Proceedings of the 4th Remote Sensing Applications Conference. U.S. Forest Service, Orlando, Florida, USA.

Mattson, D. J., R. R. Knight, and B. M. Blacnchard. 1987. The effects of developments and primary roards on grizzly bear habitat use in Yellowstone National Park, Wyoming. International Conference on Bear Research and Management 7:259-273.

McLellan, B. N. and D. M. Shackleton. 1988. Grizzly bears and resource extraction industries: effects of roads on behavior, habitat use, and demography. Journal of Applied Ecology 25:451-460.

McLellan, B. N. and D. M. Shackleton. 1989. Immediate reactions of grizzly bears to human activities. Wildlife Society Bulletin 17:269-274.

McLellan, B. N., F. W. Hovey, R. D. Mace, J. G. Woods, D. W. Carney. M. L. Gibeau, W. L. Wakkinen, and W. F. Kasworm. 1999. Rates and causes of grizzly bear mortality in the interior mountains of British Columbia, Alberta, Montana, Washington and Idaho. Journal of Wildlife Management. 63:911-920.

Mech, L. D., S. H Fritts, G. L. Radde, and W. J. Paul. 1988. Wolf distribution and road density in Minnesota. Wildlife Society Bulletin 16:85-87.

Mills, L. S., and P. E. Smouse. 1994. Demographic consequences of inbreeding in remnant populations. American Naturalist 144:412-431.

Nellemann, C., and G. Fry. 1995. Quantitative analysis of terrain ruggedness in reindeer winter grounds. Arctic 48: 172-176.

Pereira, J. M. and R. M. Itami. 1991. GIS-based habitat modeling using logistic multiple regression: a study of the Mt. Graham red squirrel. Photogrammetric Engineering and Remote Sensing. 57:1475-1486.

Ralls, K., P. H. Harvey, and A. M. Lyles. 1986. Inbreeding in natural populations of birds and mammals. Pages 35-56 *in* M. E. Soule, editor. Conservation Biology: The science of scarcity and diversity. Sinauer Associates, Inc., Sunderland, Massachusetts, USA.

Romin, L. A., and J. A. Bissonette. 1996. Deer-vehicle collisions: Status of state monitoring activities and mitigation efforts. Wildlife Society Bulletin 24:276-283.

Samuel, M. D. and M. R. Fuller. 1996. Wildlife radiotelemetry. Pp. 370-418 *in* T. A. Bookhout, editor. Research and management techniques for wildlife and habitats. Fifth edition. The Wildlife Society, Bethesda, MD., USA.

Servheen, C., and P. Sandstrom. 1993. Ecosystem management and linkage zones for grizzly bears and other large carnivores in the northern Rocky Mountains in Montana and Idaho. Endangered Species Bulletin 18:3 10-13.

Stevens, S., C. Mamo, T. Shury, and M. L. Gibeau. 1999. Eastern slopes grizzly bear project capture program. Unpublished report for the Eastern Slopes Grizzly Bear Project Steering Committee, University of Calgary, AB. Canada.

Thiel, R. P. 1985. Relationships between road densities and wolf habitat suitability in Wisconsin. American Midland Naturalist 113:404-407.

Van der Zee, F. F., J. Wiertz, C. J .F. Ter Braak, R. C. van Apeldorn, and J. Vink. 1992. Landscape change as a possible cause of the badger *Meles meles L*. decline in The Netherlands. Biological Conservation 61:17-22.

Van Dyke, F. B., R. H. Brocke, H. G. Shaw, B. B. Ackerman, T. P. Hemker, and F. G. Lindzey. 1986. Reactions of mountain lions to logging and human activity. Journal of Wildlife Management. 50:95-102.

Wilcox, B. A., and D. D. Murphy. 1985. Conservation strategy: the effects of fragmentation on extinction. American Naturalist 125:879-887.

Woodward, S. M. 1990. Population density and home range characteristics of woodchucks at expressway interchanges. Canadian Field Naturalist. 104:421-428.