University of Alberta

GRIZZLY BEAR (*Ursus arctos* L.) SELECTION OF ROADED HABITATS IN A MULTI-USE LANDSCAPE

by

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This work is dedicated to the memory of my mother Barb (1957- 2001).

ABSTRACT

Given persistent and growing human encroachment into grizzly bear (*Ursus arctos*) habitats, it is imperative that we strive for a mechanistic understanding of bear behaviour to justify and direct conservation efforts, particularly in high-mortality areas such as near roads. I hypothesized that bears were not necessarily attracted to roads but that roads were associated with preferred bear habitats. Grizzly bear attractants near roads were examined at multiple spatial scales. I then identified habitats similar to where roads were built and tested grizzly bear selection of roads and these road-like habitats. Finally, I analyzed grizzly bear step selection and movements around roads. I found that grizzly bears were selecting habitats in close proximity to roads, possibly because of their associations with cutblocks and the spatial placement of roads in low elevation valleys. Due to high mortality near roads, I conclude that roaded habitats are an attractive sink for grizzly bears.

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CHAPTER 1

GENERAL INTRODUCTION

Throughout North America, a growing human population and a high standard of living increase the pressure to expand into undeveloped land for resources, settlement, and economic growth. As a result, the consequence of land development on wildlife has become a topic of concern. Historically, areas with high human presence have experienced substantial declines in grizzly bear (*Ursus arctos*) populations due to both human-caused mortality (McLellan and Shackleton, 1988; Benn and Herrero, 2002; Nielsen et al., 2004a) and habitat loss (Brown, 1985; Mattson, 2002). The forests of Alberta, Canada only recently have been opened to industrial development, yet the resulting landscape change has been considerable (Schneider, 2002). In rugged, uninhabitable areas, grizzly bear populations continue to be secure (Mattson and Merrill, 2002), but in the foothills where pressure from development is highest, the future persistence of grizzly bear populations is less certain.

Not all development practices are detrimental to grizzly bears. Some have been shown to be beneficial. For example, timber harvesting creates early successional stage forests that promote the growth of several important bear foods (Bratkovich, 1986; Hillis, 1986; Nielsen et al., 2004b). In west-central Alberta, bears within managed forests have lower levels of cortisol and higher levels of progestin than neighboring bears in National Parks, suggesting that bears within managed forests experience less stress and have higher levels of reproductive activity (Wasser et al., 2004). However, while timber harvesting has some benefits, industrial development creates a permanent network of roads on the landscape. Increasing human access has proven to be detrimental to bear survival by increasing vehicular collisions, hunter access, and illegal poaching (McLellan and Shackleton, 1988; Mace et al., 1996; Johnson et al. 2004; Nielsen et al., 2004a). Human-caused mortalities in Alberta between 2000 and 2005 fell into several categories: legal harvest (85), illegal harvest (24), self-defense (20), mistaken for a black bear by a hunter (11), native or métis harvest (8), research (5), problem bear removal (4), and accident (3) (Alberta Government). Even within Banff National Park, where bears are protected, human-caused mortalities accounted for 90 percent of all grizzly bear deaths between 1971 and 1998, and of those with known locations, all occurred within 500 m of a road or 200 m of a trail (Benn and Herrero, 2002). Furthermore, no females over 10 years of age were captured in the managed portion of my study area between 1999 and 2004, suggesting that female mortality is high (Stenhouse, personal communication). Thus, even though timber harvested stands appear to increase bear foods, their association with open roads may be creating an attractive sink (Delibes et al., 2001; McLellan et al., 1999).

The behavioural response of grizzly bears to roads has been variable. Weilgus and Venier (2003) found that grizzly bears avoid roads; however, the extent of avoidance seemed to be contingent on the traffic volume (Mattson et al, 1987; Archibald et al., 1987). Others have found a neutral or positive selection (Mace et al, 1996) particularly when roads were near an important food source (Chruszcz et al., 2003) or when alternative foods were less abundant (Mattson et al., 1992). There was also variation in the response between the sexes. Some studies observed females using habitats near roadways more readily than males (Mattson et al., 1987; Mattson et al., 1992) particularly when they had cubs (McLellan and Shackleton, 1988). Conversely, Gibeau et al. (2002)

found that females remained further from roads, but were more tolerant of human settlement.

In the eastern foothills of the Rocky Mountains, it was observed that grizzly bears were closely associated with roads, but due to the correlation between roads and other landscape features the mechanism of selection was unknown (Nielsen, *unpublished*). The purpose of my work is therefore to do a comprehensive investigation of sources of attraction around roads and to explore confounded variables near roads. Previous research addressing confounding factors near roads is limited, with some studies only describing grizzly bear response to roads (Mattson et al., 1987; Mueller et al., 2004). Therefore in Chapter 2, I explore sources of attraction around roads at different spatial scales, examining the occurrence of grizzly bear food items near roads and the spatial orientation of roads. It is also the purpose of this study to quantify grizzly bear response to roads while controlling for confounded factors. Although experimental manipulation or a before-after, control-impact (BACI) design are the most straightforward means to explore confounded variables, these methods are not often feasible when landscape development is well underway (Appendix A). Therefore in Chapter 3, I use information gained from the spatial orientation of roads to test grizzly bear selection of roads and "road-like" habitats (i.e., undeveloped areas that were similar to where roads were built). In Chapter 4, I quantify grizzly bear selection of roads using step selection functions (Fortin et al., 2005) and explore behavioural changes near roads using step length analysis. General conclusions resulting from these investigations are discussed in Chapter 5, along with management recommendations to decrease grizzly bear mortalities around roads in the foothills landscape.

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CHAPTER 2

ROAD VEGETATION AND SPATIAL ARRANGMENT AS AN ATTRACTANT TO GRIZZLY BEARS

1. INTRODUCTION

The ecological effects of roads have become a major issue in conservation biology because roads can have a lasting influence on ecosystem functioning (Bennett, 1991; Forman and Alexander, 1998; Trombulak and Frissel, 2000; Forman et al., 2003). Roads affect ecological communities both chemically and physically by increasing nitrogen oxides and chemical pollutants (Forman et al., 2003), aiding in the transport of non-native and disturbance species (Schowalter, 1988; Watkins et al, 2003), creating edges and increasing fragmentation (Forman et al., 2003; Riitters et al., 2004), and increasing human access (Forman and Alexander, 1998). The most noticeable road effects are within 10-15 m of the roadside (Forman et al, 2003; Watkins et al, 2003; Hansen and Clevenger, 2005), but impacts on some bird and mammal species have been observed greater than 1 km away (Forman and Deblinger, 2000). In the foothills of Alberta, road densities are increasing due to increased industrial development (Schneider, 2002), fragmenting once secure grizzly bear (*Ursus arctos*) habitats. Grizzly bear populations can persist only where they have access to secure habitats with reduced human-caused mortality (Servheen, 1990; McLellan, 1998), yet because of possible attractants around roads, human development may be creating an attractive sink (Delibes et al., 2001; Nielson et al., 2004a).

In general, grizzly bears prefer a blend of forest and open meadows (Herrero, 1972) that historically have been maintained by fire in Alberta (Tande, 1979; Andison, 1998; Rhemtulla, 1999). Natural openings increase the abundance of ants, ungulates, fruiting plants, herbaceous vegetation, roots, and other foods (Martin, 1983; Zager et al., 1983; Knight, 1999), which are critical in sustaining grizzly bear populations (Craighead, et al., 1995). In the foothills of Alberta, where natural openings such as alpine meadows are scarce and fires are suppressed, artificial openings created by anthropogenic disturbances, such as regenerating cutblocks, pipelines, and roadside ditches, may be particularly attractive to grizzly bears. While several studies have recognized the importance of forestry in maintaining good grizzly bear habitats (Bratkovich, 1986; Hillis, 1986; Nielsen et al., 2004b; 2004c), limited research is available on how the road development associated with those forestry practices affects grizzly bear foods. Few studies have examined potential sources of attraction to roads (Mattson et al., 1992; Chruszcz et al., 2003), with most examining only grizzly bear response to different road classes or traffic volume levels (Mattson et al., 1987; McLellan and Shackleton, 1988; Kasworm et al., 1990; Kaczensky, 2003). To effectively manage grizzly bear populations we must understand not only bear response to roads, but also the underlying habitat variables that influence their behaviours.

Grizzly bears respond to road development at different spatial scales. At the local scale, grizzly bears may be attracted to the herbaceous vegetation directly associated with the disturbed edge. Roadside ditches are often planted with clover (*Trifolium* spp.) to prevent erosion (MacKinnon et al., 1999). Grasses, another forage item, also have been found to increase significantly within 5 m of roads, due to both decreased canopy closure and increased soil disturbance (Forman et al., 2003; Watkins et al. 2003). However, information on the spatial distribution of most grizzly bear food items in relation to roads is lacking.

In addition to direct associations of bear foods within the ditch, road placement on the landscape may be particularly important when examining the relationship between grizzly bears and roads. At the landscape scale, roads may be associated with habitats that grizzly bears select. In mountain ecosystems, Noss et al. (1996) found that carnivores use valley bottoms for movement and resources, but human development, travel, and recreation also are concentrated in valley bottoms. No research has examined patterns of road placement and grizzly bear selection in the foothills, where topography is less restrictive. Even less is known about grizzly bear landscape use in the eastern foothills, an area with little topographic variation and an extensive network of drainage basins and bogs. In these habitats, both roads and bears may be associated with higher, drier habitats. Ultimately, grizzly bears may not be attracted to roads and road margins per se, but instead to the habitats and/or landscape variables associated with roads.

To further our understanding of grizzly bear/ road relationships it is therefore essential that we understand the foods available around roads and how road placement may affect grizzly bear foraging and movement patterns. I devised several hypotheses to explain grizzly bear occurrence near roads. First, roadsides may offer immediate foraging opportunities in the ditch due to edge effects and an increase in nonnative forage species. At a larger scale, roads that are associated with high-quality habitats may contain a greater variety of foraging opportunities for grizzly bears with the occurrence of both edge species and interior native species. To test this hypothesis, I examine one such habitat, roads that were associated with water, because grizzly bears show selection for low elevation riparian habitats (McLellan and Hovey, 2001). Finally, I hypothesize that patterns exist in road placement on the landscape, and these patterns may coincide with areas of high grizzly bear occurrence.

To test these hypotheses, I examined possible grizzly bear attractants around roads at both the local and landscape scales. The objectives were to: (1) determine the prevalence of 15 grizzly bear food items within close proximity to roads; (2) determine whether roads near water had a greater variety of these foods than roads further from water; and (3) quantify patterns of road placement at the landscape scale. Ultimately, this information can be used in future road development planning as a way to decrease the abundance of bear foods around roads to avoid creating an attractive sink (Delibes et al., 2001).

2. STUDY AREA

This study was conducted in a 7,689-km^2 managed forest in west-central Alberta, Canada (53° 15' 118° 30'), encompassing the towns of Hinton, Edson, and Robb (Fig. 2-1). This area was chosen because of its high road density and its gradient from mountains to foothills. The western portion of the study area includes the eastern foothills of the Rocky Mountains, characterized by rugged terrain and closed conifer forest. The eastern section was at lower elevation, and was typified by an extended network of drainage channels and composed of a greater percentage of black spruce (*Picea mariana*) and boggy habitats than the more mountainous areas to the west. Resource extraction industries, including timber harvesting, oil & gas activities, and coal and gravel mining, operated throughout the area. Development in the area started as recently as the 1950's but has been increasing rapidly since (Schneider, 2002). A large network of roads, trails, and seismic lines increase human access, with an average road density of 0.57 km/km^2 as of 2003. Grizzly bear densities are relatively low (e.g. 4.79 individuals per 1000 km^2) as compared to other areas throughout their range (Boulanger et al., 2005).

3. METHODS

3.1 Site Selection and Vegetation Sampling

Fieldwork was conducted between July and August of 2005 to assess differences in bear food abundance between xeric roadsides, mesic roadsides, and mesic habitats not associated with roads. Sample sites were randomly selected using a soil wetness index, also known as a compound topographic index (CTI), provided by Nielsen et al. (2004c) and road layers provided by the Foothills Model Forest. I identified all roads that occurred within 150 m of high wetness areas (CTI > 10), which corresponded to known water features. Although most road disturbance occurs within 10-15 m of the road, clover from road plantings can occur 150 m from the road (Watkins et al., 2003); therefore I used that value as the cutoff. Random locations were generated using a stratified random design to ensure that all road classes (paved, gravel, and dirt) were represented in proportion to their availability. This random location served as the center of the block and the mesic road plot (Fig. 2-2). Within each block, two additional plots were identified: 1) a xeric road (CTI < 10); and 2) a mesic area (CTI > 10) greater than 200 m from a human disturbance feature (henceforth referred to as "interior mesic"). I used a minimum distance of 500 m between plots to ensure independence.

Nested within each plot, 3 subplots were identified and placed in 1) the roadside ditch, 2) inside the forest edge and greater than 20 m from the ditch subplot (henceforth referred to as "edge"), and 3) at least 200 m away from any human disturbance feature (henceforth referred to as "interior forest"). For the interior mesic plot, the ditch was classified as the area of open canopy on either side of the waterway. Twenty-nine blocks were sampled, containing 87 nested plots, and 259 subplots. Samples were balanced with the exception of one mesic road plot that lacked a forest reference subplot within a matrix of bog and cutblocks, and one mesic reference plot did not have a clear opening in the canopy to be considered a ditch.

Subplots consisted of one 20 m long belt transect laid out parallel to the road or stream. Quadrats (0.25 m^2) were established every 5 m along the belt transect, following the methods of Nielsen et al. (2004c). The percent cover of 13 grizzly bear foods were assessed in each quadrat. A 10 m meander search for ants and ungulate pellets was conducted on either side of the belt transect (20 × 20 m). The presence of ungulate pellets was not assumed to reflect ungulate density, but was used only as an indicator of ungulate occurrence (Nielsen et al., 2004c). Care must be taken when interpreting the occurrence of ungulate pellets, because a bias has been shown to exist in their abundance between open and forested habitats (Collins and Urness, 1979). In addition to bear food occurrence, stand composition and terrain variables were assessed at the subplot level. Canopy cover was measured using a spherical densiometer in the four cardinal directions at 0, 10, and 20 m. The presence or absence of each grizzly bear food item was averaged over the subplot scale, thus results from the five quadrats were pooled.

Fifteen grizzly bear food items (Table 2-1) were chosen based on local grizzly bear food habits (Hamer and Herrero, 1987; Nagy et al., 1989; Hamer et al., 1991; McLellan and Hovey, 1995; Munro et al., *in press*). During hypophagia (1 May to 15 June), the grizzly bear diet consists of (in order of importance) *Hedysarum* spp. roots, ungulate carcasses, herbaceous vegetation such as horsetail (*Equisetum* spp.), forbs, grasses, and sedges, and overwintering *A. uva-ursi* berries (Hamer and Herrero, 1987; Nagy et al., 1989; Hamer et al., 1991; McLellan and Hovey, 1995; Munro et al., *in press*). During early hyperphagia (15 June to 15 Aug), *Hedysarum* spp. roots and ungulates become less abundant in their diet, and the presence of insects and forbs, such as clover and cow parsnip (*H. lanatum*), increases (Hamer and Herrero, 1987; Nagy et al., 1989; Hamer et al., 1991; McLellan and Hovey, 1995; Munro et al., *in press*). During late hyperphagia (15 Aug to 15 Oct), berries predominate the diet along with resurgence in *Hedysarum* spp. roots (Hamer and Herrero, 1987; Nagy et al., 1989; Hamer et al., 1991; McLellan and Hovey, 1995). Ungulates and herbaceous vegetation are still consumed, but to a lesser extent (Munro et al., *in press*).

3.2 Predictor variables

Many factors influence vegetation growth and road placement on the landscape. Variables were selected that have been shown to be predictors of grizzly bear habitat selection in the study area (Nielsen et al., 2002; 2004b), and that we believed also would affect plant growth and/or road placement. In addition to the CTI, several other variables were generated from a GIS including elevation (km), a global solar radiation index (SOLAR) that was calculated based on slope, aspect, and hill shade to determine short wave radiation exposure between the months of June and August (Kumar et al., 1997; Zimmermann, 2000; Nielsen, 2005), and a terrain ruggedness index (TRI) based on both slope and aspect values within a 300 m moving window (Nielsen, 2004a).

3.3 Modelling the occurrence of grizzly bear foods

The occurrence of 15 grizzly bear food items was modelled using mixed-effects logistic regression. In addition to continuous variables, categorical 'dummy' variables were used to identify plot (xeric/ mesic) and subplot (ditch/ edge), with interior mesic and interior forest serving as the reference categories respectively. To account for the hierarchical structure of the data, a nested hierarchy of random effects was used (plots within blocks). Hosmer and Lemeshow (1989) model building procedures were used to create a full model. Continuous variables were assessed for collinearity by calculating Pearson's correlations (r), and screening variables at $\geq |0.7|$. Continuous variables were further assessed for collinearity with the plot and subplot levels by monitoring the stability of the coefficients and standard errors during univariate and multivariate analysis (Hosmer and Lemeshow, 1989). Nonlinear relationships were tested among all continuous variables with the addition of a quadratic term. K-fold cross validation (K=3) was used to validate all models (Boyce et al., 2002). Small sample sizes precluded several species from the analysis, including *H. lanatum*, *Medicago* spp., *V. caespitosum*, *V. membranaceum*, and forbs.

To test whether grizzly bear foods were more prevalent near roads, I examined the coefficients derived for the subplot level, which includes the ditch, edge, and interior forest that served as a reference. To test whether mesic roads had a greater prevalence of grizzly bear foods, I examined the coefficients at the level of the plot, which included the xeric road, mesic road, and interior mesic habitat. Full model results were presented as beta coefficients, but to assist interpretation results for the plot and subplot level were presented as odds ratios (OR).

3.4 Modelling road placement

In addition to assessing the distribution of grizzly bear foods, I examined patterns in road placement on the landscape and whether they corresponded to areas of high grizzly bear use. The study area was divided into a west (larger elevation gradient) and east (flatter with extensive bogs) region based on a distinctive ridgeline starting near the town of Hinton and running approximately southwest to the town of Robb (Fig. 2-1). Models describing road placement were developed separately for each region, because it was assumed that road construction and perhaps grizzly bear habitat preferences may vary between the two regions.

To identify landscapes closely associated with roads, random points were generated for the entire landscape extent at a sampling intensity of 5 points/ km^2. In a GIS, road polylines were buffered 100 m (200 m diameter). Random points falling within the road buffer (1) were compared to those outside of the buffer (0) using logistic regression and the same suite of predictor variables used to assess grizzly bear food presence/ absence described above. Although other variables such distance to edge were considered important to grizzly bear habitat selection (Nielsen, 2005), they were excluded because they were an artifact or product of road development. Model building and testing procedures were the same as above with the exception that continuous variables were evaluated for nonlinearity independently within the east and west models using a likelihood ratio test (Hosmer and Lemeshaw, 1989). K-fold cross validation (K=5) was used to assess model fit (Boyce et al., 2002).

Data were analyzed using a resource selection function (Manly et al., 2002). Each model was extrapolated to the entire study area using Spatial Analyst (ESRI, 2004) by applying the formula:

$$Tr(x) = r(x) / (1 + r(x)) \qquad (1)$$

where Tr(x) is the relative probability of road occurrence and r(x) is the road placement function scaling the relative probability of road occurrence based on selected predictor variables and coefficients estimated from logistic regression. Values of Tr(x) were grouped into 10 quantile bins (Spatial Analyst; ESRI, 2004) following Nielsen (2005). The first bin (1) was indicative of a low relative probability of road occurrence while the last bin (10) represented high relative probability of road occurrence. For both the west and east study area regions, I tested the overall fit of the binned road occurrence map to existing roads. Area-adjusted frequency of occurrence (*f*) for each bin was estimated using the formula from Nielsen (2005):

$$f = 0.1 / a * u \qquad (2)$$

where a is the number of available pixels for that bin on the landscape and u is the number of use (road) points within that bin. Because there were ten bins, 0.1 was used for the numerator, which gave an equal frequency for each bin. Both in-sample (from the same region) and out-of-sample (neighboring region) data were assessed. Predictive performance of each map was assessed using a Spearman rank correlation statistic (Boyce et al., 2002) and Somers' D statistic with associated standard errors (Nielsen, 2005).

4. RESULTS

4.1 Modelling the occurrence of grizzly bear foods

The final grizzly bear food occurrence models contained elevation and the TRI, along with the dummy variables for plot (xeric/ mesic) and subplot (ditch/ edge). Variables for CTI and canopy closure were removed from all models due to correlations with the plot (xeric/ mesic) and subplot (ditch/ edge) variables respectively. In addition, solar radiation was excluded because it did not improve the fit of any model and it greatly inflated the condition number, which specifies model convergence (Rabe-Hesketh and Skrondal, 2005). Models were either perfectly correlated or strongly correlated according to a Spearman's rank correlation, with the exception of graminoids ($s_r = 0.25$) (Table 2-2).

The response of grizzly bear food items to elevation and the TRI was variable. *Equisetum* spp., *S. canadensis*, and *Trifolium* spp. were significantly more prevalent at lower elevations, while ungulates were significantly more prevalent at higher elevations (Table 2-2). *A. uva-ursi* and *Trifolium* spp. occurred in areas with higher terrain ruggedness. Ants, *T. officinale*, *V. myrtilloides*, *V. vitis-idaea*, graminoids, and sedges were not significant for either elevation or the TRI.

4.1.1 Occurrence of grizzly bear foods near roads (subplot results)

After controlling for the effects of elevation and the TRI, I found that ants, *Equisetum* spp., *T. officinale*, *Trifolium* spp., graminoids, and sedges were more prevalent in roadside ditches than in the forest interior (Table 2-3). *Trifolium* spp. were particularly prevalent in the ditch (odds ratio = 237.8), occurring in 69 percent of road plots but never occurring in the forest interior (Table 2-4). *T. officinale* was also highly prevalent in roadside ditches (odds ratio = 83.3).

When comparing edge to forest interior, ants, *Equisetum* spp., *T. officinale*, and sedges had significantly higher occurrence in edges than in forests (Table 2-3). *Trifolium* spp. occurrence was not significantly different between edge and forest, suggesting that ditch plantings have not spread extensively into areas with higher canopy cover. *T.*

officinale occurrence in the edge (10.3 - 13.8%) was reduced from its occurrence in the ditch (48.3 - 72.4%) (Table 2-4), but it was still significantly more prevalent than in the forest interior (odds ratio = 11.34).

Species that had a significantly higher occurrence in the forest than in ditches were *S. canadensis*, ungulates (based of pellet presence), *V. myrtilloides*, and *V. vitis-idaea* (Table 2-3). Conversely, no species were significantly more prevalent in the forest than compared to the edge. *A. uva-ursi* was not significantly different between any of the subplots.

4.1.2 Grizzly bear foods, roads, and association with high-quality habitats (plot results)

Both xeric and mesic roads had significantly higher occurrence of *T. officinale* and *Trifolium spp.* (Table 2-5). *A. uva-ursi* and *Equisetum* spp. were significantly less prevalent near xeric roads, with odds ratios of 0.16 and 0.30 respectively. These same species were not significantly different when comparing mesic roads to interior mesic habitats, which odds ratios close to 1 (Table 2-5). This gives some indication that roads associated with water have both road species and water-dependent species. Another water-dependent species, *V. vitis-idaea*, was significantly less prevalent around mesic roads (46.5%) than interior mesic habitats (60.5%) possibly because mesic road plots are drier than interior mesic plots due to the restrictions required for road construction (Table 2-4). Ants, *S. canadensis*, *V. myrtilloides*, graminoids, and sedges were not significantly different from either the xeric road or mesic road plots.

4.2 Modelling road placement

The final road occurrence model for both the western and eastern study area regions included the CTI, elevation, the solar radiation index, and the TRI. Elevation and the TRI were highly correlated ($r = 0.77$), but beta coefficients and standard errors remained stable in both univariate and multivariable analyses. Because variables were stable (Hosmer and Lemeshow, 1998), and because I believed that both elevation and ruggedness were important to road development, both variables were retained in the models. In the west, a quadratic term was added to elevation, the TRI, and the solar radiation index, but the CTI remained linear. In the east, elevation, the CTI, and the solar radiation index exhibited linear relationships, and the TRI alone received a quadratic term.

In both the west and east, roads were placed in areas with intermediate terrain ruggedness with a strong avoidance of extremely rugged areas (Table 2-6). Roads in both regions were less likely to have been built in very flat areas, and this pattern was slightly more pronounced in the east, possibly because these areas tended to be boggy. In the west, where there was greater variation in terrain, the effect of CTI on road location was non-significant ($\beta = -0.01, p = 0.51$). In contrast, the CTI was in important predictor of eastern roads ($\beta = -0.07, p < 0.001$), with roads being more common in drier areas (Table 2-6). Relative to elevation, roads were found at intermediate elevations in the west region, and less likely at very high elevations. In the east, however, roads occurred at lower elevations ($\beta = -0.055, p = 0.02$). Finally, in the west, roads were most often placed in areas with low solar radiation but also showed a slight preference for very high values, potentially because they occur in valley bottoms in the shade of hills or occasionally on southern exposed slopes. East roads were constructed in areas with higher solar radiation values ($\beta = 1.10\text{E}-04, p < 0.001$).

Using K-fold cross validation (K=5), both models accurately predicted where roads occurred on the landscape, with Spearman rank correlation coefficients for the west and east being 0.99 and 0.98 respectively (Table 2-6). Coefficients were applied to the entire landscape to create an index of high, medium, and low relative probability of road placement (Fig. 2-3 & 2-4). Road occurrence maps were validated using both the training data and the data for the neighboring region. Both models accurately predicted where roads were placed on the landscape within their region (Table 2-7). The western model, however, did not predict road construction accurately in the east, but the east model did well in the west.

5. DISCUSSION

Of the 15 grizzly bear food items examined in this study, all herbaceous vegetation consumed by grizzly bears in the spring had a greater occurrence near roads. *Equisetum* spp., *T. officinale*, *Trifolium* spp., graminoids, and sedges were significantly more prevalent in roadside ditches than in the forest interior. Munro et al. (*in press*) found that herbaceous vegetation makes up 10-69 percent by volume of grizzly bear scat during spring and early summer, and in late June and early July, *Trifolium* spp. alone can consist of up to 10 percent by volume. While *Trifolium* spp. have colonized other disturbed habitats, such as cutblocks, Nielsen et al. (2004b) found they occurred at only 23 percent of plots within cutblocks in this area. Conversely, I found *Trifolium* spp. occurred in 69 percent of ditch plots (Table 2-4), suggesting that this important food, although in disturbed areas, is more abundant near roads, potentially due to planting in ditches after road construction to prevent soil erosion (MacKinnon et al., 1999). The other 31- 90 percent of grizzly bears' spring scat consisted of ungulates and the roots of

Hedysarum spp. (Munro et al., *in press*), both of which my results were inconclusive. *Hedysarum* spp. were not found in many of the plots that I sampled. In addition, ungulate pellets were potentially biased because they preferentially defecate in forest habitats (Collins and Urness, 1979); although, I found no significant difference between edge and interior forest plots (Table 2-4), suggesting that ungulates were still in close proximity to roads. Overwintering *A. uva-ursi* berries were also eaten in the spring but make up a small portion of their diet (< 5 percent by volume on average; Munro et al., *in press*), however no significant difference with respect to roads was observed.

In the late summer and fall, grizzly bear food preferences change to include more fruits, insects, and forbs (Hamer and Herrero, 1987; Nagy et al., 1989; Hamer et al., 1991; McLellan and Hovey, 1995), with fruits consisting of up to 63 percent by volume of bear scat (Munro et al., *in press*). While ants were still found in close proximity to roads, berry-producing plants were less likely to be near roads. *S. canadensis*, *V. myrtilloides*, and *V. vitis-idaea* were significantly less prevalent in ditch plots, but *A. uva-ursi* was not significantly different. During the late summer and fall, bears continue to consume grasses and forbs (Munro et al., *in press*), so roads may still serve as an attractant, particularly in years of berry crop failure. Such was the case in the greater Yellowstone ecosystem when grizzly bears were found closer to roads in years of whitebark pine seed crop failure, a locally important grizzly bear food item (Mattson et al., 1992). As a result, grizzly bear mortality increased 2.3 - 3.3 times that of high seed crop production years. Due to this seasonal shift in grizzly bear diet, I would expect grizzly bear proximity to roads to peak in the spring and early summer when they consume more herbaceous vegetation, and then decline in the late summer and fall when their diet consists of berries.

In addition to direct food associations with roadsides, roads may also serve as an attractant because they are constructed in habitats that are preferred by grizzly bears. As expected, roads constructed in both xeric and mesic habitats contained significantly more *T. officinale* and *Trifolium* spp. than the interior mesic habitat (Table 2-5). Conversely xeric roads contained significantly fewer mesic to hydric species, which included *A. uva-ursi* and *Equisetum* spp. The mesic road plots were not significantly different, suggesting that roads associated with water contain not only disturbance species, but also plants associated with the water feature. These results become particularly important when examining patterns of road placement on the landscape because roads were consistently placed within similar landscape types.

The undulating terrain associated with the upper foothills influenced road placement in the west. Roads were generally found at low to intermediate terrain ruggedness, but were not associated with either steep or very flat terrain. They were also more likely to be at lower elevation, but were less commonly built at very low elevations. Therefore, roads in the west generally follow the valley bottoms, but they were not at the lowest point in the valley. These valleys also may attract grizzly bears due to seasonal increases in resources and ease of travel. In the early spring, lower elevations thaw sooner and green-up begins earlier than at higher elevations, forcing grizzly bears into close proximity to roads in order to gain access to resources. Whereas mountain bears used avalanche chutes in the early spring, bears in the foothills selected low-elevation riparian habitats (McLellan and Hovey, 1995). Valley bottoms also may be used for travel because they require less energy to traverse than the more rugged terrain at higher elevations. Ultimately, grizzly bears may not be attracted to roads per se; instead, roads may be placed in essential grizzly bear habitats in the west.

In the east, results support my hypothesis that road placement would be influenced by boggy habitats. The area is much flatter and contains a large network of drainage basins; therefore, roads were placed in significantly drier areas. Roads also occurred at intermediate terrain ruggedness, again avoiding very flat areas, which increased the likelihood of standing water. Grizzly bears may be attracted to these habitats, but for different reasons than above. Grizzly bears in this area have a negative association with bogs, which contain few bear foods (Nielsen et al., 2004b; 2005) and may be difficult for bears to traverse. Of the 15 grizzly bear food items examined, only *Equisetum* spp. were more likely to be found in areas with high CTI values (Nielsen et al., 2004b). Therefore, drier habitats were more likely to contain berries, grasses, and forbs (Nielsen et al, 2004b), but I found that they are also more likely to contain roads, which increases the mortality risk of foraging grizzly bears.

When industrial development in this area began in the 1950's, road construction and forest harvesting were most likely concentrated in areas that were easiest to access. As a result, the areas currently available for harvest are situated in increasingly rugged areas. As technology increases, roads will be constructed in more remote and more rugged terrain. Consequently, the current model for road construction that I devised might not be applicable to future road development. In other areas, grizzly bears have been able to persist within the security of mountain habitats (Mattson and Merrill, 2002), but because topography is less limiting for human development in the foothills, secure grizzly bear habitats might not be secure much longer.

6. CONCLUSION

To effectively manage grizzly bear populations near roads and ultimately decrease bear mortality, we must first understand potential sources of attraction to human-altered landscapes. I found that spring grizzly bear food items increased near roads, and at a larger scale, roads placement itself could be playing a critical role in grizzly bear selection of roadside habitats. Because of the high mortality risk associated with roads (McLellan, 1989; Benn and Herrero, 2002; Nielsen et al., 2004c), management guidelines should be implemented to reduce grizzly bear attractants in these high-risk areas. The planting of clover in roadside ditches for the purpose of erosion control should be prohibited to minimize grazing opportunities for bears. Instead, ditches should be seeded with native vegetation, preferably less palatable species. The roadside ditch should also be narrowed, to reduce the amount of herbaceous vegetation available for grazing. Decreasing foraging opportunities for bears near roads has the potential to decrease vehicular collisions and reduce human/ grizzly bear encounters, which often result in the death of bears. Removing these attractions also could lessen grizzly bear habituation to vehicles. Bears feeding within close proximity to humans often become habituated, and these "problem bears" are frequently removed from the population if they lose their fear of humans and become aggressive. Next, the spatial location of new road development should be reevaluated in areas of high grizzly bear use. Road placement in low-elevation valleys could be creating an attractive sink (Delibes et al., 2001). For preexisting roads, I recommend gating rarely used roads and decommissioning roads that are no longer in use, particularly in areas of high grizzly bear abundance or areas with high-quality grizzly bear habitats. Gated roads could be closed seasonally or in years of berry crop failure to minimize human access at times when bear foods are most abundant around roads, i.e. during the spring and early summer. To ensure the future persistence of grizzly bears on the landscape, we must mitigate human-caused mortality and reduce grizzly bear attractants around roads.

Table 2-1. Grizzly bear foods sampled in west-central Alberta including the type of food or use and the season of use (adapted from Nielsen et.al, 2004b)

Food	Common Name	Food Type or Feeding Activity	Season of Use
Ants		Myrmecophagy	Summer
A. uva-ursi	Bear berry	Fruits	Spring and late summer
Equisetum spp.	Horse tail	Herbaceous	Spring and summer
Hedysarum spp.	Sweet vetch	Roots/ tuber digging	Spring and fall
H. lanatum	Cow parsnip	Herbaceous	Summer
S. canadensis	Buffalo berry	Fruits	Late summer and fall
T. officinale	Dandelion	Herbaceous	Spring and summer
Trifolium spp.	Clover	Herbaceous	Spring and summer
Ungulates (pellets)		Carnivorous	Spring and early summer
V. caespitosum	Dwarf blueberry	Fruits	Late summer and fall
V. membranaceum	Huckleberry	Fruits	Late summer and fall
V. myrtilloides	Common blueberry	Fruits	Late summer and fall
V. vitis-idaea	Bog cranberry	Fruits	Late summer and fall
Forbs		Herbaceous	Spring and summer
Graminoids		Herbaceous	Spring and summer
Sedges		Herbaceous	Spring and summer

Table 2-2. Results for the grizzly bear food occurrence modelling presented as beta coefficients and standard errors (parenthesis). For the plot and subplot, interior mesic and interior forest were held out for reference respectively. Validation reported as the mean Spearman rank correlation statistic (s_r). Bold text indicates significance.

	Plot		Subplot					
Species	Xeric Rd	Mesic Rd	Ditch	Edge	Elevation	TRI	Constant	s_r
Ants	0.65 (0.63)	0.90 (0.63)	**1.71 (0.51)**	**1.12 (0.50)**	1.00 (2.08)	13.06 (10.99)	-2.17 (14.67)	1.00
A. uva-ursi	**-1.84 (0.77)**	-0.58 (0.65)	-0.28 (0.52)	0.82 (0.50)	0.80 (3.03)	**27.81 (14.18)**	-18.08 (21.52)	0.80
Equisetum spp.	**-1.19 (0.51)**	-0.24 (0.48)	**2.25 (0.45)**	**1.06 (0.40)**	**1.00 (1.95)**	-10.64 (9.96)	**28.92 (13.74)**	1.00
S. canadensis	-0.27 (0.73)	0.07 (0.69)	**-1.55 (0.75)**	-0.86 (0.64)	**0.80 (4.25)**	25.76 (15.86)	**103.14 (29.71)**	0.80
T. officinale	**2.08 (0.54)**	**1.46 (0.55)**	**4.42 (1.04)**	**2.43 (1.07)**	0.95 (1.57)	-5.70 (9.46)	-16.64 (11.14)	0.95
Trifolium spp.	**2.82 (0.73)**	**3.13 (0.75)**	**5.47 (1.20)**	2.01 (1.16)	**0.95 (2.01)**	**29.43 (11.33)**	20.94 (13.89)	0.95
Ungulates (pellets)	-0.35 (0.45)	**-1.12 (0.48)**	**-1.13 (0.40)**	-0.55 (0.37)	**0.95 (1.85)**	-10.07 (9.11)	**-29.20 (13.07)**	0.95
V. myrtilloides	0.86 (0.66)	0.67 (0.65)	**-2.86 (0.60)**	-0.69 (0.43)	1.00 (3.15)	-22.76 (12.99)	-26.70 (22.33)	1.00
V. vitis-idaea	**-1.55 (0.49)**	**-0.93 (0.46)**	**-2.72 (0.49)**	-0.46 (0.38)	1.00 (2.09)	-10.70 (9.38)	-19.34 (14.73)	1.00
Graminoids	0.20 (0.44)	0.36 (0.45)	**2.14 (0.58)**	0.53 (0.39)	0.25 (1.98)	12.87 (10.33)	-16.63 (13.95)	0.25
Sedges	-1.10 (0.62)	-0.20 (0.56)	**2.56 (0.63)**	**1.52 (0.61)**	1.00 (2.03)	-8.05 (12.40)	22.19 (14.26)	1.00

Table 2-3. Odds ratios (OR) comparing the occurrence of grizzly bear foods within the ditch and edge to food occurrence within the forest. Validation reported as the mean Spearman rank correlation statistic (s_r). Bold indicates significant results.

	Ditch			Edge			
Species	OR	SE	*P*	OR	SE	*P*	s_r
Ants	**5.55**	**1.66**	**0.001**	**3.06**	**1.65**	**0.025**	1.00
A. uva-ursi	0.76	1.68	0.595	2.27	1.64	0.098	0.80
Equisetum spp.	**9.50**	**1.58**	**<0.001**	**2.90**	**1.50**	**0.009**	1.00
S. canadensis	**0.21**	**2.13**	**0.040**	0.42	1.90	0.182	0.80
T. officinale	**83.26**	**2.84**	**<0.001**	**11.34**	**2.91**	**0.023**	0.95
Trifolium spp.	**237.75**	**3.33**	**<0.001**	7.43	3.19	0.084	0.95
Ungulates (pellets)	**0.32**	**1.49**	**0.005**	0.58	1.45	0.138	0.95
V. myrtilloides	**0.06**	**1.83**	**<0.001**	0.50	1.53	0.107	1.00
V. vitis-idaea	**0.07**	**1.63**	**<0.001**	0.63	1.46	0.224	1.00
Graminoids	**8.47**	**1.78**	**<0.001**	1.69	1.48	0.181	0.25
Sedges	**13.00**	**1.89**	**<0.001**	**4.58**	**1.84**	**0.013**	1.00

All odds ratios are given in reference to the forest interior

Table 2-4. Frequency of occurrence of grizzly bear food items within plots of upland roads (roads), roads associated with water (road/riparian), and riparian areas not associated with human access features (riparian) in west-central Alberta. Frequencies are reported for the subplots (ditch, forest edge, and interior forest) and summed for the plots.

	Xeric Road				Mesic Road				Interior Mesic			
Species	Ditch	Edge	Forest	**Total**	Ditch	Edge	Forest	**Total**	Ditch	Edge	Forest	**Total**
Ants	34.5	24.1	13.8	**24.1**	37.9	20.7	17.9	**25.6**	21.4	24.1	3.4	**16.3**
A. uva-ursi	10.3	17.2	10.3	**12.6**	13.8	31.0	17.9	**20.9**	21.4	31.0	31.0	**27.9**
Equisetum spp.	51.7	24.1	17.2	**31.0**	72.4	48.3	21.4	**47.7**	64.3	55.2	34.5	**51.2**
Hedysarum spp.	0.0	3.4	3.4	**2.3**	3.4	10.3	7.1	**7.0**	10.7	3.4	6.9	**7.0**
H. lanatum	3.4	0.0	0.0	**1.1**	3.4	3.4	0.0	**2.3**	3.6	0.0	0.0	**1.2**
Medicago spp.	3.4	0.0	0.0	**1.1**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**
S. canadensis	3.4	6.9	13.8	**8.0**	6.9	10.3	14.3	**10.5**	7.1	10.3	13.8	**10.5**
T. officinale	72.4	10.3	3.4	**28.7**	48.3	13.8	0.0	**20.9**	10.7	10.3	0.0	**7.0**
Trifolium spp.	69.0	3.4	0.0	**24.1**	69.0	10.3	0.0	**26.7**	7.1	3.4	3.4	**4.7**
Ungulate pellets	17.2	41.4	44.8	**34.5**	10.3	24.1	32.1	**22.1**	42.9	31.0	48.3	**40.7**
V. caespitosum	0.0	0.0	0.0	**0.0**	3.4	0.0	0.0	**1.2**	0.0	0.0	0.0	**0.0**
V. membranaceum	3.4	6.9	10.3	**6.9**	3.4	3.4	3.6	**3.5**	7.1	13.8	6.9	**9.3**
V. myrtilloides	17.2	44.8	41.4	**34.5**	10.3	34.5	53.6	**32.6**	10.7	27.6	37.9	**25.6**
V. vitis-idaea	3.4	48.3	58.6	**36.8**	10.3	62.1	67.9	**46.5**	50.0	62.1	69.0	**60.5**
Forbs	100.0	100.0	100.0	**100.0**	100.0	96.6	100.0	**98.8**	93.1	100.0	100.0	**97.7**
Graminoids	100.0	79.3	69.0	**82.8**	82.1	79.3	75.9	**79.1**	100.0	79.3	71.4	**83.7**
Sedges	20.7	6.9	6.9	**11.5**	42.9	24.1	3.4	**23.3**	34.5	24.1	7.1	**22.1**
Total plots (n)	29	29	29	**87**	29	29	28	**86**	28	29	29	**86**

Table 2-5. Odds ratios (OR) comparing grizzly bear food occurrence surrounding xeric roads and mesic roads to that of interior mesic habitats. Validation reported as the mean Spearman rank correlation statistic (s_r). Bold indicates significant results.

	Xeric Road			Mesic Road			
Species	OR	SE	*P*	OR	SE	*P*	s_r
Ants	1.91	1.87	0.300	2.47	1.87	0.148	1.00
A. uva-ursi	**0.16**	**2.15**	**0.017**	0.56	1.91	0.366	0.80
Equisetum spp.	**0.30**	**1.66**	**0.019**	0.79	1.61	0.617	1.00
S. canadensis	0.77	2.07	0.714	1.07	2.00	0.918	0.80
T. officinale	**7.99**	**1.72**	**<0.001**	**4.30**	**1.73**	**0.008**	0.95
Trifolium spp.	**16.86**	**2.07**	**<0.001**	**22.83**	**2.12**	**<0.001**	0.95
Ungulates (pellets)	0.70	1.56	0.428	**0.33**	**1.61**	**0.019**	0.95
V. myrtilloides	2.36	1.93	0.190	1.95	1.91	0.301	1.00
V. vitis-idaea	**0.21**	**1.63**	**0.001**	**0.39**	**1.59**	**0.044**	1.00
Graminoids	1.22	1.55	0.647	1.43	1.56	0.422	0.25
Sedges	0.33	1.86	0.076	0.82	1.76	0.724	1.00

All odds ratios are given in reference to interior mesic

Table 2-6. Beta coefficients and standard errors for road placement models. Validation using K-fold cross validation (*K*=5) reported as the mean Spearman rank correlation statistic (r_S). Bold indicates significant results.

	West			East		
Coefficient	*β*	SE	*P*	*β*	SE	*P*
cti	-0.01	0.01	0.51	**-0.07**	**0.01**	**<0.001**
elevation	**17.05**	**1.97**	**<0.001**	**-0.55**	**0.23**	**0.02**
elevation^2	**-6.69**	**0.70**	**<0.001**			
solar	**-3.76E-04**	**0.00**	**<0.001**	**1.10E-04**	**0.00**	**<0.001**
solar^2	**2.42E-09**	**0.00**	**<0.001**			
tri	**14.24**	**2.84**	**<0.001**	**36.66**	**5.62**	**<0.001**
tri^2	**-208.57**	**24.80**	**<0.001**	**-593.42**	**97.05**	**<0.001**
constant	1.80	4.09	0.66	**-10.49**	**1.49**	**<0.001**
r_S	**0.99**		**<0.001**	**0.98**		**<0.001**

Table 2-7. Map validation using both in and out-of-sample data. Fit was determined using both the Spearman rank correlation statistic and Somers' D statistic. P-values are presented, and standard errors are given for the Somers' D statistic.

	Total	Road	Spearman rank		Somers' D		
Validation	Locations	Locations	r_s	*P*	D	SE	*P*
West Model							
West data	19519	3959	0.952	<0.001	0.867	0.153	<0.001
East data	18958	2252	0.455	0.187	0.333	0.350	0.340
East Model							
East data	18958	2252	0.976	<0.001	0.911	0.082	<0.001
West data	19519	3959	0.952	<0.001	0.867	0.111	<0.001

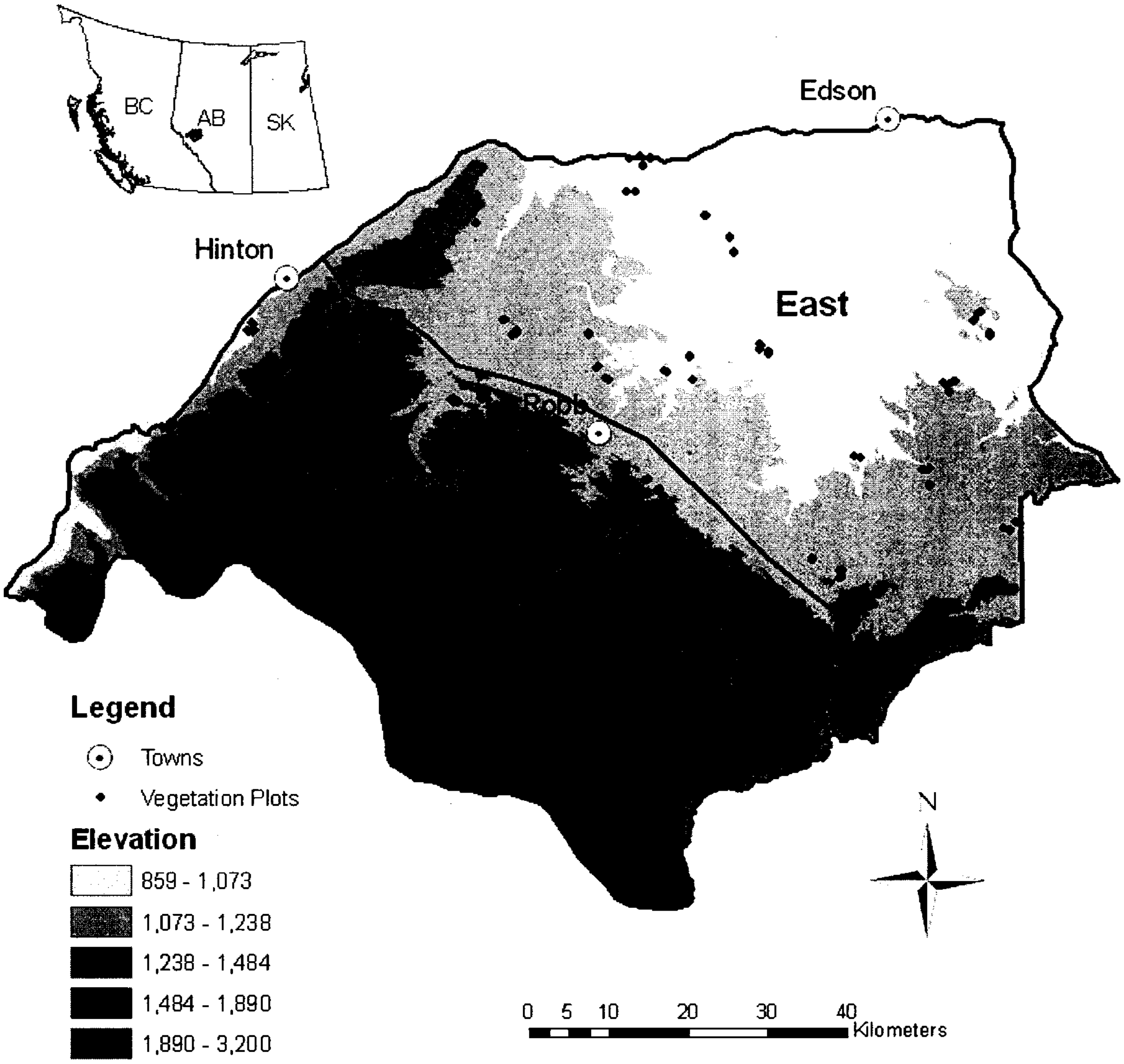

Figure 2-1. Map of the study area located in west-central Alberta. The western portion (West) encompasses the eastern foothills of the Rocky Mountains and is at higher elevation and contains more rugged terrain. The eastern portion (East) is at lower elevation and is characterized by less rugged and wetter habitats.

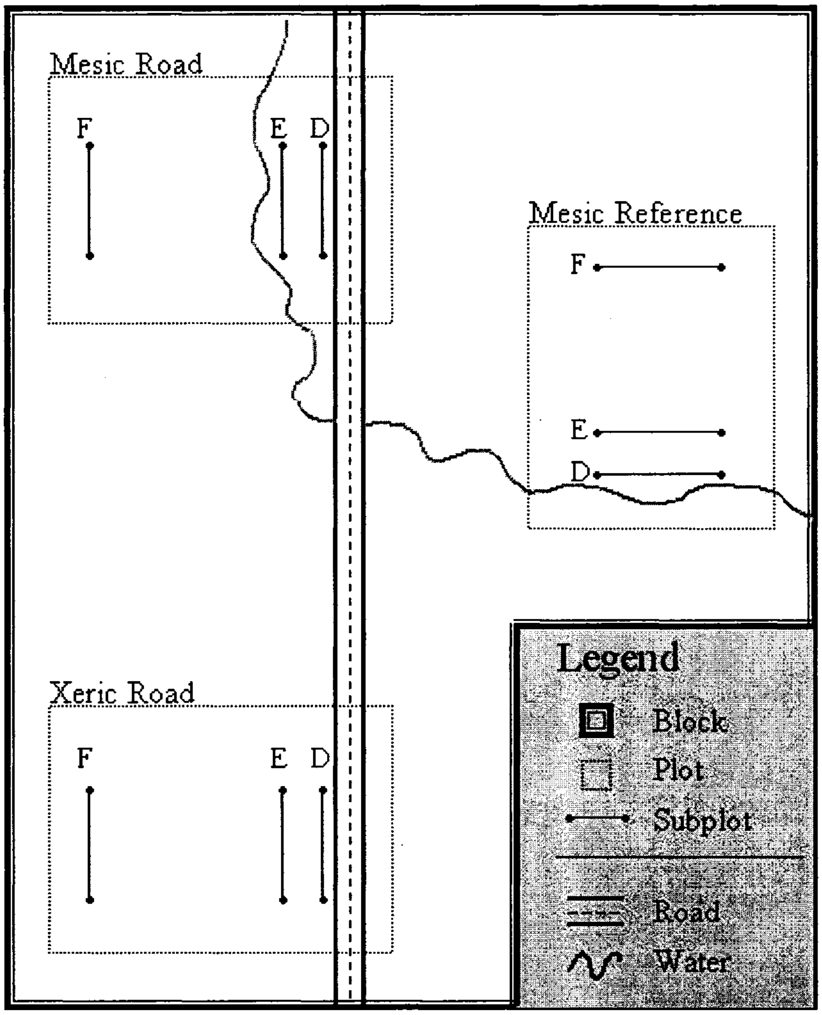

Figure 2-2. Diagram of the vegetation sampling design. The entire figure is 1 block and an independent replicate. Within the block, 3 plots were identified: a mesic road, a xeric road, and a mesic reference that was not associated with any human disturbance features. Within each plots, 3 subplots (belt transects) were sampled in the ditch (D), forest edge (E), and interior forest (F).

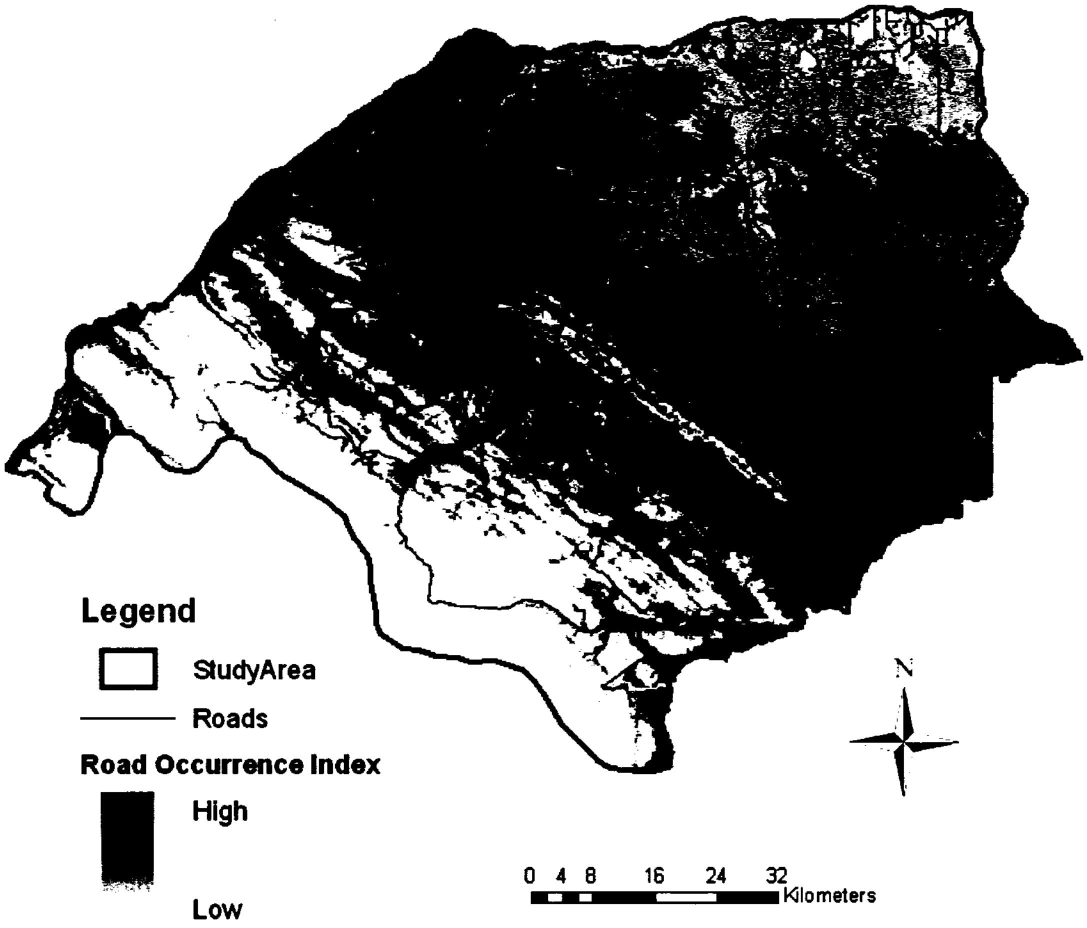

Figure 2-3. Relative index of road occurrence created using data from the *western* portion of the study area, but applied to the entire study area. High values indicate that roads are more likely to be constructed in these areas.

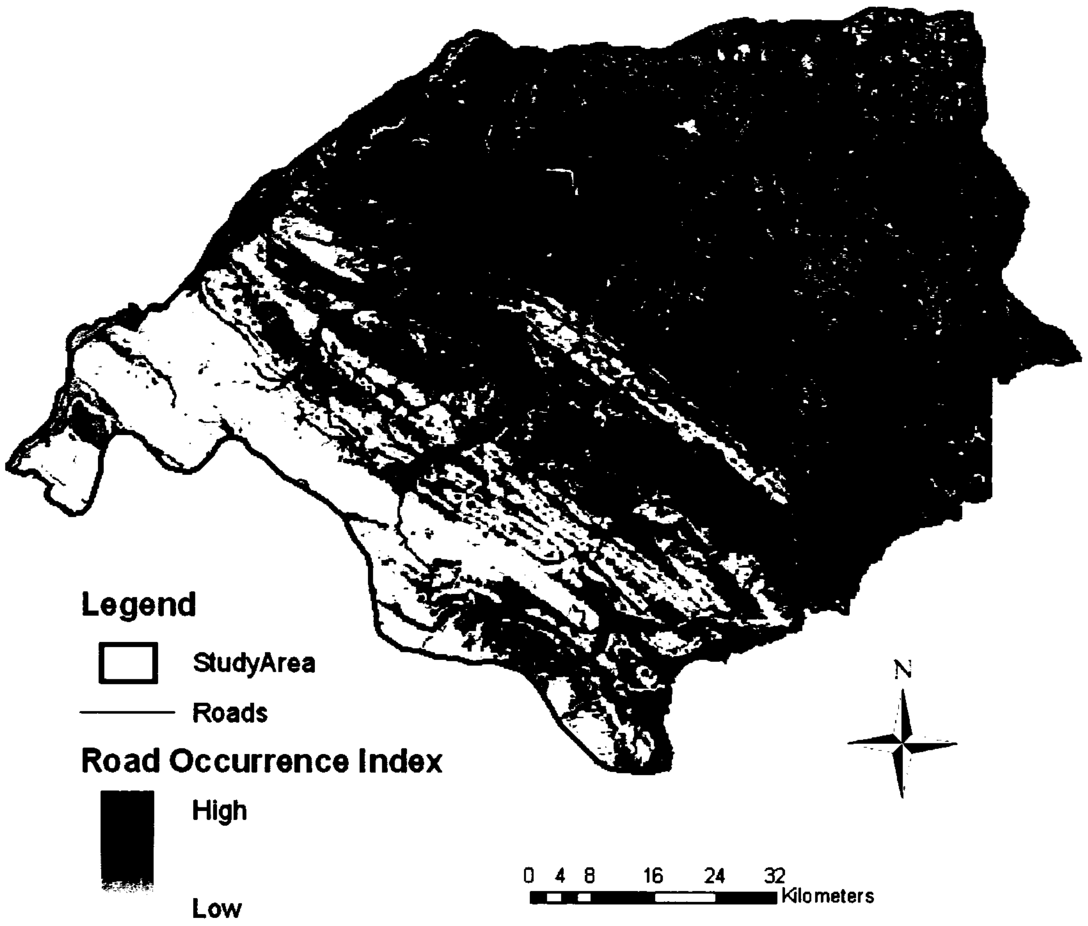

Figure 2-4. Relative index of road occurrence created using data from the *eastern* portion of the study area, but applied to the entire study area. High values indicate that roads are more likely to be constructed in these areas.

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CHAPTER 3

GRIZZLY BEAR HABITAT SELECTION AND POTENTIAL SPATIAL OVERLAP WITH ROAD DEVELOPMENT

1. INTRODUCTION

Roads have become a significant feature on the landscape and understanding their affects on rare and threatened species has become a topic of concern in conservation biology (Forman and Alexander, 1998; Trombulak and Frissel, 2000; Bennet, 1991). In large carnivore studies throughout North America, roads have been implicated in reducing habitat due to noise, human avoidance, and fragmentation (McLellan and Shackelton, 1988; Dyer et al. 2001; Papouchis et al., 2001; Waller and Servheen, 2005), decreasing gene flow across major thoroughfares (Alexander and Waters, 2000; Epps et al., 2005; Waller and Servheen, 2005), and increasing mortality due to both improved hunter access (McLellan and Shackleton, 1988; McLellan, 1989; McLellan et al., 1999; Benn and Herrero, 2002; Nielsen et al., 2004a) and greater road collisions (Clevenger et al., 2001; Gunther et al., 2004). In Alberta, Canada, road densities are increasing rapidly due to industrial activity (Schneider et al., 2002), and grizzly bear (*Ursus arctos*) populations are at risk of declining (Banci et al., 1994; McLellan, 1998). Grizzly bear persistence on the landscape is determined by habitat quality, human density, and human attitudes and actions towards bears (McLellan, 1998), and no place are conflicts between bear habitats and human behaviour more apparent than near roads.

Grizzly bears may be attracted to roads because they provide direct resource benefits. Roadside ditches contain herbaceous vegetation, such as dandelions, horsetails, grasses, sedges, and clover (Chapter 3), which becomes more abundant in the bear's diet in spring and early summer (Munro et al., *in press*) when other resources are limiting.

Roads also create edges, which allow light penetration further into the forest, and are a good predictor of grizzly bear occurrence on the landscape (Nielsen, 2005). Grizzly bears require a mix of forest and open meadows (Herrero, 1972), historically maintained by fire (Tande, 1979; Andison, 1998), but due to recent fire suppression, cutblocks may provide a viable alternative (Bratkovich, 1986; Hillis, 1986; Nielsen et al., 2004b; 2004c). Unfortunately, cutblocks are generally associated with open roads, requiring grizzly bears to move closer to roads to take advantage of these resources. Grizzly bears may also be attracted to roads because they act as a refuge for females with cubs and subadults to avoid dominant male bears (Mattson et al., 1987; McLellan and Shackleton, 1988; Mattson et al., 1992).

Road placement on the landscape also may explain grizzly bear attraction to these areas. In the foothills, roads are often built at lower elevations and less rugged terrain (Chapter 2). Bears may use these areas as travel corridors between food patches, rather than traversing steep mountainous terrain. Habitats associated with road development also may be rich in grizzly bear foods due to the mesic soils and high sun exposure (Chapter 2). However, information about how road-placement on the landscape affects preferred grizzly bear habitats is lacking. Previous grizzly bear/ road studies have taken an anthropocentric approach, examining only bear displacement after road development (Mattson, 1987; McLellan and Shackleton, 1988; Kasworm et al., 1990; Mattson et al., 1992; Wielgus and Vernier, 2003). To effectively manage grizzly bear populations, we must first understand how grizzly bears are using the landscape, particularly in areas that have a high probability of being developed in the future. This will help us to understand, first how new road development may impact grizzly bear populations and furthermore may help explain current grizzly bear response to roads.

Given the increasing human encroachment into grizzly bear habitats, a mechanistic understanding of grizzly bear behavior is necessary to direct conservation efforts, particularly in high-mortality areas such as near roads. I hypothesize that grizzly bears do not necessarily select roads, but that roads are placed in areas that bears prefer. To test this hypothesis, I examined both roads and other habitats that have characteristics similar to roads, but do not yet have any road construction (henceforth road-like habitats). The objectives of this study were to: (1) determine whether grizzly bears select roads or road-like habitats; and (2) investigate seasonal variation in grizzly bear use of road and road-like habitats. Ultimately, this information can be used by managers to plan future road development and road closures to best benefit grizzly bear populations.

2. STUDY AREA

The study area was located in a 7,689-km^2 managed forest in west-central Alberta, Canada (53° 15' 118° 30') (Fig. 3-1). The area incorporated portions of Jasper National Park and Whitehorse Wildlands Provincial Park and the towns of Hinton, Edson, and Robb. The dominant land cover was conifer forest, intermixed with lesser amounts of deciduous forest, regenerating cutblocks, and open meadows (Franklin et al., 2001). Further east, bogs became more common on the landscape due to increased drainages and decreased topographic variation (Franklin et al., 2001). Resource extraction began in the 1950's in this area and included timber harvesting, oil & gas extraction, and coal and gravel mining (Schneider, 2002). Extensive recreational use also occurred throughout the year. As of 2003, total road density within the study area was

0.57 km/km^2, with some areas experiencing a 12 percent increase in road density since 1999. Recent population assessments estimated grizzly bear densities at 4.79 individuals per 1,000 km^2, which is less than half that of previous estimations for the area (Boulanger et al., 2005).

3. METHODS

3.1 Grizzly bear data

Grizzly bears were captured between 1999 and 2004. To decrease potential bias created by trapping only near roads, bears were captured using both leg-hold snares (67% of captures) and helicopter net gunning techniques (33% of captures) (Cattet et al., 2003). Bears were fitted with Televilt Simplex and ATS (Advanced Telemetry Systems) brand GPS radiocollars (complete capture methods in Cattet et al 2003), which were programmed to acquire locations at intervals between 2 and 4 hrs. At the time of capture, grizzly bear sex was noted and age was determined by tooth extraction (Stoneburg and Jonkel, 1966). Individuals with an average age less than 5 years were classified as subadults. During GPS collar uploads, a visual identification was established for females when possible to check for the presence and approximate age of cubs. In ArcGIS 9.1 (ESRI, 2004), home ranges for each individual were estimated with minimum-convex-polygons (MCP) using Hawth's Analysis Tools (Beyer, 2004). Only those individuals with ≥ 50 locations and the majority of their MCP within the study area were retained for analysis. I further removed all locations that fell outside of the study area boundary. In total I analyzed 22,230 locations from 30 grizzly bears. To help discern patterns in overall selection, grizzly bears were grouped based on demographic features (Table 3-1).

3.2 Landscape Mapping

Roads were identified using a road polyline layer obtained from the Foothills Model Forest in cooperation with West Fraser Inc. The distance (km) of each grizzly bear location to the nearest road was queried using ArcGIS 9.1 (ESRI, 2004). A road occurrence model was created to determine locations where roads were more likely to occur on the landscape (Chapter 2). The model was based on landscape and terrain variables (ruggedness, soil wetness, elevation, and solar radiation) that were associated with roads. When applied to the entire landscape, it predicted the relative probability that each pixel would have a road based on those same attributes, with low road occurrence values indicating low probability of a road and high values indicating high probability. The model predicted not only where roads were on the landscape, but it also identified habitats that were similar to those found in areas containing roads, which allows me to distinguish whether bears were using these road-like habitats even in the absence of a road. Separate road occurrence indices were created for the east and west regions of the study area, but because the east model accurately predicted road placement in the west (Chapter 2), it was used for analysis. The east road occurrence model was predicted for the entire study area (Chapter 2) and the value was queried for each grizzly bear location. Because distance to road and the road occurrence index were similar, I tested for correlations between these 2 variables within every grizzly bear home range using Pearson's correlations (r). While the correlations varied from 0.0034 to 0.47, values never exceeded the threshold value of $\geq |0.6|$ for collinearity (Hosmer and Lemeshow, 1989), so both variables were retained in the analysis.

3.3 Grizzly bear use of roads and road habitats

A resource selection function (RSF) was used to understand grizzly bear selection of roads and road-like habitats (Manly, 2002). Individual models were chosen because bears are highly variable in their behaviour and selection (Nielsen et al., 2002). To quantify availability at the home range scale, random points were generated within each grizzly bear MCP at a density of 5pts/ km^2. A design III RSF was employed using the logistic discriminant:

$$w(\mathbf{x}) = \exp(\beta_1 x_1 + \ldots + \beta_p x_p) \qquad (1)$$

where w(**x**) is the resource selection function and β is the selection coefficient for the *i*-th predictor variable, x_i (Manly et al., 2002). Logistic regression was used to estimate β coefficients (Manly et al., 2002; Johnson et al., 2006), where grizzly bear locations (1) were compared to random locations (0). All data were combined across years and seasons, to obtain an average response to roads. Care must be taken when interpreting distance to road because negative values indicate that the bear was closer to the road.

3.4 Seasonal use of roads by grizzly bears

To investigate temporal change in grizzly bear behaviour, telemetry locations were divided into two seasons, spring/ early summer (1 May – 14 July) and late summer/fall (15 July – 31 October). In Mid-July, grizzly bears in this area begin to integrate more berries into their diet and become less reliant of herbaceous vegetation (Munro et al., *in press*), which is abundant near roads (Chapter 2); therefore, we would expect to see the greatest shift in behaviour around roads between these two periods. To confirm this assumption, I plotted mean monthly distance from road for each grizzly bear. Only bears that had ≥ 50 locations per season were analyzed; as a result, 23 bears were retained for this analysis. Using a comparison resource selection function (CRSF) (Lele et al., *in preparation*), I compared the change in grizzly bear selection between the different seasons for distance to road and the road occurrence index. The CRSF assumes equal availability between the two groups of comparison, and because availability was estimated at the individual's home range, the assumption holds (Lele et al., *in preparation*). Logistic regression was used to estimate beta coefficients, where early summer habitat selection (0) was compared to late summer (1).

In addition to the shift in overall habitat usage, I also examined whether use of areas close to roads differed between the two seasons. For each season, I examined the proportion of locations that fell within 150 m of a road. A 150 m buffer was chosen because edge effects can extend 150-200 m into the forest (Watkins, et al, 2002; Forman et al., 2003). A two-sample test of proportions was used to assess significance (Zar, 1984).

4. RESULTS

4.1 Grizzly bear selection of roads and road habitats

Of the 11 female grizzly bears examined, 7 (63%) selected habitats close to roads, 2 (18%) avoided roads, and 2 (18%) were not significantly different from random (Table 3-2). The 2 females that avoided roads (G004 and G038) had home ranges that extended into the Rocky Mountains, where roads were less abundant. When examining female selection of road-like habitats, 4 (36%) avoided road-like habitats, 4 (36%) selected road-like habitats, and 3 (27%) showed no preference. All females with positive selection for road-like habitats also selected to be close to roads. Females that avoided road-like habitats were variable in their selection of roads.

Male grizzly bears had similar pattern of selection for roads as females, with 5 (55%) selecting to be close to roads, 2 (22%) avoiding roads, and 2 (22%) showing no preference (Table 3-1). Males that had home ranges extending into the mountains had variable selection of roads, with 1 selecting (G008) and 1 avoiding (G029) roads. Road-like habitats do not appear to be an important factor in male habitat selection, with 6 (66%) showing no significant preference. Male G043 avoided road-like habitats and males G005 and G024 selected road-like habitats.

Overall, subadult bears appear to select roads and road-like habitats most of the sex/age classes. Seven (70%) selected areas close to roads and 6 (60%) selected road-like habitats. Only 2 subadults, G040 and G036, significantly avoided roads and road-like habitats respectively, and bear G054 exhibited no significant preference for either variable. Subadults were the only sex/age group in which bears that selected road-like habitats did not necessarily select to be close to roads. One subadult female (G040) selected road-like habitats but avoided roads, and another subadult female (G037) preferred road-like habitats but exhibited no preference for roads.

Of all individuals surveyed, only 5 bears (16%) showed no preference for either roads or road-like habitats, and of that, only female G004 significantly avoided both roads and road-like habitats (Table 3-1). After explaining the variance associated with roads, overall I found that 12 bears (40%) selected road-like habitats, and 6 (20%) avoided road-like habitats. The results for the remaining 12 bears were not significant. Those individuals that selected areas close to roads, but avoided road-like habitats generally had their home range within the far western portions of the study area where roads were not accurately predicted because roads traversed very steep terrain. All bears with home ranges in the east selected roads, with the exception of male G045. Selection of road-like habitats for eastern bears, on the other hand, was variable with home range placement.

4.2 Seasonal use of roads

A posteriori analysis of monthly mean distance from road confirmed my selection of July 15 as the time when bears exhibited the greatest difference in behaviour with respect to roads (Fig. 3-2). Grizzly bears were on average closer to roads in the spring and late summer, but in August and thereafter several bears moved away from roads, and the variance between individuals increased.

Seasonal use of roadsides varied between grizzly bears. Female proximity to road was evenly distributed between individuals, with 3 (38%) individuals moving away from roads in the fall, 3 (38%) moving closer to roads, and 2 (25%) showing no significant difference (Table 3-3). Conversely, female selection of road-like habitats was more consistent, with 5 out of 8 females (63%) selecting habitats with a higher road occurrence value in the fall. Exceptions to this were females G004 and G061, which selected higher road occurrence values in the spring. Female G027 showed no change in selection for either variable.

Males also showed variability in proximity to road between the two seasons. Four males (50%) moved further from roads, 3 (38%) moved closer, and G005 did not vary significantly from spring to fall (Table 3-3). Unlike females, most males (6 of 8) did not significantly alter their selection of road-like habitats between spring and fall; although, 2 males, G055 and G024, selected for areas with higher road occurrence values in the fall.

These results are not surprising because results from the use/ available analysis showed males had little preference for road-like habitats.

The change in subadult selection of roads and road-like habitats was consistent with results of the adult sex/age classes. Two (29%) subadults moved closer, 2 (29%) moved further and 3 (42%) showed no significant change in selection in the fall (Table 3-3). Like males, no subadults selected for lower road occurrence habitat values in the fall, but 3 (42%) selected higher road occurrence habitat values and 4 (50%) showed no difference in selection. Of those subadults that selected higher road occurrence habitats, G100 moved closer to roads, G040 moved further from roads, and G036 showed no change in selection, demonstrating the variability found in bear behaviour.

Overall, no individuals moved away from both roads and road-like habitats (Table 3-3). Bears with home ranges in the east moved closer or showed no change in distance from road, with the exception of G012. Of bears found to avoid roads in the use vs. available model (Table 3-2), all moved further from roads in the fall or showed no significant change in selection. Most grizzly bears showed a stronger selection for road-like habitats in the fall, but bears varied in their selection of roads themselves.

Finally, I examined the proportion of locations that occurred within 150 m of roads for the different seasons. For all sex age groups, twice as many individuals had significantly more locations within 150 m of roads in the spring than in the fall (Table 3-4, Fig. 3-3). Overall, 10 bears had a significantly higher proportion of locations near roads in the spring, and 5 had a higher number of locations near roads in the fall. Eight bears showed no significant difference in locations within close proximity to roads.

5. DISCUSSION

My results lend support to the hypothesis that bears were selecting roads and road-like habitats, and that roads often were placed in habitats that bears prefer. Of the 30 grizzly bears surveyed, I found that 19 (63%) were closer to roads than random, and 12 (40%) selected habitats with high road occurrence values. Overall, 10 bears (30%) selected both roads and road-like habitats. The seasonal analysis supports my hypothesis that selection of these habitats was food motivated. In the late summer and fall, when berries begin to ripen, 9 bears (39%) moved further from roads and 10 (43%) had significantly fewer locations within 150 m of roads.

Roads were an important predictor of bear occurrence for all sex/ age classes. Of the 30 bears surveyed, only 5 bears avoided roads. Three of these (G004, G038, and G008) had home ranges that extended into the Rocky Mountains, possibly allowing them to gain access to alternative food sources such as avalanche chutes (McLellan and Hovey, 1995). When examining these 3 bears' mean monthly distance from road (Fig. 3-2), I found that female G038 and male G008 moved closer to roads in the spring months, lending further support that areas near roads were an attractant to bears in this area even when they have home ranges within the mountains. Bears in other areas have been found to use roadside habitats when alternative foods were less abundant (Mattson et al., 1992) or when roads were near an important food source (Chruszcz et al., 2003).

In August, when bears begin to incorporate more berries into their diet (Hamer and Herrero, 1987; Nagy et al., 1989; Hamer et al., 1991; McLellan and Hovey, 1995), the variance in overall distance from road increases between individuals (Fig. 3-2), possibly because bears segregated into different habitats once food became more abundant (Wielgus and Bunnell, 1995). G020, G061, G024, moved significantly closer to road habitats in the fall (Table 3-3), yet exhibited significantly fewer locations within 150 m of roads (Table 3-4), suggesting that although bears were using habitats associated with roads, some may not be using the roadside itself to acquire resources.

An alternative explanation for grizzly bear selection of roads could be that roads act as a refuge for females with cubs and subadults to avoid dominant males (Mattson et al., 1987; Wielgus and Bunnell, 1995). My results do not support this hypothesis because males were also found near roads at high rates. In addition, males exhibited similar selection for areas within close proximity to roads (Fig. 3-3), with half of male bears having a significantly greater percentage of locations within 150 m of roads in the spring. This pattern holds even during spring mating season, when male bears increase their travel distance in search of estrus females. Male bears did not show a significant preference for road-like habitats but were still associated with roads, suggesting that they were either (1) using roads as travel corridors, (2) there in search of estrous females, or (3) attracted to roads for food. The shift in road use was congruent with the diet shift from herbaceous vegetation to berries (Munro et al., *in press*), supporting the food-motivated hypothesis. Increased habitat segregation between the sexes could potentially be occurring in the late summer when resources become more abundant across the landscape, but again I found no support for this because males, females, and subadults had approximately equal proportions of individuals remaining near roads. Future work should examine whether differentiating roads by traffic volume affects the presence of subordinate individuals in this area.

While use of roads was consistent among sex/ age groups, selection of road-like habitats varied with sex and age. After explaining the variance associated with roads, 6 subadults (60%) selected road-like habitats, whereas 6 males (67%) showed no significant preference. Conversely, 4 females (36%) selected and 4 females (36%) avoided road-like habitats. While females and subadults appear to be responding to road-like habitats, males may be responding to variables not examined in my models. Males may be motivated to find mates, whereas females and subadults may spend more time searching for food or avoiding males.

An unexpected pattern that arose when comparing seasonal change in grizzly bear selection was that bears, while variable in their selection of roads from spring to fall, consistently chose areas with higher road occurrence values in the fall. Of the 23 grizzly bears analyzed, 10 (43%) showed a preference for higher road occurrence values, and only 2 (9%) bears moved into lower road occurrence habitats. One possible explanation could be that berries are more abundant in undisturbed road-like habitats whereas herbaceous vegetation is more typical of road-like habitats that contain roads due to the disturbance and edge effect. Road-like habitats were typically at lower elevation and low to intermediate rugged terrain (Chapter 2). They also received higher level of sun exposure and were significantly drier (Chapter 2). These attributes, in the absence of a disturbance, could promote the growth of berry plants. Nielsen et al. (2004c) found that most berry-producing plants in this area occurred at low to intermediate elevation, low to intermediate soil wetness, and high sun exposure, with the exception of *V. membranaceum* which preferred the lower sun exposure of northeast facing slopes. *Shepherdia canadensis*, a particularly important berry-producing plant for grizzly bears in the fall (Hamer and Herrero, 1987; Nagy et al., 1989; Hamer et al., 1991), occurs at low elevations, low soil wetness areas, and high sun exposure (Hamer, 1996; Nielsen et al, 2004c). These results suggest that grizzly bears prefer low elevation valleys with disturbance in the spring, but switch to undisturbed valleys in the fall in search of berries. As a result, future road development into these undisturbed valleys could be detrimental to grizzly bear populations.

6. CONCLUSION

The results of this study indicate that road placement was associated with habitats grizzly bears select, particularly for subadults and some females. In addition, grizzly bear selection of roads seems to be influenced by seasonal shifts in diet. Bears within all sex/ age classes had a higher preference for roads in the early summer and for road-like habitats in the late summer. Although road placement may explain some preference for roads by grizzly bears, roads were still selected above and beyond simply their placement on the landscape. As a result, more work is necessary to examine the correlations between roads and other sources of attraction, such as cutblocks, which have been shown to increase the prevalence of several grizzly bear food items (Bratkovich, 1986; Hillis, 1986; Nielsen et al., 2004c).

Unfortunately, roads also pose a high mortality risk for grizzly bears (McLellan, 1989; Benn and Herrero, 2002; Nielsen et al., 2004a). Nielsen et al. (2004a) found that bears had higher mortality rates within close proximity to human access features, including roads and trails. Even within national parks, all human-caused grizzly bear mortalities with known locations occur within 500 m of roads or 200 m of trails (Benn and Herrero, 2002). Because grizzly bears were attracted to roads yet were more likely to die there, roads are acting as an attractive sink (Delibes et al., 2001), particularly for subadult bears, which had the highest affinity for roads.

Mortality risk must be mediated if we want to maintain viable grizzly bear populations in the foothills landscape. Bears were attracted to roadside habitats, whether due to food resources or travel corridors, therefore road closures should be considered in areas of high grizzly bear abundance to reduce human-caused mortalities. In the foothills, industrial development is expanding, so access is continually increasing on the landscape (Schneider, 2002) allowing humans to penetrate further into grizzly bear habitats. I found that bears were selecting habitats that were suitable for new road development; therefore, future road development may be detrimental to grizzly bear populations. Future road planning should strive to avoid areas with high grizzly bear use, or if that is not possible, roads should be decommissioned after they are no longer needed. The only way bears can coexist with humans is if we provide secure habitats. Grizzly bears are adaptable to development, and even benefit from some development practices such as forestry, but grizzly bear populations cannot sustain high rates of mortality.

Table 3-1. Demographic information for grizzly bears used within this study. Bears are ordered based on demographic traits, first based on sex and age class, and then according to the presence of cubs (years with cubs/total years collared) and home range location (W = west, E = east, and Mnt = extends out of the study area into the Rocky Mountains).

Bear ID	N	Sex	Age	Cubs	Home Range
G004	1660	F	adult	1/3	W/Mnt
G038	337	F	adult	2/2	W/Mnt
G007	184	F	adult	3/5	W
G011	360	F	adult	1/4	W
G020	1649	F	adult	1/2	W
G023	1964	F	adult	3/3	W
G012	1692	F	adult	3/5	E/W
G027	960	F	adult	3/4	E/W
G060	103	F	adult		E/W
G061	672	F	adult		E/W
G013	90	F	adult		E
G008	800	M	adult		W/Mnt
G029	1088	M	adult		W/Mnt
G005	480	M	adult		W
G014	333	M	adult		W
G017	1054	M	adult		W
G043	566	M	adult		W
G055	443	M	adult		W
G024	1028	M	adult		E/W
G045	62	M	adult		E
G037	420	F	subadult		W/Mnt
G100	1169	F	subadult	1/3	W
G040	1324	F	subadult	1/3	W
G036	502	F	subadult		W
G026	243	F	subadult		E
G106	88	F	subadult		E
G033	2372	M	subadult		E/W/Mnt
G054	124	M	subadult		W
G050	191	M	subadult		W
G058	272	M	subadult		W

Table 3-2. Coefficients, standard errors, and p-values for the individual-based models examining grizzly bear selection of roads (distance to road) and the road occurrence index (road habitats). Bold denotes significance.

	Distance to Road			**Road Habitats**		
Bear ID	β	**SE**	**P**	β	**SE**	**P**
G004	**0.126**	**0.020**	**<0.001**	**-0.158**	**0.017**	**<0.001**
G038	**0.224**	**0.029**	**<0.001**	-0.011	0.029	0.715
G007	**-0.500**	**0.175**	**0.004**	**0.060**	**0.025**	**0.016**
G011	-0.184	0.112	0.100	0.005	0.020	0.785
G020	**-0.293**	**0.036**	**<0.001**	**0.072**	**0.009**	**<0.001**
G023	**-0.284**	**0.023**	**<0.001**	**-0.096**	**0.009**	**<0.001**
G012	**-0.170**	**0.054**	**0.002**	**0.067**	**0.011**	**<0.001**
G027	**-0.556**	**0.057**	**<0.001**	**-0.045**	**0.012**	**<0.001**
G060	**-0.030**	**0.297**	**0.921**	0.082	0.043	0.053
G061	**-1.511**	**0.128**	**<0.001**	**0.038**	**0.017**	**0.026**
G013	-0.020	0.150	0.891	**-0.111**	**0.051**	**0.028**
G008	**0.053**	**0.019**	**0.005**	-0.025	0.013	0.052
G029	**-0.123**	**0.021**	**<0.001**	0.000	0.011	0.965
G005	**-0.316**	**0.048**	**<0.001**	**0.051**	**0.014**	**<0.001**
G014	-0.032	0.057	0.572	-0.005	0.018	0.778
G017	0.002	0.029	0.957	0.000	0.011	0.997
G043	**-0.100**	**0.030**	**0.001**	**-0.068**	**0.014**	**<0.001**
G055	**-0.122**	**0.049**	**0.012**	0.006	0.016	0.713
G024	**-0.767**	**0.084**	**<0.001**	**0.111**	**0.012**	**<0.001**
G045	**0.347**	**0.149**	**0.020**	-0.140	0.073	0.056
G037	0.057	0.030	0.056	**0.056**	**0.017**	**0.001**
G100	**-0.487**	**0.043**	**<0.001**	-0.015	0.010	0.159
G040	**-0.261**	**0.028**	**<0.001**	**-0.178**	**0.012**	**<0.001**
G036	**0.153**	**0.033**	**<0.001**	**0.084**	**0.016**	**<0.001**
G026	**-1.257**	**0.175**	**<0.001**	-0.027	0.031	0.371
G106	**-0.343**	**0.197**	**0.082**	**0.225**	**0.062**	**<0.001**
G033	**-0.392**	**0.029**	**<0.001**	**0.007**	**0.008**	**0.382**
G054	-0.213	0.111	0.054	0.045	0.028	0.105
G050	**-0.651**	**0.172**	**<0.001**	**0.126**	**0.025**	**<0.001**
G058	**-0.126**	**0.040**	**0.002**	**0.048**	**0.018**	**0.008**

Table 3-3. Coefficients, standard errors, and p-values for the individual-based models examining the change in grizzly bear selection of roads and road habitats from spring to fall using a comparison RSF. Positive distance-to-road coefficients indicate bears moving further from roads in the fall. Positive road habitat coefficients indicate a greater selection for high road-occurrence habitats in the fall. Non-significance indicates no change in selection.

	Distance to Road			Road Habitats		
Bear ID	***β***	**SE**	**P**	***β***	**SE**	**P**
G004	-0.014	0.030	0.630	**-0.135**	**0.028**	**<0.001**
G038	**0.964**	**0.094**	**<0.001**	**0.255**	**0.077**	**0.001**
G007	**-0.994**	**0.420**	**0.018**	**0.117**	**0.057**	**0.039**
G020	**-0.182**	**0.065**	**0.005**	**0.088**	**0.017**	**<0.001**
G023	**0.227**	**0.042**	**<0.001**	**0.166**	**0.016**	**<0.001**
G012	**0.370**	**0.112**	**0.001**	**0.104**	**0.024**	**<0.001**
G027	-0.112	0.090	0.210	-0.018	0.021	0.378
G061	**-0.755**	**0.237**	**0.001**	**-0.163**	**0.036**	**<0.001**
G008	**0.394**	**0.042**	**<0.001**	-0.006	0.026	0.827
G029	**0.136**	**0.036**	**<0.001**	0.013	0.024	0.597
G005	-0.069	0.093	0.461	-0.040	0.029	0.168
G014	**-0.381**	**0.165**	**0.021**	0.073	0.038	0.056
G017	**-0.535**	**0.122**	**<0.001**	-0.028	0.027	0.303
G043	**0.467**	**0.082**	**<0.001**	0.007	0.028	0.793
G055	**0.919**	**0.162**	**<0.001**	**0.079**	**0.034**	**0.020**
G024	**-0.388**	**0.119**	**0.001**	**0.112**	**0.025**	**<0.001**
G037	0.070	0.057	0.220	-0.031	0.035	0.367
G100	**-0.357**	**0.091**	**<0.001**	**0.109**	**0.020**	**<0.001**
G040	**0.470**	**0.072**	**<0.001**	**0.221**	**0.039**	**<0.001**
G036	-0.037	0.050	0.451	**0.118**	**0.020**	**<0.001**
G026	0.392	0.356	0.271	-0.076	0.065	0.241
G033	**-0.220**	**0.064**	**0.001**	-0.010	0.016	0.533
G058	**0.613**	**0.133**	**<0.001**	0.059	0.044	0.182

Table 3-4. The proportion of grizzly bear telemetry locations falling within 150 m of a road in the spring and fall. A two-sample test of proportion (Z) was used to assess significance. The sample size and p-values are presented. Bold indicates significance.

	Spring		Fall			
Bear ID	**N**	**Prop.**	**N**	**Prop.**	**Z**	**P**
G004	624	0.010	1036	0.001	**2.63**	**0.008**
G038	150	0.033	187	0.027	0.35	0.723
G007	112	0.357	72	0.278	1.12	0.262
G020	1059	0.427	590	0.354	**2.88**	**0.004**
G023	898	0.109	1066	0.182	**-4.52**	**<0.001**
G012	1152	0.284	540	0.176	**4.78**	**<0.001**
G027	405	0.333	555	0.420	**-2.72**	**0.007**
G061	238	0.433	434	0.320	**2.91**	**0.004**
G008	452	0.042	348	0.020	1.73	0.083
G029	810	0.159	278	0.252	**-3.44**	**0.001**
G005	302	0.219	178	0.124	**2.60**	**0.009**
G014	203	0.167	130	0.131	0.91	0.364
G017	847	0.157	207	0.333	**-5.78**	**<0.001**
G043	231	0.234	335	0.149	**2.55**	**0.011**
G055	205	0.371	238	0.252	**2.70**	**0.007**
G024	384	0.409	644	0.345	**2.06**	**0.039**
G037	162	0.130	258	0.120	0.29	0.774
G100	501	0.174	668	0.192	-0.78	0.433
G040	313	0.323	189	0.233	**2.15**	**0.031**
G036	694	0.180	630	0.225	**-2.05**	**0.040**
G026	85	0.447	158	0.361	1.31	0.189
G033	1017	0.199	1355	0.212	-0.79	0.432
G058	102	0.265	170	0.029	**5.83**	**<0.001**

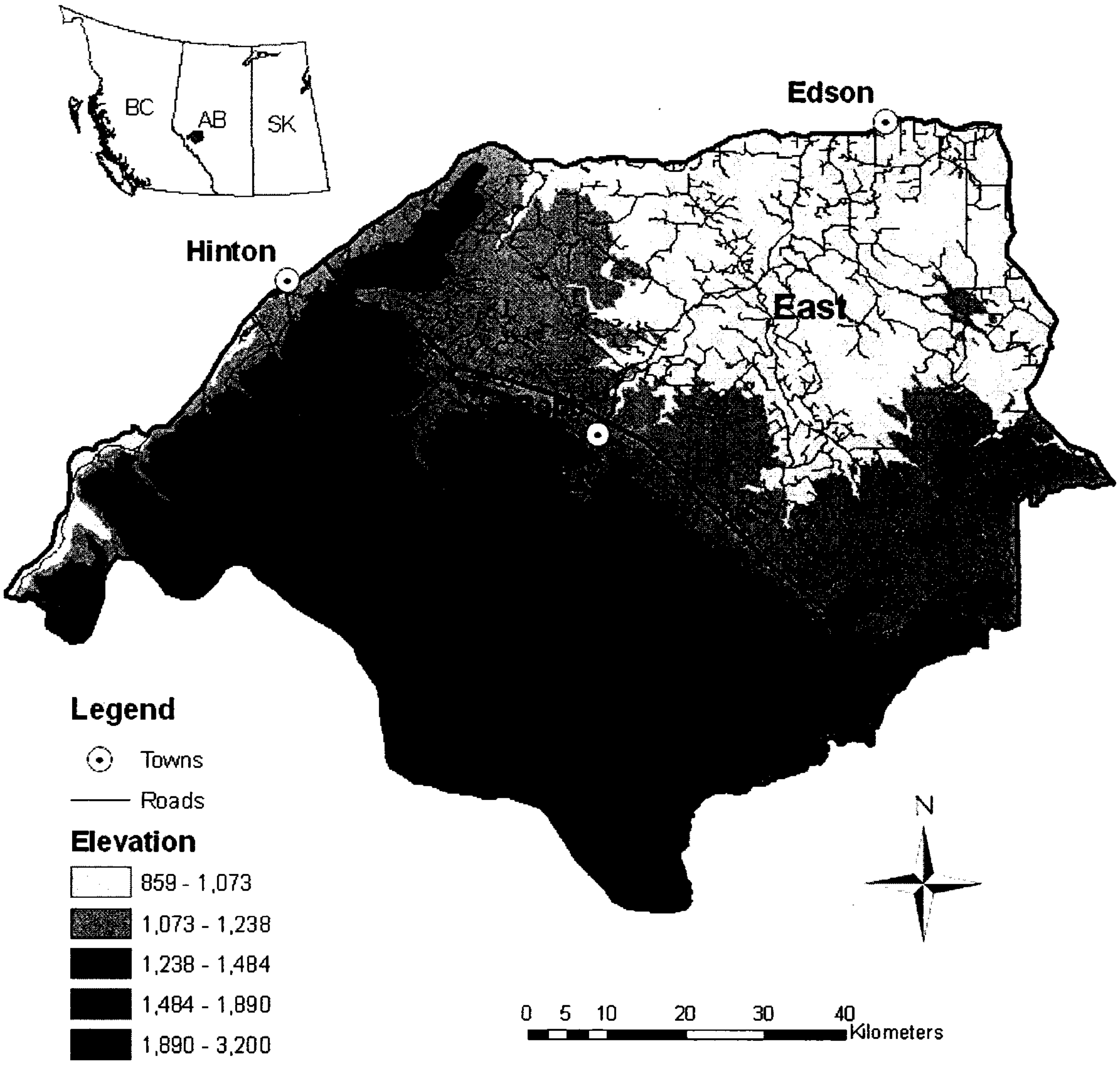

Figure 3-1. Map of the study area in west-central Alberta. Roads are common throughout the area, but dissipate further west within Jasper National Park. The western portion (West) encompasses the eastern foothills of the Rocky Mountains and is at higher elevation and contains more rugged terrain. The eastern portion (East) is at lower elevation and is characterized by less rugged and wetter habitats.

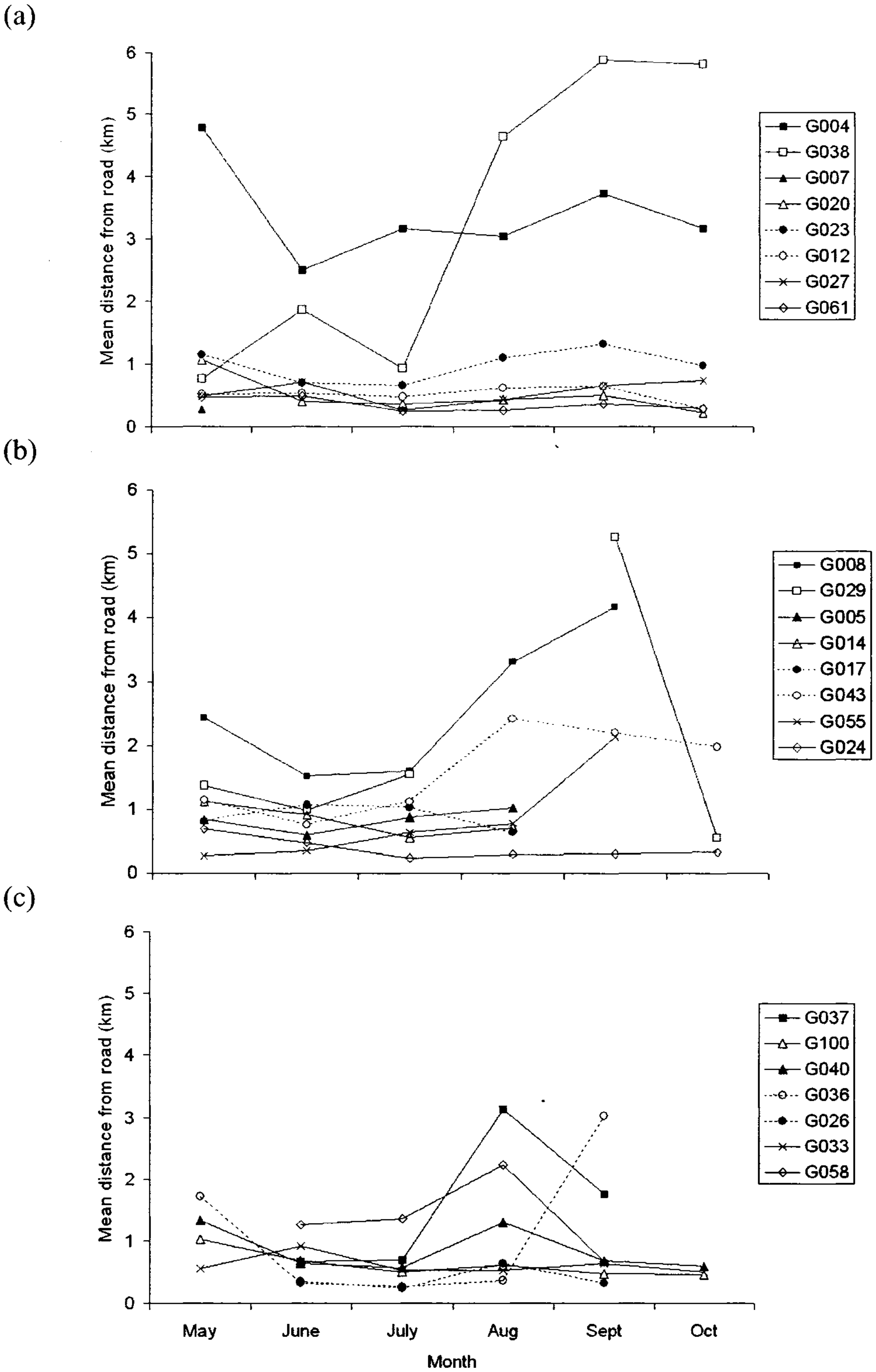

Figure 3-2. The mean distance from road per month for females (a), males (b), and subadults (c). Mean distance was calculated only when individuals had N≥50 locations per month. From May to July, mean distance on average is closer to roads with little variance between individuals. From August to October, some bears moved further from roads and variance between individuals increased.

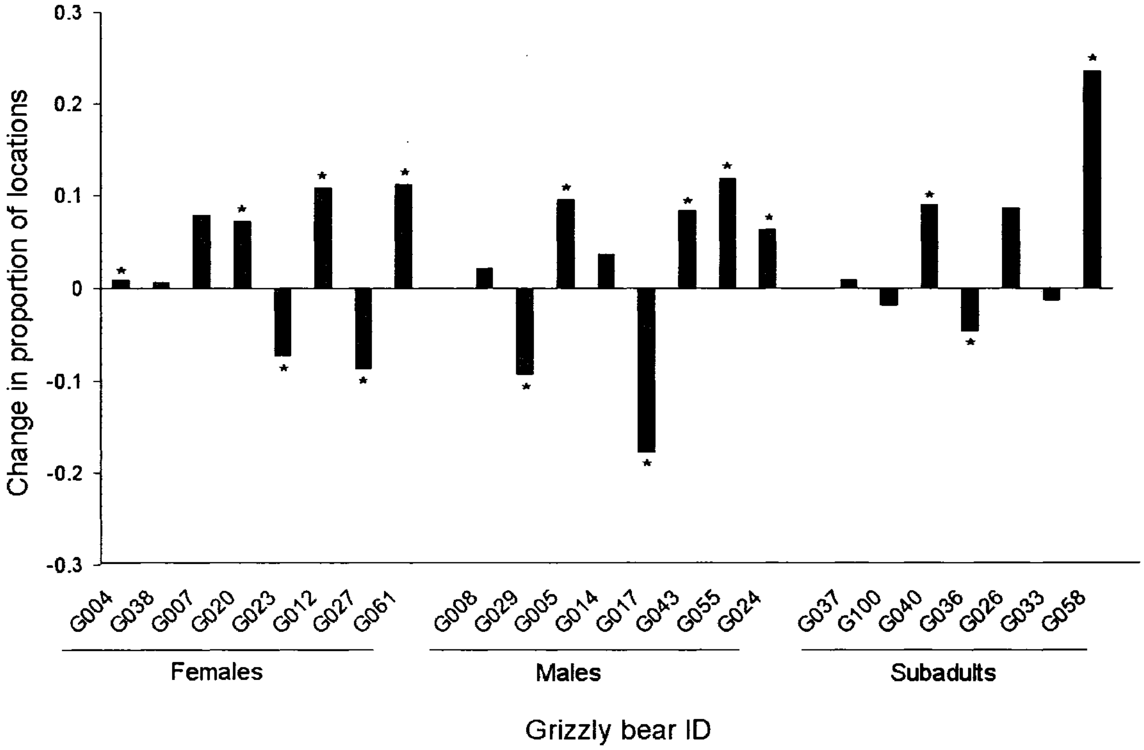

Figure 3-3. The change in the proportion of telemetry locations within 150 m of roads between the spring/early summer and the late summer/fall. Positive values indicate a greater proportion of locations close to roads in the spring/early summer. Negative values indicate a greater proportion of locations close to roads in the late summer/fall. (*) indicates significance.

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CHAPTER 4

EXPLORING CONFOUNDED VARIABLES: QUANTIFYING GRIZZLY BEAR MOVEMENTS AROUND ROADS IN A MULTI-USE LANDSCAPE

1. INTRODUCTION

Grizzly bear (*Ursus arctos*) populations cannot sustain high rates of mortality due to their long developmental period and low reproductive rates (McLellan, 1989; Mace and Waller, 1998). Throughout the world, grizzly bear numbers have declined when in continued contact with humans largely as a result of direct human-caused mortality, but secondarily from habitat loss (Storer and Trevis, 1955; Brown, 1985). Most grizzly bear mortality is concentrated in areas of high human use, such as near roads (McLellan et al., 1999; Benn and Herrero, 2002; Nielsen et al., 2004a). Benn and Herrero (2002) found that 90 percent of grizzly bear mortalities in western Alberta were human-caused, and of those with a known location, all occurred within 500 m of a road or 200 m of a trail. In the foothills of Alberta, roads are increasing on the landscape at a rapid pace (Schneider et al., 2002) resulting in increased fragmentation, increased human access, and a decline in secure (human-free) grizzly bear habitats.

Trying to describe grizzly bear response to roads can be difficult due to confounded factors. Throughout the mountains and upper- and lower-foothills, roads are built in distinctive landscape types to accommodate vehicular travel. Roads are generally constructed at low to intermediate elevation and on flatter terrain (Chapter 2), i.e., characteristics that typify valley bottoms. In mountain ecosystems, carnivores also concentrate their activities in valley bottoms to acquire food resources and for travel

(Noss et al., 1996). As a result, it is difficult to determine whether grizzly bears are selecting roads or instead prefer landscape features associated with road development.

In addition to road placement, an added complication in managed forests is that roads are often associated with other industrial activities, such as timber harvesting. Harvested stands, or cutblocks, have been found to promote the production of several important grizzly bear food items (Bratkovich, 1986; Hillis, 1986; McLellan, 1990; Nielsen et al., 2004b; 2004c). In west-central Alberta in particular, cutblocks have significantly higher occurrence of ants, *Equisetum* spp. (horsetail), *Hedysarum* spp. (sweet vetch), *T. officinale* (dandelion), and *Trifolium* spp. (clover), along with increased occurrence of the following berry producing plants: *V. caespitosum* (dwarf blueberry), *V. membranaceum* (huckleberry), and *V. vitis-idaea* (bog cranberry; Nielsen et al., 2004c). Cutblocks are particularly important to grizzly bears in forests that have a history of fire suppression (Nielsen et al., 2004b), where natural openings and young seral forests are rare. As a result, grizzly bears are forced into close proximity to roads to gain access to resources within the cutblock. This again could result in an apparent selection for roads.

While some studies of grizzly bear road use have simply described response based on sex and age class (Mattson et al., 1987; Mueller et al., 2004), others have recognized the importance of confounded variables near roads (McLellan and Shackleton, 1988; Kasworm and Manley, 1990; Mattson et al., 1992; Mace et al., 1996). Early research on habitat selection examined use-versus-availability within bands of increasing distance from roads; unfortunately, analysis was limited to only habitat types with large sample sizes (McLellan and Shackleton, 1988; Kasworm and Manley, 1990). More recently, Mace et al. (1996) used both band analysis and resource selection functions (RSF) to find patterns in grizzly bear habitat selection and road use. They found that road use increased in the spring, which was correlated with increased use of low temperate forests and cutblocks. Mattson et al. (1992) found that bears were closer to roads in years of whitebark pine (*Pinus albicaulis*) seed crop failure.

While these studies have been useful in helping to understand grizzly bear use of areas near roads, limited information is available on how grizzly bear movement decisions and behaviours are affected by roads. Most movement studies of grizzly bears have been limited to analysis of road crossings (Waller and Servheen, 2000; Kaczensky et al., 2003; Chruszcz et al., 2003; Waller and Servheen, 2005) or corridor use (Singleton et al., 2004; Clevenger and Waltho, 2005), with little information available on overall grizzly bear movement patterns. Recent advances in habitat-selection studies, called step selection functions (SSF), allow researchers to incorporate movement parameters into a structure similar to RSF analysis (Fortin et al, 2005). The result is a more mechanistic model, operating at a scale more realistic to selection decisions of the animal. In addition, it draws from the known movement parameters of the study species and incorporates behaviours such as directional persistence (Fortin et al., 2005). While RSF analysis examines only the telemetry locations, SSF uses habitat characteristics along the movement path to try to understand what factors effect step selection. I used a SSF to identify variables that influenced grizzly bear movements across the landscape. SSF not only can predict whether bears avoid roads, but it also quantifies their response to roads while controlling for influences of other habitat factors.

The purpose of this study was to explore how landscape factors influence grizzly bear selection and movements near roads. I focused on examining grizzly bear movement response to roads during spring and early summer only, when bears are most likely to be near roads (Chapter 3; Mace et al., 1996). Objectives were (1) to quantify how roads influenced grizzly bear step selection at different times of day while controlling for other landscape factors, and (2) to analyze grizzly bear step length as a function proximity to road.

2. STUDY AREA

The study took place in a 7,689-km^2 managed forest in west-central Alberta, Canada (53° 15' 118° 30'), east of Jasper National Park (Fig. 4-1). The northern boundary was a major thoroughfare (Hwy 16), which serviced the towns of Hinton and Edson, but was also a major travel route between the city of Edmonton and Jasper National Park. The area was classified as upper foothills in the west and lower foothills in the east (Achuff, 1994), with elevations ranging from 859 to 2,682 m. Land cover for this region included conifer, mixed, and deciduous forests, both open and treed bogs, herbaceous meadows, and regenerating cutblocks (Achuff, 1994; Franklin et al., 2001). Resource extraction industries operating in the area included timber harvesting, oil & gas extraction, and coal and gravel mining. As of 2003, the average road density was 0.57 km/km^2 within the study area. Grizzly bear densities were relatively low (e.g. 4.79 individuals per 1000 km^2) as compared to other areas throughout their range (Poole et al., 2001; Boulanger et al., 2005) due in part to the short growing season, the absence of salmon, and limited availability of other high protein foods (Jacoby et al., 1999).

3. METHODS

3.1 Grizzly bear data

Between 1999 and 2004, the spring and early summer (01 May to 15 July) movements of 27 grizzly bears equipped with GPS radiocollars were monitored (Cattet et al., 2003). Collars were programmed to acquire locations at intervals between 1-4 hrs. For consistency, telemetry locations occurring less than 4 hrs apart were subsampled, and only 4 hr time steps were used in analysis. Data were combined across years. In total, I examined 27 grizzly bears (12 females, 9 males, and 6 subadults) with 4,325 observations.

Because grizzly bears are highly variable in behaviour both between sex/age groups, individuals, and even within different seasons of the same individual, many grizzly bear studies divided individuals into sex/age and season groups (Mattson et al., 1987; McLellan and Shackleton, 1988; Mattson et al., 1992; Gibeau et al., 2002; Nielsen et al., 2002). However, in Chapter 3 I found that grizzly bear selection of areas near roads is relatively consistent between sex/age groups in this study area. Kasworm and Manley (1990) also found identical patterns of habitat selection relative to roads between males and females. Furthermore, fine-scale divisions of data can reduce power of analysis. Therefore data for sex/age classes were combined.

3.2 Modelling grizzly bear step selection

A step selection function (SSF) was used to identify landscape variables that influenced grizzly bear movement beyond the assumption of directional persistence (Fortin et al., 2005). This method is similar to other case-control habitat selection studies (e.g., Manly et al., 2002; Boyce et al., 2003), except the step is the unit of replication. A step is defined as a straight-line path between successive telemetry locations taken at regular intervals (Turchin, 1998). The relative probability of step selection, $\hat{w}(x)$, was estimated by comparing observed grizzly bear steps to a random sample of available steps taking the form:

$$\hat{w}(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p) \qquad (1)$$

where x_1 to x_p are environmental variables and β_1 to β_p are the respective coefficients estimated using conditional logistic regression. SSF models do not assume that the animal traveled the sampled straight-line path, only that the landscape characteristics between the starting and ending points influenced animal movements (Fortin et al., 2005).

Grizzly bear response to anthropogenic features has been known to vary with time of day (McLellan and Shackleton, 1988; Mueller et al., 2004; Waller and Servheen, 2005), therefore using mean hourly step length, data were segregated into four time periods based on high and low activity: night (11pm – 2am, inclusive), dawn (5am – 8am), day (10am – 1pm), and dusk (4pm – 7pm; Beyer, 2006). Grizzly bear step selection was then modelled independently for each time period. Dividing the data into time periods also decreased autocorrelation within the dataset, because each individual was sampled only once within a 24 hr period.

Each observed grizzly bear step was compared to 20 random steps, created by randomly drawing step lengths and turn angles from grizzly bear movement distributions observed in this study. Separate step-length and turn-angle distributions were created for each time period (night, dawn, day, dusk) and for each grizzly bear sex/age group (adult female, adult male, and subadult), resulting in 12 distributions. Kolmogorov- Smirnov tests were used to test for differences between distributions, and distributions that were not significantly different were combined (Beyer, 2006). Sampled steps were then drawn based on the sex/age class of the individual and the time period of each observation.

Models were created using Hosmer and Lemeshow's (1989) model building procedures. I used a full model, with the exclusion of correlated variables. All continuous variables were tested for collinearity using Peason's correlations (r), and variables with $r > |0.6|$ were not included in the same model. All continuous variables were further assessed for nonlinearities with the addition of a quadratic term. Robust standard errors were used to specify that telemetry locations from the same individual were not independent (White, 1980). Finally, I tested the independence between consecutive steps by examining autocorrelation and partial autocorrelation of model residuals (Fortin et al., 2005).

I hypothesized that grizzly bears might not be attracted to roads per se but rather to the associated cutblocks. But because roads were associated with cutblocks, I believed they might be correlated and therefore, could not be included in the same model. To test whether grizzly bear movements were best described by roads or by cutblocks, I examined the change in log likelihood between two global models, interchanging only 1) minimum distance to road with 2) minimum distance to cutblock, to determine which provided better fit of the data (Table 4-1). The use of an information theoretic approach was not required in this case because the number of variables (K) within the models of comparison remained constant. Both distance variables were tested for nonlinearities with the inclusion of a quadratic term. Models were ranked based on their log likelihood, and for ease of comparison, I examined the change in log likelihood from the null model.

Separate analyses were conducted for each time of day period (night, dusk, day, and dawn).

3.3 Modelling grizzly bear step length

In addition to examining how landscape variables influenced grizzly bear step selection, I also was interested in understanding whether bear behaviour differed with landscape features, particularly roads. Step lengths can be used to distinguish animal behaviours, with longer steps indicating increased travel or relocating and shorter steps corresponding to foraging or resting (Franke et al., 2004; 2006). Step length also can be an indicator of residency time because shorter steps increase the probability of remaining in a given habitat (Turchin, 1998).

Using mixed-effects linear regression, I modelled grizzly bear step length as a function of landscape variables, with individual grizzly bear as a random intercept (Rabe-Hesketh and Skrondal, 2005). Time periods (night, dawn, day, dusk) were again modelled separately. To normalize the right skew of step length, I used a $\log_{10}$ transformation. Model building procedures were identical to the SSF procedures above, to create a full model with the exclusion of correlated variables. All statistical analysis was done using Stata (2005).

3.4 Landscape Variables

A roads layer was obtained from the Foothills Model Forest in cooperation with West Fraser Inc. Dates of construction were determined for all roads in the study area using Landsat imagery (30 m resolution), taken in September of every year. Roads were dated with the year that they first appeared on the Landsat image. Roads that were not visible due to image resolution were dated using surrounding anthropogenic features, such as new cutblocks or well sites. Yearly road maps were then created. Minimum distance (km) to nearest road (*Rd*) was calculated along each step based on the year of the step, ensuring that the road was in existence at the time of location acquisition. In addition, a count of the number of roads crossed (*Cross*) was determined.

Traffic volume was estimated yearly for all roads. Dates were obtained for cutblock harvesting (FMF; Hinton, AB) and well site construction (SRD; Edson, AB). In addition, campsites were located throughout the area. Least-cost paths from the cutblock, active well site, or campsite to the processing plant or nearest population center were estimated. To account for recreational traffic, a diffusion index was created from population centers based on population size and travel time to all points on the road network (Apps et al., 2004). All variables (forestry, oil & gas, campsites, and recreation) were combined to create and index of low and high human use (complete methods in Appendix B). I then calculated minimum distance (km) along each step to the nearest low volume (*RdLow*) and high volume (*RdHigh*) road.

Distance to edge (*Edge*) was calculated as the length-weighted mean distance (km) from boundaries separating forested and open habitats. Length-weighted mean was calculated by dividing each step into segments that pass through single raster cell. The length of each segment is multiplied by the value of the raster cell, summed across the entire step, and this value was divided by the total step length. Using a land cover classification (Franklin et al., 2001), I reclassified habitats as open (alpine, herbaceous, shrub, open bog, rock, snow, pipelines, well sites, recent burns, and cutblocks ≤ 12 years old) or forested (conifer, deciduous, mixed forest, treed bog, and cutblocks > 12 years old). Roads were considered a special type of edge, so they were removed to avoid correlations with road variables. To do so, roads were categorized as the dominant land cover class (i.e. forested), and were therefore eliminated from the edge classification when bisecting forested habitats. Roads bisecting open habitats were less common across the landscape. In addition, roads were occasionally misclassified as an open habitat class in the landcover classification (e.g. a road bisecting a cutblock was classified as a cutblock), so they were also removed from the edge classification. Although some roads bisecting open habitats were still classified as edges through this process, these instances were rare. In addition to edge, a dummy variable (*EndOpn*) was used to determine whether a step ended in an open (1) or forested (0) habitat.

Forest age was determined for all forested habitats listed above using Alberta Vegetation Inventory (AVI) data and fire history maps (FMF; Hinton, AB; Nielsen, 2005). Ages were binned into 10-year increments, creating an index ranging from 1 to 15, with 0 indicating non-forested habitats. Forests $\geq$ 140 years old were placed in bin 15, representing old growth. Length-weighted mean forest age (*For-Age*) was then queried for each step. Next, cutblocks were identified on a yearly basis using Landsat imagery (FMF; Hinton, AB). A separate cutblock layer was created for each year and minimum distance to cutblock (*Cut*) was determined for all steps based on the year the step was acquired.

Using a 30-m digital elevation model, three terrain-based variables were created. A compound topographic index (*CTI*) was used as an index of soil wetness, and was calculated using Arc Macro Language from Evans (2002). CTI has been found to be correlated with several soil attributes such as organic matter (Moore et al., 1993; Gessler et al., 1995) and also has been used as a predictor of grizzly bear habitat selection

(Nielsen, 2005). Next, an index of summer global solar radiation (*SOLAR*) was created based on short wave and diffused solar radiation on 3 summer days: June 15, July 15, and August 15 (see Nielsen, 2005). Finally, a terrain ruggedness index (*TRI*) was estimated by modifying an existing equation from Nellemann and Cameron (1996; see Nielsen et al., 2004a). For all terrain-based variables, the length-weighted mean value was calculated for each step.

4. RESULTS

4.1 Grizzly bear step selection

The distribution of turn angles was not significantly different between any sex/age classes or time of day period ($p > 0.05$), so they were combined into one distribution. Step length distributions were not significantly different between dawn and dusk, so they were combined into a crepuscular distribution. Step-length distributions for night, day, and crepuscular were significantly different ($p < 0.05$). Step-length distributions also were significantly different across all sex/ age classes, resulting in 9 final step length distributions (female, male, subadult by night, day, crepuscular).

For all time periods, grizzly bears were more likely to move towards roads (Table 4-2). Traffic volume appeared to have little influence on bear movements, with bears selecting steps nearer to both low and high volume roads. Although at dawn, a quadratic relationship existed with high volume roads, with step selection increasing with proximity to road but leveling off in areas very close to high-volume roads. Road crossings were positive at all time periods, indicating that grizzly bears crossed roads more often than random. Because this could be due to rare events skewing results, I removed all observed steps that crossed >8 roads and reran the model. The direction and significance level of the road-crossing variable did not differ, reinforcing the original results.

Although grizzly bear selection of road variables was consistent throughout the day, results show that time of day had a strong influence over selection of forest structure and terrain variables. At night, bears moved towards areas of intermediate terrain ruggedness and intermediate forest ages between 40 and 100 years (Table 4-2). At dawn, steps were still directed towards forests of intermediate age, but this relationship was not as strong as at night (Fig. 4-2). In addition, terrain ruggedness was no longer a predictor of grizzly bear steps at dawn, instead bears selected steps with higher solar radiation values ($\beta = 0.257$, SE = 0.128). During the day, grizzly bears began selecting older forests ($\beta = 0.047$, SE = 0.012). Conversely, forest age was no longer a predictor of step selection at dusk; instead grizzly bears chose steps that were significantly closer to edges ($\beta = -12.16$, SE = 2.76). For all time periods, bears chose steps that ended in open habitats (Table 4-2). *CTI* was not a significant predictor of grizzly bear step selection in any model.

As hypothesized, distance to road was highly correlated with distance to cutblock ($r = 0.702$), therefore *Cut* was not included in the final SSF model, and instead the two variables (*Rd* or *Cut*) were interchanged within global models to determine which had the greatest explanatory power. At dawn, day, and dusk, the cutblock model explained the most variation in the data, but conversely at night, the road model was the top ranked model (Table 4-3). However, the changes in log likelihood values between the road and cutblock models (ΔRd-Cut) were negligible at night and dusk, with values of 0.12% and 0.05%, respectively (Table 4-3). For the dawn and day models, the change in log likelihood increased slightly, but still was < 1% (ΔRd-Cut$_{dawn}$ = 0.54% and ΔRd-Cut$_{day}$ = 0.57%). So overall, the two models performed equally well at explaining grizzly bear step selection across the landscape.

4.2 Grizzly bear step length analysis

The final model for the step length analysis contained all variables examined with the exception of *Cut* due to correlations with distance to road ($r = 0.702$). The variable *Cross* was natural log transformed to normalize model residuals. Forest age was the only variable that demonstrated nonlinearities, so a quadratic term was added.

Overall, grizzly bear step lengths were consistent across all time periods for most variables (Table 4-4). Step lengths increased when approaching both high and low trafficked roads. Bear response to high trafficked roads was stronger than low trafficked roads for all time periods, with beta values for *RdHigh* being twice that of *RdLow*; however, no difference in response was found at night, when traffic volume around all roads decreased substantially. As expected, step length increased with the number of roads crossings for all time periods (Table 4-4).

For all time periods, step length increased linearly with increasing distance from edge (Table 4-4). No difference in step length was apparent between steps ending in open versus closed habitats (Table 4-4). Grizzly bear steps were longer at intermediate forest age classes throughout the day (Table 4-4). When examining step length as a function of terrain-derived variables, terrain ruggedness alone influenced step length. For the dawn, day, and dusk models, grizzly bear steps increased linearly with increasing terrain ruggedness. At night, however, terrain ruggedness was not a significant predictor of grizzly bear step length ($\beta = 0.042$, SE = 0.022). *CTI* and *SOLAR* were not significant at any time of day (Table 4-4).

5. DISCUSSION

My results indicate that grizzly bears in the foothills of Alberta directed their movements towards roads. In addition, as distance to road decreased, steps length increased. Examining step length alone would suggest that bears avoided roads because residency time within a given habitat is hypothesized to decline with increasing step length (Turchin, 1998). However, combining information on step length with the SSF indicates that bears were selecting roads for travel. The higher number of road crossings than random also supports this hypothesis because travel directed parallel to roads increases the likelihood of multiple crossings.

Traffic volume had little effect on grizzly bear step selection, except at dawn when movements within close proximity to high volume road declined slightly (Table 4-4). This response could be a result of higher traffic at dawn (5am- 8am) as the workday begins, although the same response was not observed at dusk. Other studies have found that grizzly bear avoidance of roads was contingent on traffic volume, near both highways (Waller and Servheen, 2005) and less trafficked logging roads (Archibald et al., 1987; Mace et al., 1996). In addition, grizzly bears have been found to increase use of roadsides at night (Mattson et al., 1987; McLellan and Shackleton 1988; Mueller et al., 2004; Waller and Servheen, 2005). My results indicate that grizzly bears in the foothills of Alberta selected roads irrespective of traffic volume and time of day; although, bears did exhibit a difference in behaviour around roads of different traffic volumes. Step length analysis indicated that bears had a stronger response to high trafficked roads, with beta values being at least twice that of low trafficked roads for all time periods (Table 4-4).

Grizzly bears have been found to use roads when they were near important food resources and when alternative foods are less abundant (Mattson, 1990; Mattson et al., 1992). During spring in particular, female grizzly bears in Yellowstone National Park chose more productive habitats irrespective of human development (Mattson et al., 1987). In the foothills of Alberta, fire suppression has decreased the productivity of conifer forests as they mature and crown closure reduces light to the forest floor. Cutblocks have been found to promote the production of several grizzly bear food items in this area (Bratkovich, 1986; Hillis, 1986; Nielsen et al., 2004c), and provide an alternative to natural openings and young seral forests, which are rare. As a result, the correlation between roads and cutblocks may be forcing grizzly bears into close proximity to roads to gain access to forage. Model selection indicated that the road and cutblock models had equal explanatory power for grizzly bear step selection (Table 4-3). The result was minimal change in log likelihood values, lending support to my hypothesis that roads were an attractant because of their association with cutblocks.

Unfortunately, grizzly bear mortality increases when bears are forced into close proximity to roads to access food resources. Mattson et al. (1992) found that grizzly bear mortality declined in years with high whitebark pine seed yields because bears were able to spatially segregate themselves from roads. In the foothills however, segregation might not be possible due to the association of roads with cutblocks and the spatial orientation of roads (Chapter 2, 3). The increased mortality risk associated with food patches near roads could increase grizzly bear vigilance, resulting in less efficient foraging, and increased energy expenditure from costly flight responses (Lima and Dill, 1990; McLellan, 1990; Houston et al., 1993). Grizzly bears in British Columbia exhibited a stronger flight response to humans when in open habitats (McLellan, 1989). As a result, foraging in young cutblocks and roadside ditches could prove to be more energetically costly than foraging in older cutblocks or uncut forests.

The results of this study confirmed that grizzly bears had longer step lengths when approaching roads, but the underlying behaviour could be the result of several factors. Increased step lengths around roads could indicate increased disturbance and flight response when vehicles approach, although no change in response was found at night when traffic was negligible. Roads could also act as a conduit for movement. Cougars and wolves use dirt roads for travel (Thurber et al., 1994; Dickson et al., 2005), and grizzly bears have been known to prefer well-worn paths and game trails when traveling to more easily traverse understory vegetation (Weber, 1987). If road corridors were being used for travel, longer steps could be a result of less tortuous movement. An individual directing its movements parallel to a linear feature could maintain the same travel rate while increasing travel distance by decreasing movement tortuosity. Movements on the road itself might also allow bears to increase step rate due to fewer impediments to travel, which would explain why grizzly bear step length remained high near roads at night.

Based on previous research and what we know about grizzly bear behaviour around human access features, the most likely explanation for grizzly bear selection and behaviour near roads is a combination of the above factors. Roads are an attractant because they are associated with cutblocks and because of their spatial orientation in low elevation valleys. But roads are also a source of mortality (Benn and Herrero, 2002; Nielsen et al., 2004a), so grizzly bear steps lengths increase due to increasing vigilance and flight response. At night, roads also provide a convenient trail between cut blocks or other food patches, so roads are used for travel resulting in longer step lengths.

Combining traditional movement studies, such as step length analysis, with new step selection methods allows for added explanation of complex movement and selection behaviours. The general assumption that step length equates to residency time (Turchin, 1998) does not necessarily hold true when following linear features. As I have demonstrated, movement parallel to roads can result in increased step length, while still exhibiting apparent selection for that feature. In addition, incorporating movement parameters into standard resource selection models provides a more direct link between landscape features and individual behaviours at a scale more realistic with the selection of the animal, i.e., the distance it can realistically travel in one step. SSF also incorporates known behaviours of animals, such as directional persistence, which allows researchers to inform selection models more explicitly.

6. CONCLUSION

Ultimately, I have demonstrated that, irrespective of other landscape factors, roads are a predictor of grizzly bear step selection in the spring. Unfortunately grizzly bear mortality is also high near roads (Benn and Herrero, 2002; Nielsen et al., 2004a); therefore, roads are acting as an attractive sink for grizzly bears (Delibes et al., 2001). To decrease bear mortality near roads, managers must either 1) reduce sources of attraction near roads or 2) reduce sources of mortality (i.e., humans). Because both the cutblock and the road model equally predicted grizzly bear movements, grizzly bears may select roaded habitats in order to access foods in the harvested stand. As a result, beauty strips should be placed between the road and the cutblock to decrease visibility into harvested stands and increase bear security. In addition, measures should be taken to place cutblocks further from main roads, and arterial roads leading to cutblocks should be decommissioned. This would allow bears to access foods within more secure cutblocks and potentially draw bears away from cutblocks that are associated with main roads. Nielsen et al. (2004c) found that stand treatment could affect the abundance of grizzly bear foods; therefore, more secure cutblocks could be treated in a way to promote bear foods (e.g. leaving slash), and harvested stands near heavily trafficked roads could be treated to decrease bear foods (e.g. scarification). The focus, however, should be on increasing bear security and not decreasing habitat.

The surest way to increase bear security is to implement more rigorous access management guidelines. Cooperation between the forestry and energy sector is necessary to ensure that new road development is optimal for both purposes and that multiple roads are not being built to access the same area. In addition, roads should be minimized in areas with high-density grizzly bear populations, either through temporary road closures or permanent decommissioning. Recent research in Alberta has indicated that grizzly bear populations are less than half that of previous estimations (Boulanger et al., 2005). It is therefore imperative that a management action is implemented to reduce grizzly bear mortalities in the foothills landscape.

Table 4-1. Candidate models for model comparison are presented for grizzly bear step selection functions (SSF). Due to correlations between distance to road (*Rd*) and distance to cutblock (*Cut*), those variables were interchanged to see which best-predicted grizzly bear step selection. Models were applied separately for each time period (night, dawn, day, and dusk) and the change in log likelihood between the two models was examined.

	Name	Model	K
1	Null		1
2	Road	Rd Cross Edge EndOpn For-Age For-Age^2 CTI SOLAR TRI TRI^2	11
3	Cutblock	Cut Cross Edge EndOpn For-Age For-Age^2 CTI SOLAR TRI TRI^2	11

Table 4-2. Beta coefficients and robust standard errors for the final grizzly bear step selection function (SSF) models comparing grizzly bear steps to randomly generated steps. Separate models were generated for each time of day period. Variables included in the model are the minimum distance to low trafficked roads (*RdLow*) and high trafficked roads (*RdHigh*), the number of road crossings (*Cross*), the length-weighted mean distance from edge (*Edge*), a dummy variable distinguishing whether steps ended in open or closed habitats (*EndOpn*), and the length-weighted mean was examined for: forest age (*For-Age*), a compound topographic index (*CTI*), a solar radiation index (*SOLAR*), and a terrain ruggedness index (*TRI*).

	Night		Dawn		Day		Dusk	
	β	SE	β	SE	β	SE	β	SE
RdLow	-0.488	0.092 **	-0.238	0.034 **	-0.398	0.068 **	-0.167	0.043 **
RdHigh	-0.559	0.134 **	-0.028	0.088	-0.430	0.071 **	-0.307	0.052 **
RdHigh^2	---	---	-0.025	0.012 *	---	---	---	---
Cross	0.489	0.048 **	0.244	0.026 **	0.455	0.050 **	0.262	0.026 **
Edge	-4.252	9.481	-2.660	4.195	-8.799	5.390	-12.349	2.871 **
EndOpn	0.464	0.130 **	0.257	0.105 *	0.276	0.079 **	0.284	0.097 **
For-Age	0.279	0.075 **	0.116	0.039 **	0.047	0.012 **	-0.001	0.016
For-Age^2	-0.025	0.007 **	-0.008	0.004 *	---	---	---	---
CTI	0.029	0.081	0.074	0.042	0.060	0.047	0.020	0.056
†SOLAR	-0.107	0.141	0.257	0.128 *	0.233	0.142	0.271	0.162
†TRI	0.195	0.100 *	-0.013	0.025	0.030	0.024	0.006	0.027
†TRI^2	-0.009	0.004 *	---	---	---	---	---	---

† estimated coefficients and standard errors reported at 10,000 times their original values

Note: (*) denotes coefficients significant at the p=0.05 level and (**) denotes significance to the p=0.01 level.

Table 4-3. Log likelihood rankings for step selection function (SSF) models examined at four time periods (night, dawn, day, and dusk). Because models have equal numbers of variables (K), the information theoretic approach was not necessary. Models were ranked according to log likelihood (LL). The percent change in log likelihood from the null (ΔLL_{null}) and the difference explained between the road and cutblock models (ΔRd-Cut) are presented.

	Name	K	Rank	LL	ΔLL_{null}	ΔRd-Cut
Night						
2	Road	11	1	-1404.97	31.02%	
3	Cutblock	11	2	-1407.38	30.90%	0.12%
1	Null	1	3	-2036.79	0.00%	
Dawn						
3	Cutblock	11	1	-3638.46	5.90%	
2	Road	11	2	-3659.22	5.36%	0.54%
1	Null	1	3	-3866.54	0.00%	
Day						
3	Cutblock	11	1	-2925.02	18.92%	
2	Road	11	2	-2945.79	18.35%	0.57%
1	Null	1	3	-3607.76	0.00%	
Dusk						
3	Cutblock	11	1	-3422.39	6.40%	
2	Road	11	2	-3424.23	6.35%	0.05%
1	Null	1	3	-3656.47	0.00%	

Table 4-4. Beta coefficients and standard errors for grizzly bear step length modelled as a function landscape variables. Variables included in the model are the minimum distance to low trafficked roads (*RdLow*) and high trafficked roads (*RdHigh*), the length-weighted mean distance from edge (*Edge*), a dummy variable distinguishing whether steps ended in open or closed habitats (*EndOpn*), and the length-weighted mean was examined for: forest age (*For-Age*), a compound topographic index (*CTI*), a solar radiation index (*SOLAR*), and a terrain ruggedness index (*TRI*). The variable for the number of road crossings per step (*Cross*) was natural log transformed to normalize model residuals.

	Night		Dawn		Day		Dusk	
	β	SE	β	SE	β	SE	β	SE
RdLow	-0.046	0.017**	-0.052	0.014**	-0.073	0.016**	-0.069	0.016**
RdHigh	-0.133	0.044**	-0.139	0.035**	-0.132	0.039**	-0.205	0.045**
ln(Cross)	0.689	0.038**	0.685	0.039**	0.681	0.037**	0.701	0.041**
Edge	1.099	0.334**	1.495	0.321**	1.668	0.337**	1.210	0.344**
EndOpn	0.087	0.066	0.074	0.062	0.004	0.063	0.072	0.068
For-Age	0.353	0.046**	0.251	0.043**	0.239	0.040**	0.226	0.040**
For-Age^2	-0.026	0.005**	-0.017	0.005**	-0.019	0.004**	-0.013	0.004**
CTI	0.010	0.080	0.041	0.059	0.056	0.061	0.044	0.063
SOLAR	-0.024	0.021	-0.019	0.019	-0.014	0.019	-0.031	0.018
TRI	0.042	0.022	0.059	0.019**	0.043	0.018**	0.063	0.020**
constant	1.759	2.032	1.013	1.758	0.908	1.772	2.104	1.719

Note: (*) denotes coefficients significant at the p=0.05 level and (**) denotes significance to the p=0.01 level.

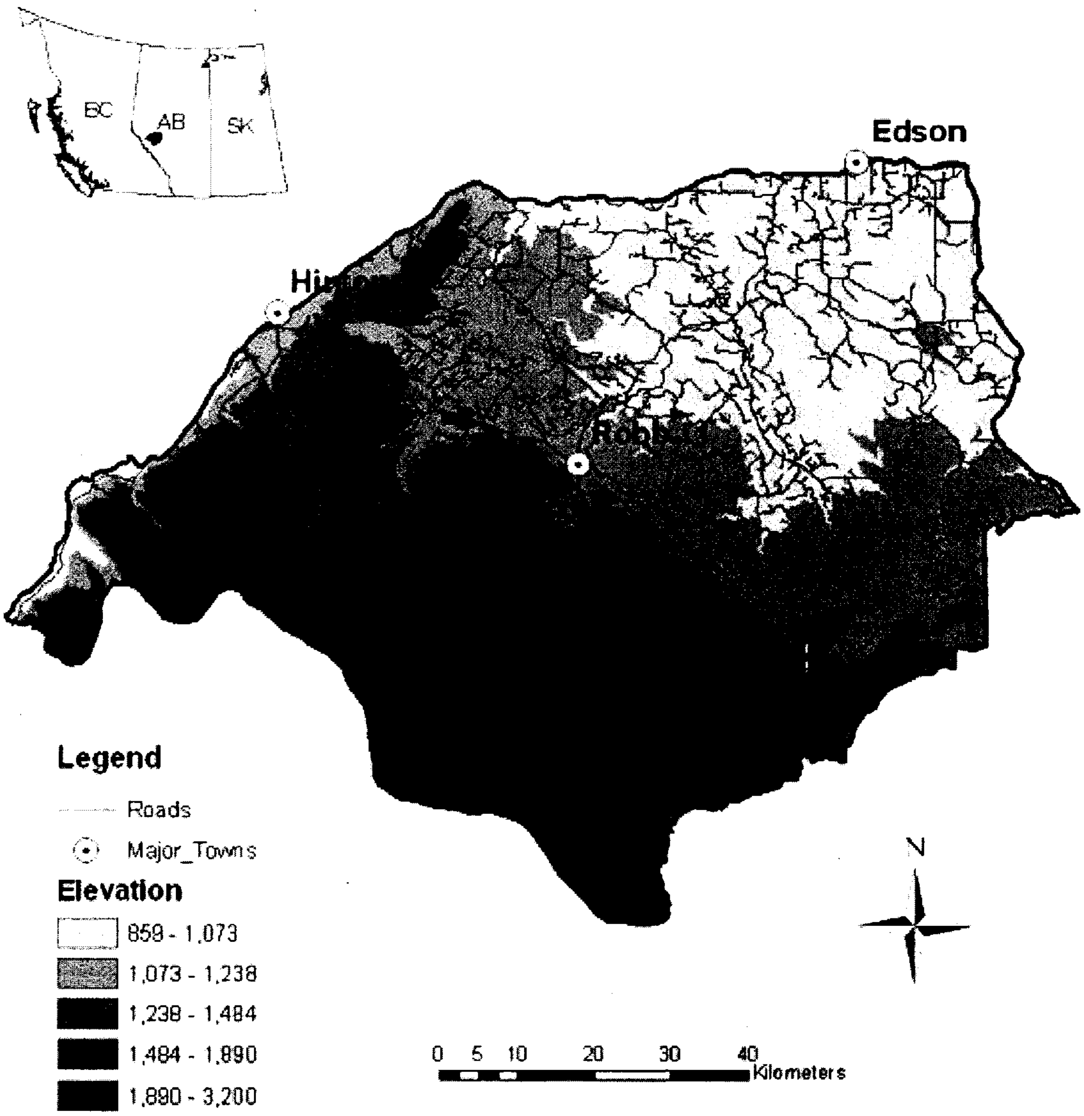

Figure 4-1. The study area was located in west central Alberta in the eastern foothills of the Rocky Mountains. The average road density in 2003 was 0.57 km/km^2.

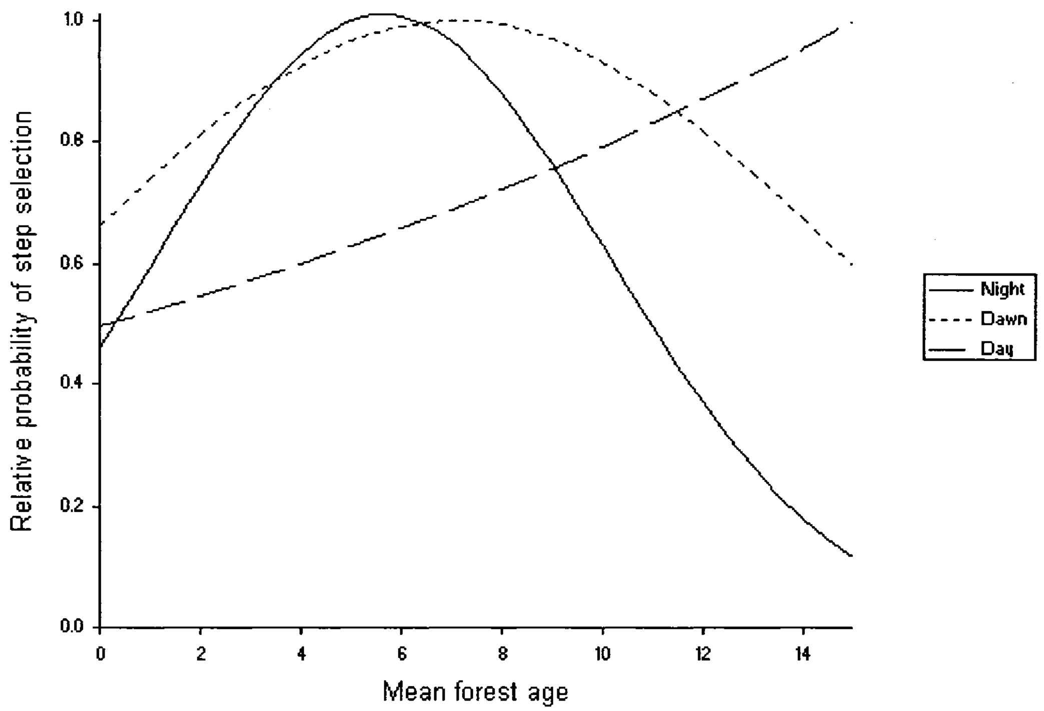

Figure 4-2. Relative probability of step selection by grizzly bears during night, dawn, and day given the length-weighted mean age of forest (mean forest age). Selection at dusk was not significant. Forest age was binned into 10-year increments (e.g. bin 1 encompassed forests 0 to 10 years of age) with 0 indicated non-forested habitats.

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CHAPTER 5

GENERAL CONCLUSION

Studying grizzly bear selection of roadside habitats can be difficult given the confounded landscape factors. In the previous chapters, I have described the potential attractants around roads at multiple spatial scales. Overall, my results indicate that grizzly bear selection of roaded habitats is food motivated. I found that grizzly bear food items near roads increased in the spring and declined in the fall when bears began to eat more berries (Chapter 1). Grizzly bear selection of roaded habitats appears to be correlated with this shift in diet, in that grizzly bears were closer to roads in the spring when bear foods were more abundant in those areas (Chapter 2). In addition to direct food associations, road placement on the landscape may be correlated with grizzly bear habitat selection (Chapter 1, 2). Road placement was particularly important for subadults and some females, although it did not appear to be a good predictor for males. Finally, I found that grizzly bears' apparent selection for roads could be an artifact of their selection for cutblocks, because these two variables are highly correlated (Chapter 3). In general, roads appear to be a good predictor of grizzly bear selection in the foothills because roads are correlated with a suite of other variables that increase bear forage. The results of this study, along with previous research on grizzly bear mortality, indicate that roads and their associated habitats are attractive sinks for grizzly bears.

An attractive sink is defined as a habitat that has an abundance of food and potentially high reproductive rates but also has high rates of mortality and/or breeding failure (Geona et al., 1998). Attractive sinks are generally associated with human-altered landscapes (Knight et al., 1988; Woodruff and Ginsberg, 1998; Revilla et al., 2001), which are novel, evolutionarily speaking, making it difficult for organisms to evaluate the potential risk. Previous research has demonstrated that grizzly bear mortality is highest near roads (McLellan and Shackleton, 1988; Benn and Herrero, 2002; Nielsen et al., 2004), and I have established that grizzly bears are selecting roads, whether for roadside vegetation, their association with cutblocks, or their spatial orientation on the landscape.

Given that roads are attractive sinks, determining the threat they pose to grizzly bear populations depends on many factors. First, the habitat preference of the species is highly important in predicting threshold rates for sink habitats (Delibes et al., 2000). If the species exhibits a strong selection for the sink habitat, even small amounts can be deleterious. Moreover, individual habitat selection preferences play a key role (Lima and Zullner, 1996), making it difficult to determine thresholds even when detailed knowledge is available on the abundance of source and sink habitats on the landscape (Delibes et al., 2000). The threat posed by sink habitats also depends on the species reproductive rates (Wiegand et al., 1998; Delibes et al., 2000). Grizzly bears are long-lived with an old age of first reproduction (4-6 years of age), small litter sizes (1-4 cubs), and a long interval between litters (2-7 years) (Schwartz et al., 2006). These traits result in low reproductive rates and high sensitivity to changes in mortality rates, which ultimately increases the population's sensitivity towards attractive sinks.

To negate the threat posed by roads to grizzly bear populations, we must either decrease grizzly bear selection of roaded habitats or decrease grizzly bear mortality near roads. To reduce grizzly bear selection of roads, we must reduce bear food items in the roadside ditch and in the associated habitats. Roadside ditches should be narrowed to decrease grazing opportunities and the planting of clover for erosion control should be prohibited. Because the associated cutblock also serves as an attractant, forested "beauty strips" should be maintained between the road and cutblock to decrease human visibility into regenerating stands and increase grizzly bear security. In addition, I recommend placing cutblocks further from main roads, and arterial roads into cutblocks should be decommissioned. Increasing grizzly bear security on the landscape will require increased access management. Road closures should be concentrated in areas of high grizzly bear use, and temporary blockades, such as gates, should be installed on roads that will be needed in the future. To discourage illegal road use, fines should be imposed and more importantly enforced, and education programs should be implemented throughout the community.

We have known for many years that grizzly bears are dying near roads as a result of interactions with people, as a result of illegal poaching, management removals, and defense of life and property. Recommendations for roads closures in grizzly bear habitats date to the 1980's (McLellan and Shackleton, 1988), but still little has been done to conserve grizzly bear populations and roads continue to become more numerous. Scientific research has provided us with invaluable tools to identify conservation issues and inform management options, but the decision to conserve grizzly bear habitats ultimately rests with the public. It is the responsibility of the public to make their wishes known to the government, and the responsibility of the government to hold industry accountable. Ultimately, the people must decide what is valued in society, unlimited access or grizzly bears.

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APPENDIX A

GRIZZLY BEAR HABITAT SELECTION BEFORE AND AFTER ROAD CONSTRUCTION

1. PURPOSE

In the Rocky Mountain foothills of Alberta, Canada, grizzly bear (*Ursus arctos*) mortalities increase near roads (Nielsen, et al., 2004a; Benn and Herrero, 2002), yet bears continue to use roadside habitats (Chapter 3, 4). We wanted to examine whether grizzly bears were attracted to roads or whether they were already using these habitats before road construction. To do this, we identified areas of new road construction and examined grizzly bear proximity to road before, during, and after road construction. We hypothesized that grizzly bears would move further from roads after road construction, but would not completely leave the area. This analysis will allow us to distinguish whether grizzly bear attractants around roads should be reduced or whether road placement should be reevaluated in order to decrease the prevalence of grizzly bears near roads.

2. STUDY AREA

This study was conducted in a 7,689 km^2 managed forest in west-central Alberta, Canada (53° 15' 118° 30'). We chose this area because of the high abundance of road development that has occurred in recent years. Road development varied spatial across the area, with some areas experiencing very high rates of development over a short period. One such region (887 km^2 area) contained 473.9 km of roads in September 2000, and by September 2002, 103.8 km of new roads were added, which is a 22 percent increase in linear kilometers and a 12 percent increase in road density (km/km^2). Several resource extraction industries were represented throughout the area, including timber harvesting, oil & gas extraction, as well as coal and gravel mining. Development in this region started as recently as the 1950's and has been increasing rapidly (Schneider, 2002). Grizzly bear densities are relatively low (≤ 5 individuals/1000 km^2) as compared to other areas throughout their range (Boulanger et al., 2005).

3. METHODS

Thirty-two grizzly bears were captured and fitted with GPS radiocollars between 1999 and 2004 (Table A-1). To decrease the potential bias created by capturing habituated bears when trapping only near roads, bears were captured using both foot snares (21 captures) and helicopter net gunning techniques (7 captures; complete methods in Cattet et al., 2003). Collars were programmed to acquire locations at intervals between 2-4 hrs. Only locations that fell within 2 km of new road development were retained for analysis (Table A-1). This cutoff was chosen because the road effect zone has been observed to extend up to several kilometers for black bear (*Ursus americanus*; Forman and Deblinger, 2000) and due to high road densities in the area, buffers greater than 2 km start to encompass surrounding roads. Grizzly bears were analyzed only if they had greater than 25 observations within each time period, resulting in a total of 10 grizzly bears and 3826 locations.

We used a comparison resource selection function (CRSF) (Lele et al., *in preparation*) to compare the change in grizzly bear selection both before/ during and before/ after road construction. This method is similar to a resource selection function (Manly et al., 2002), but instead of comparing use to availability, we compared use before construction to use after construction to determine if selection had changed in the area. It assumes that availability remains constant over time. While roads have been added to the landscape, they made up a very small proportion of the overall habitat, so we do not believe we violated this assumption. We ran both group and individual models. For group models, grizzly bears were divided into 3 groups (all bears, females only, and males only), and the robust cluster option in Stata (2005) was used to adjust standard errors around the individual (White, 1980; Nielsen et al., 2002). Beta coefficients were estimated using logistic regression. We were interested in measuring the overall grizzly bear response to road development; therefore, we did not distinguish between seasons in our analysis.

Distance to nearest road was used as the predictor variable. Roads were identified using a road polyline layer obtained from the Foothills Model Forest (Hinton, Alberta). Roads were dated using Landsat TM images (30 m resolution) taken between August and September of every year (1999-2004). Roads that were not visible due to the resolution of the image were dated with the year of the associated cutblock or well site. This was justified because when both the new road and new cutblock/well site were visible, they always appeared in the same year. Using ArcMap 9.0 (ESRI, 2004), we calculated Euclidian distance (km) to the nearest road for every grizzly bear location.

Grizzly bear response to roads has been shown to vary with time of day, with avoidance decreasing at night, when traffic volume is minimal (McLellan and Shackleton, 1988; Gibeau et al., 2002; Mueller et al., 2004; Waller and Servheen, 2005). To test whether time of day had any affect on road use, we examined two models, one that included only distance to road irrespective of time period and a second that interacted distance to road with a dummy variable for time of day. Diurnal periods were defined as 07:00 to 19:00 h and nocturnal periods were defined as 19:00 to 07:00 h.

The response variable was obtained by querying the year of construction for the nearest road. Grizzly bear locations were then divided into: 1) before construction (year of the telemetry location was less than the year of road construction); 2) during construction (year of the telemetry location was equal to the year of road construction); and 3) after construction (the year of the telemetry location was greater than the year of road construction). We then analyzed two logistic regression models: a) before (0) versus during (1) construction and b) before (0) versus after (1) construction.

4. RESULTS

During road construction, male grizzly bears moved significantly further from new roads ($\beta = 0.39$, SE = 0.02) (Table A-2). The female and the mixed sex (All) model showed no changed in selection. For both group and individuals models, time of day appeared to have no affect on distance to road because the directionality of significant variables remained consistent. Females G012 and G027 had significant responses to road construction, but in opposite directions. Female G012 moved further from new roads ($\beta = 0.76$, SE = 0.19) while female G027 moved closer to new roads during construction ($\beta = -0.93$, SE = 0.26). The only male to show a significant change in response was male G033, which moved further from roads ($\beta = 0.39$, SE = 0.14). Overall, five of the eight grizzly bears examined had no change in selection during the year of road construction.

After road construction, no group model had a significant change in selection. When examining individual selection, G027 moved significantly closer to new roads in years after construction. Overall G027 appears to be a habituated grizzly bear, spending much of her time in close proximity to roads, so we would expect her to move closer to roads after development. The other significant individual G007 moved away from roads after construction. This apparent avoidance of new roads, however, was the result of a larger shift in home range use. G007 moved away from the areas with new road construction, but continued to use preexisting roads in other areas. This move could have been the result of disturbance or merely a seasonal shift in home range use due to other unknown factors. G008 showed no change in selection during the day, but moved significantly closer to roads at night, indicating that time of day may play a role in selection of some grizzly bears.

5. DISCUSSION

Most grizzly bears did not alter their selection of roads either during or after construction. Of the 8 individuals examined for the before/ during analysis, 5 were not significant, and of the 10 individuals examined for the before/ after analysis, 8 were not significant. During road construction, two bears (G012, G033) were significantly further from roads and one (G027) moved significantly closer. After construction, two female bears had a significant response to road development. Bear G027 was closer to roads after construction, but female G007 moved further from roads. Overall, one grizzly bear (G008) was found to move closer to roads at night, otherwise no change in time of day was detected.

These results lead to two possible conclusions. First, they could lend support to the hypothesis that most grizzly bears are not influence by road development; although this is highly unlikely given that other studies have demonstrated grizzly bears response to roads (McLellan and Shackleton, 1988; Gibeau et al., 2002; Mueller et al., 2004;

Waller and Servheen, 2005). More likely, these results indicate a lack of power in the data to detect a change in response.

The limitations of this study were many. First the temporal scale of the data may have been too large to detect a small-scale change in grizzly bear response. Over a 4 hr period (which was the scale of most relocations) grizzly bears can cover large distances and cross multiple roads. If a grizzly bear encountered a new road at time x, it is doubtful that behaviours were still altered 2 or 3 hrs later, unless the encounter was highly stressful. In addition, if a bear approached or crossed 2 or more roads in that same 4 hr period, it is difficult to determine which road caused the change in response. A more appropriate scale of measurement would be 15 minutes, where one could monitor the approach, crossing, and retreat and test for changes in step length or directionality of movements. This would also greatly reduce the likelihood of encountering several roads within one time step.

An additional problem that could result in decreased power is the pattern of road construction. Roads were generally built in segments of several kilometers (0.6- 8.0 km) within a given year, resulting in long roads being built over several years. This pattern of construction means that the treatment applied in any given year is relatively small. In addition the area already had a fairly high road density, so grizzly bears were already adapting their behaviour in response to surrounding roads. The ideal experiment would test grizzly bear response in a largely undisturbed environment, to avoid the confounded response with preexisting roads. In addition the experiment should be conducted completely after construction. Immediate response to new roads could vary from response to a well-established road, due to altered vegetation near roads and changes in traffic patterns as a road becomes more heavily used.

Traffic volume has been shown to be a predictor of grizzly bear road use in other areas (Archibald, 1987; McLellan and Shackleton, 1988; Chruszcz, 2003). In this study, new road construction did not consist of main arteries, but instead side roads with limited use by forest harvesting or oil & gas extraction. Grizzly bear response to these smaller roads could be minimal, given that traffic and road noise are limited. As a result, detecting a change in response would be difficult, especially given that the 4 hr fix rate of the GPS collars.

The final problem with all studies lacking power is sample size. For many other study species, sample size can be easily augmented by capturing or collaring more individuals, but when studying grizzly bears, it is extremely important to have the same individuals before and after applying the treatment. Grizzly bears are highly adaptable and highly individualized. If one does not have the same individual before and after the treatment the results are meaningless. An additional habituated bear sampled after the treatment could result in an apparent selection for roads. Unfortunately with finicky GPS technology and uncooperative bears that drop their collars, this can be exceedingly difficult especially over a long-range study. As a result, this type of study on grizzly bears becomes very difficult to accomplish.

With all of the difficulties presented by a long-range study of grizzly bears road use, the knowledge gained would be invaluable. Grizzly bears appear to be selecting roadside habitats in the foothills of Alberta and because of the high rates of mortality near roads, it is important that we understand the underlying mechanisms in order to direct conservation efforts. The only way to definitively unravel all of the correlated variables associated with roads is through a before/ after experimental design. Ultimately, grizzly bear conservation and persistence on the landscape depends upon decreasing grizzly bear mortality, and that will only occur by decreasing interactions between grizzly bears and people.

Table A-1. Number of telemetry locations that occurred within 2 km of a newly built roads (built after 1999) for each grizzly bear. Sex for each bear is given, with subadults indicated as (s). Bears with greater than 25 locations for two seasons were analyzed (labeled in bold).

Bear ID	Sex	1999	2000	2001	2002	2003	2004
G004	F	5	-	-	-	-	-
G005	M	28	-	-	-	-	-
G007	F	-	29	-	-	94	-
G008	M	44	-	-	30	-	-
G011	F	-	165	-	96	-	-
G012	F	17	114	248	164	188	-
G013	F	14	-	-	-	-	-
G014	M	-	119	41	-	-	-
G017	M	3	32	8	190	-	-
G020	F	69	40	106	53	-	-
G023	F	-	12	9	49	-	-
G024	M	-	148	84	-	-	-
G026	F	-	95	-	-	-	-
G027	F	-	315	-	128	-	-
G029	M	-	6	96	2	-	-
G033	M (s)	-	529	298	267	207	-
G036	F (s)	-	-	50	-	-	-
G037	F (s)	-	-	-	55	-	-
G038	F	-	-	8	-	-	-
G040	F (s)	-	-	3	53	1	-
G043	M	-	-	-	-	162	-
G045	M	-	-	-	-	7	-
G050	M (s)	-	-	-	31	-	-
G054	M (s)	-	-	-	43	-	-
G055	M	-	-	-	-	29	-
G057	F	-	-	-	-	4	-
G058	M (s)	-	-	-	-	140	-
G060	F	-	-	-	-	64	-
G061	F	-	-	-	-	177	-
G062	M	-	-	-	-	5	-
G100	F (s)	-	-	38	1	19	7
G106	F (s)	-	-	-	-	3	36

Table A-2. Beta coefficients and standard errors (parentheses) comparing distant from road before construction to distance *during* construction. Model 2 adds an interaction term for time of day. Bears not modelled had inadequate sample sizes. We examined both group (All, F, M) and individual (G007,...) models for significance ($p < 0.05$ indicated in bold).

	Model 1	Model 2	
Bears	Dist Rd	Dist*Day	Dist*Night
All	0.10 (0.24)	0.10 (0.23)	0.09 (0.22)
F	-0.13 (0.46)	-0.11 (0.48)	-0.14 (0.43)
M	**0.39 (0.02)**	**0.40 (0.03)**	**0.38 (0.02)**
G007	- -	- -	- -
G008	- -	- -	- -
G011	-0.23 (0.27)	-0.19 (0.30)	-0.29 (0.32)
G012	**0.76 (0.19)**	**0.81 (0.20)**	**0.68 (0.21)**
G014	0.13 (0.37)	-0.16 (0.47)	0.28 (0.39)
G017	0.50 (0.47)	0.75 (0.53)	0.13 (0.56)
G020	-0.16 (0.32)	-0.13 (0.32)	-0.21 (0.36)
G024	0.24 (0.26)	0.20 (0.27)	0.32 (0.30)
G027	**-0.93 (0.26)**	**-1.05 (0.30)**	**-0.85 (0.28)**
G033	**0.39 (0.14)**	**0.40 (0.15)**	**0.38 (0.14)**

Table A-3. Beta coefficients and standard errors (parentheses) from two logistic regression models comparing grizzly bear distance from new roads before and *after* road construction. Model 2 adds an interaction term for time of day. We examined both group (All, F, M) and individual (G007,...) models for significance (p <0.05 indicated in bold).

	Model 1	Model 2	
Bears	Dist Rd	Dist*Day	Dist*Night
All	-0.26 (0.21)	-0.24 (0.22)	-0.28 (0.20)
F	-0.38 (0.39)	-0.37 (0.40)	-0.40 (0.39)
M	-0.11 (0.10)	-0.08 (0.09)	-0.13 (0.11)
G007	**2.05 (0.60)**	**2.25 (0.72)**	**1.72 (0.77)**
G008	-0.88 (0.46)	-0.62 (0.50)	**-1.05 (0.49)**
G011	0.25 (0.25)	0.41 (0.28)	-0.01 (0.31)
G012	0.12 (0.16)	0.11 (0.17)	0.14 (0.18)
G014	0.69 (0.43)	0.79 (0.47)	0.61 (0.45)
G017	0.69 (0.42)	0.85 (0.49)	0.57 (0.46)
G020	0.15 (0.38)	-0.05 (0.41)	0.38 (0.40)
G024	0.24 (0.35)	0.23 (0.37)	0.26 (0.39)
G027	**-1.88 (0.26)**	**-1.92 (0.30)**	**-1.84 (0.29)**
G033	-0.17 (0.12)	-0.15 (0.13)	-0.18 (0.13)

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APPENDIX B

MODELLING HUMAN USE OF ROADS TO CREATE AN INDEX OF TRAFFIC VOLUME

Developed in conjunction with: Jacqueline Frair, Hawthorne Beyer, and Evelyn Merrill; University of Alberta, Edmonton, Alberta

1. PURPOSE

In the foothills of Alberta, roads are used by a variety of industrial and recreational users. Roads are typically constructed for resource extraction, such as timber harvesting or oil & gas extraction, but later are open for use by other groups. As a result, both the type of traffic and traffic volume varies both spatially and temporally. Qualifying these traffic patterns is critical to understanding grizzly bear use and/or avoidance of roads. Unfortunately, traffic data is not available for most roads within the study area; therefore, we developed a method to model human use based on first principles (e.g. roads close to town centers have more traffic than roads far from town centers) to classify roads into low and high traffic volume.

2. METHODS

Vector road layers were obtained from the Foothills Model Forest in cooperation with West Fraser Inc. The layer contained all known roads in the study area as of 2003. Starting in 1999, dates of construction were verified for all roads in the study area using Landsat TM imagery (30 m resolution) taken in September of every year (1999-2003). Roads were dated with the year that they first appeared on the Landsat image, and those in existence before 1999 were classified as "pre 1999." Roads that were not visible due to image resolution were dated using surrounding anthropogenic features, such as new cut blocks or well sites. Yearly road maps were then created. Landsat images were also used to verify the timing and location of timber harvesting between 1999-2003 and to identify the location of new well sites.

In order to estimate the least-cost paths for travel throughout the area, we created an estimate of travel speed for each road segment. Because roads were too numerous to individually identify vehicular travel speed, we used road surface type as a relative index: 110, 90, 80, 65, 50 km/hr for divided highway, paved road, primary gravel road, secondary gravel road, and dirt (non-maintained) roads, respectively. Road surface type was obtained from the original road classification.

We estimated forestry traffic by linking active harvest sites in a given year to the mill servicing that region (Hinton or Edson). The year of harvest was obtained from forestry records and Landsat images (FMF; Hinton, Alberta). Because Landsat imagines were acquired on a yearly basis, we assumed that industrial traffic occurred throughout the Jan- Dec period. Each forestry harvest unit (cutblock) was represented as a point placed within the harvest polygon. Network analysis (Environmental Systems Research Institute, Redlands California) was used to identify least-cost paths from the cutblock to the respective mill site. A value of 1 was assigned to each road segment for each cutblock point accessed by that segment, resulting in road segments with values ranging from 0-174. Separate analyses were conducted for the Hinton and Edson mill sites and were then merged to create one index for that given year. These values were then subjectively assigned to classes of traffic intensity: 0 = no traffic, 1-5 = low-moderate traffic, >5 = high traffic (Fig. B-1). Discrepancies in known traffic routes were corrected by hand.

Road use by the oil & gas industry was modelled the same as for the forest industry, except, due to the large number of different companies operating throughout the area, the nearest population center was used as the destination site. Active well sites were also represented as points, and each was assigned to Hinton or Edson based on spatial location. As above, we assumed a least-cost path from the well site to the nearest population center and assigned a value of 1 to each road segment for each well site access by it (values ranged from 0-665). Road segments were subjectively assigned to traffic volume classes as follows: 0 = no traffic, 1-10 = low-moderate traffic, and >10 = high traffic (Fig. B-2).

Recreational use of roads was modelled as a function of human behavior and distribution across the landscape (Apps et al., 2004). Creating separate models for each town (Hinton, Edson, Robb, and Cadomin), we calculated how long it would take to travel from the town center to any point along the road network. Merrill et al. (1999) found that human use of roads decays exponentially as travel time increased, so we applied a decay exponent of –1.45 to our travel times. The values were scaled from 0 to 1, with 1 representing highest use at the town center. These values where then multiplied by the population size of the given town (Hinton = 9405, Edson = 7815, Robb = 183, Cadomin = 64) to estimate the relative road use. Values were then summed across the four population centers. Overall, large town centers tended to overestimate use along secondary roads, particularly when nearing town centers. While we expect this to be the case in the towns themselves, we suspected that this effect would drop off rapidly outside of towns. As a result, we applied a correction factor that retained overall trends but suppressed values on secondary roads. Specifically, values were multiplied by 1, 0.75, 0.50, and 0.25 for paved, primary gravel, secondary gravel, and dirt roads, respectively. A quantile algorithm was used to separate road segments into low, moderate, and high use categories (Fig. B-3).

In addition to overall recreational use, campsites were located and modelled the same as well sites using the closest population center as the destination. Because of the configuration of the study area, we assumed campers originated from Hwy 16, which makes up the northern border of the study area and services both Hinton and Edson. Using the Network analyst we created least-cost paths from each campsite to the population centers, assigning 1 to every road segment for each campsite accessed by it (ranging from 0-34). Values were summed across the two population centers to create an index of camper travel. These values were subjectively assigned to traffic volume classes as follows: 0 = no traffic, 1-5 = low- moderate, >5 = high (Fig. B-4).

Lastly, we merged all user-group classifications (forestry, oil & gas, recreation, and campsites) into a single road use index representing low and high traffic volume. If any of the four use levels were high, the final model was classified as "high volume." Roads were only classified as "low volume" if forestry was none, oil & gas was none or low/moderate, recreation was low, and there was no traffic from campsites (Fig. B-5). All other combinations of moderate volume were classified as "high volume." Separate indices were created for each year to reflect the changing use by the industrial sector and to account for new road development. Thus, the final product accounted for road use by all major sectors of the population. Ultimately, we believe this method is a more accurate means to model changing road use patterns over a large area and is superior to traditional classifications based on road size or surface type.

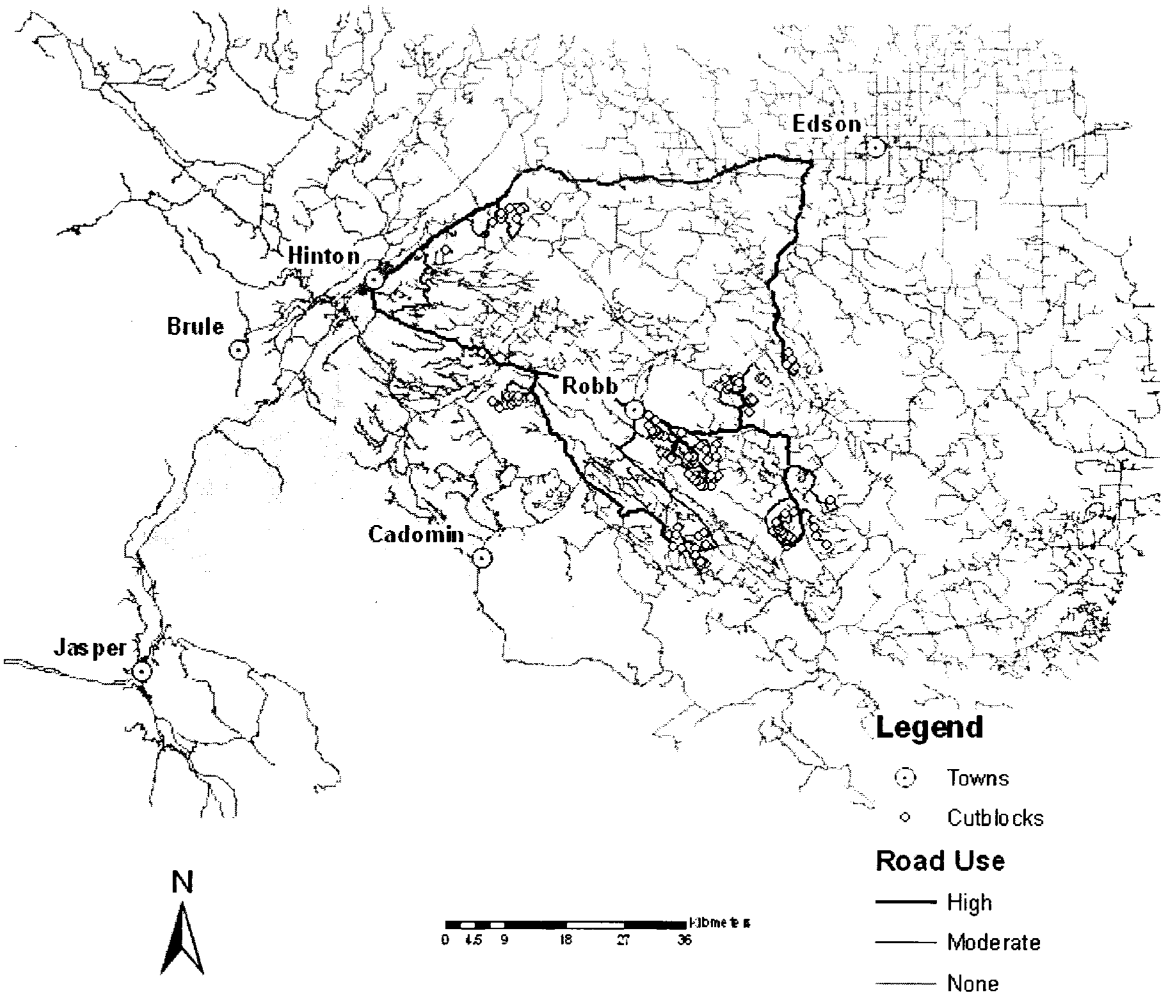

Figure B-1. Modelled road usage by forestry industries in 2002 based on least-cost paths from active cutblocks to the processing plants in the towns of Hinton and Edson.

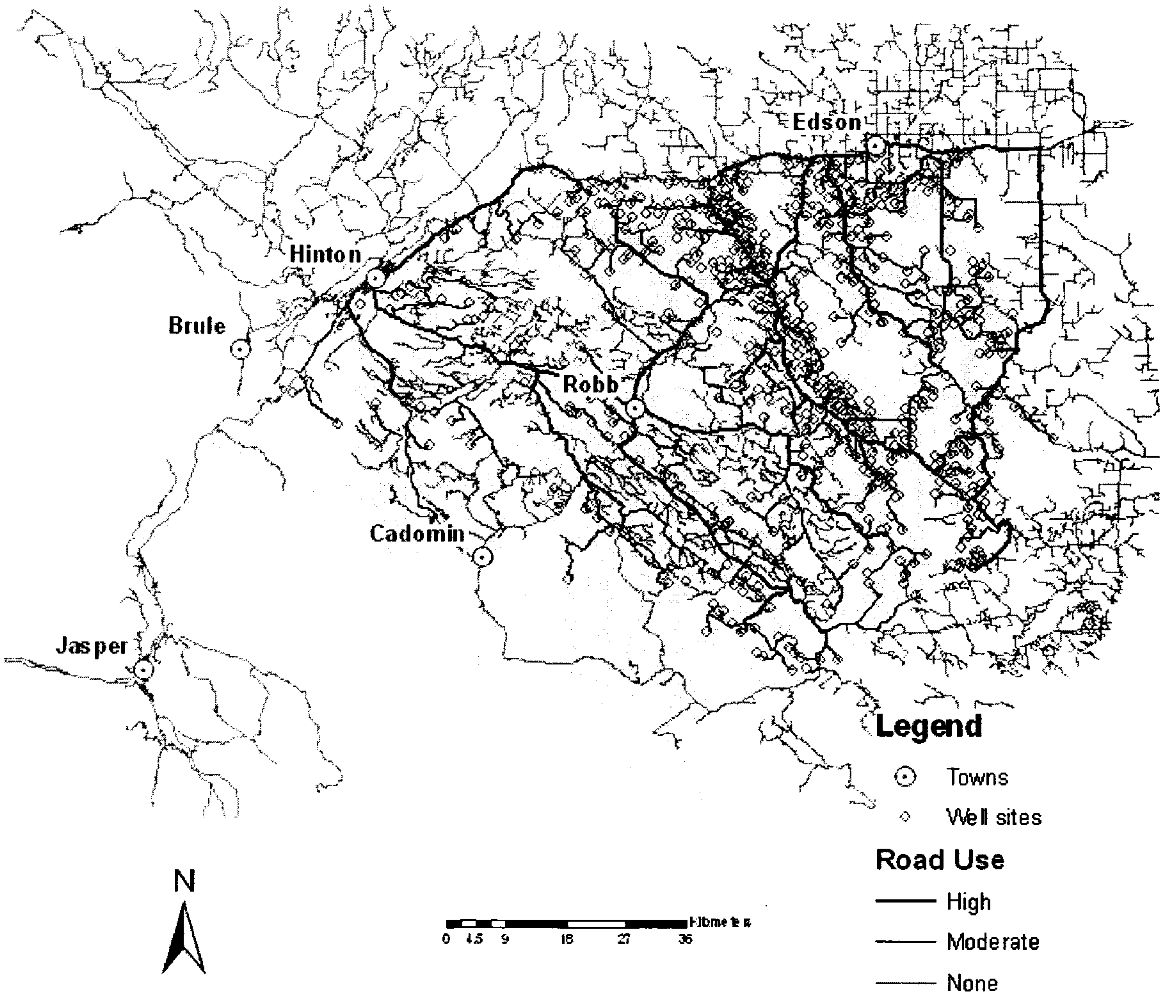

Figure B-2. Modelled road usage by the oil & gas industries in 2002 based on least-cost paths from active well sites to the nearest population center (Hinton or Edson).

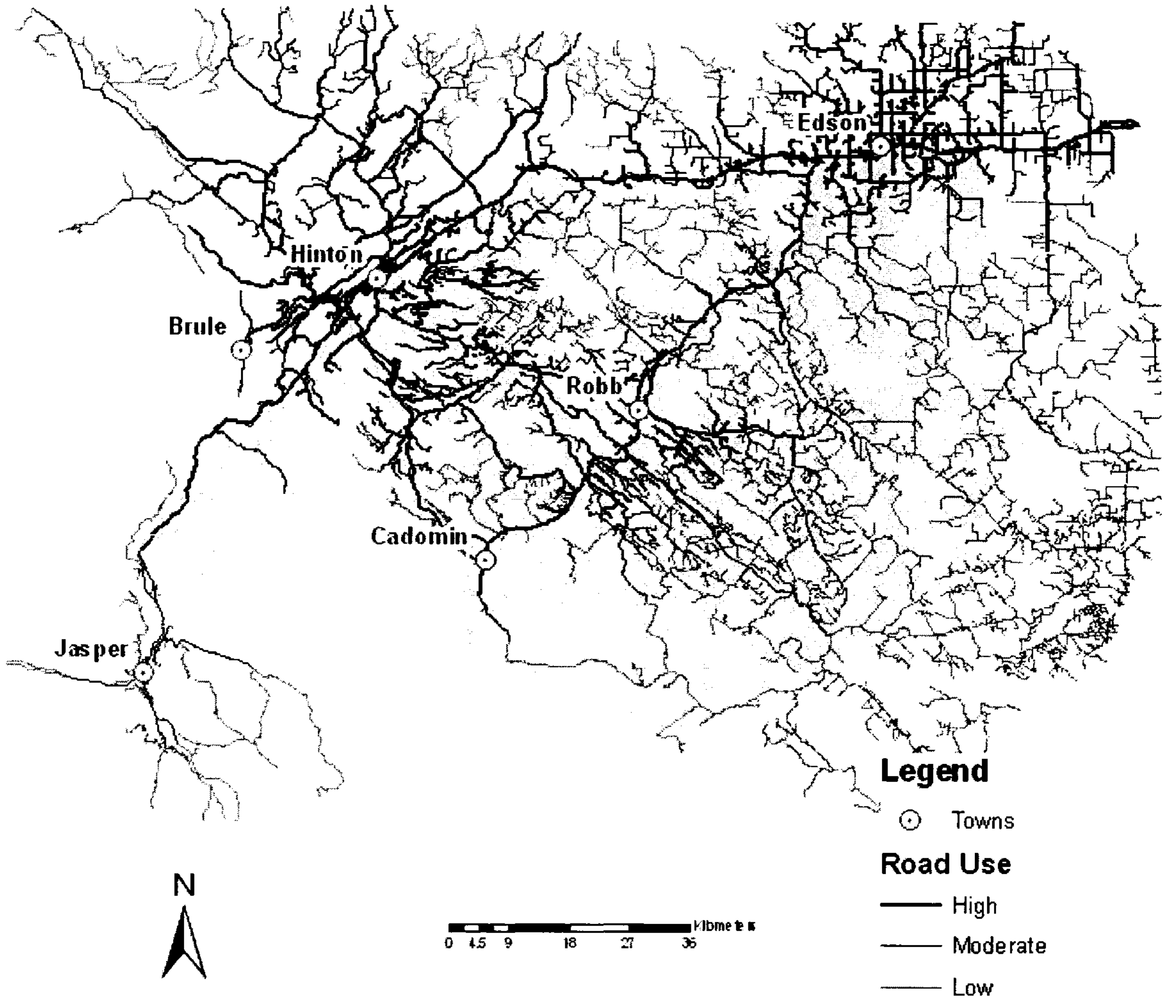

Figure B-3. Modelled road usage by recreational users based human demography and behavior. The travel time was calculated for all points along the road network to each population center within the study area (grayed area). A decay exponent of –1.45 was then applied to all travel times. Traffic was scaled based on the population of each town.

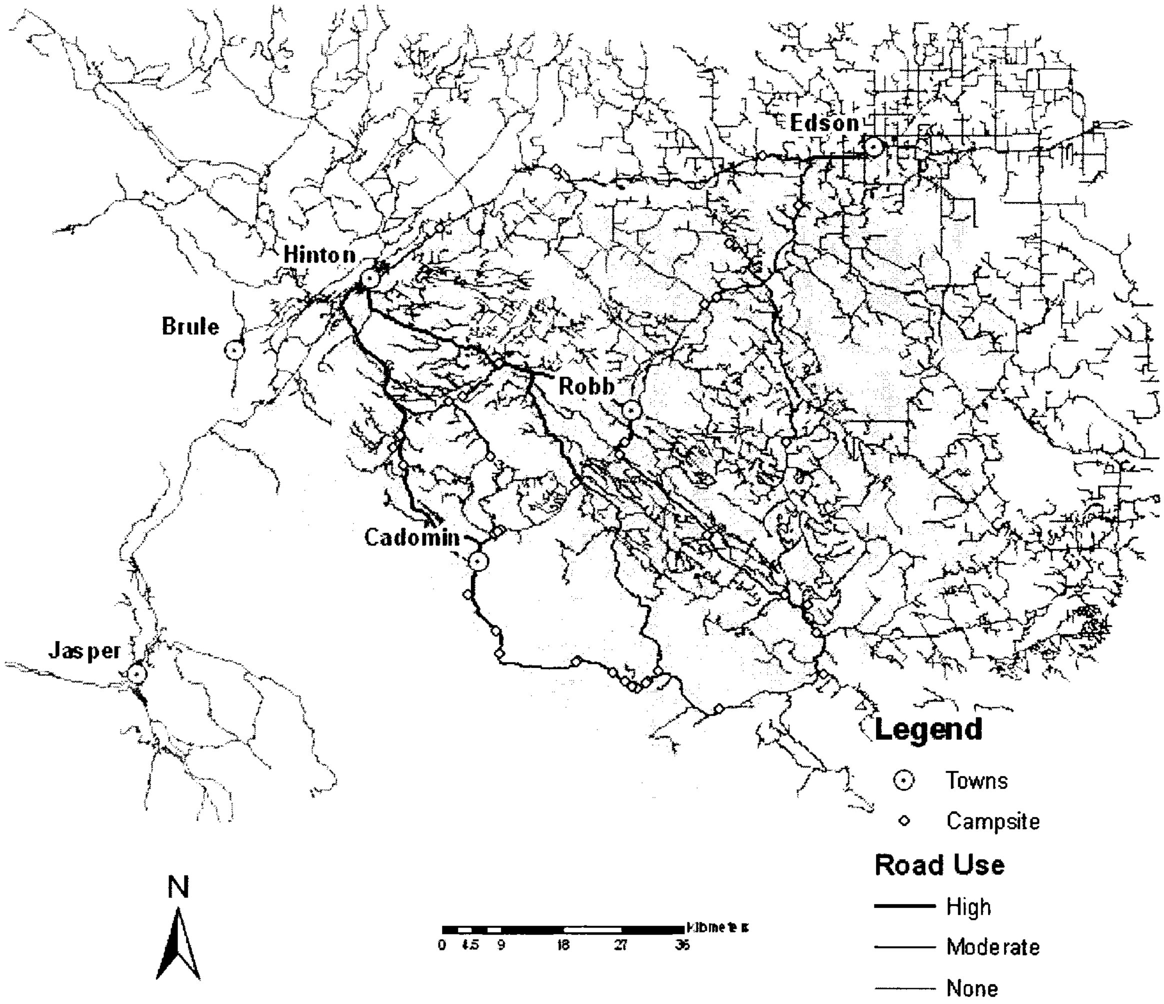

Figure B-4. Modelled road usage by campers based on least-cost paths from campsites to the nearest population center.

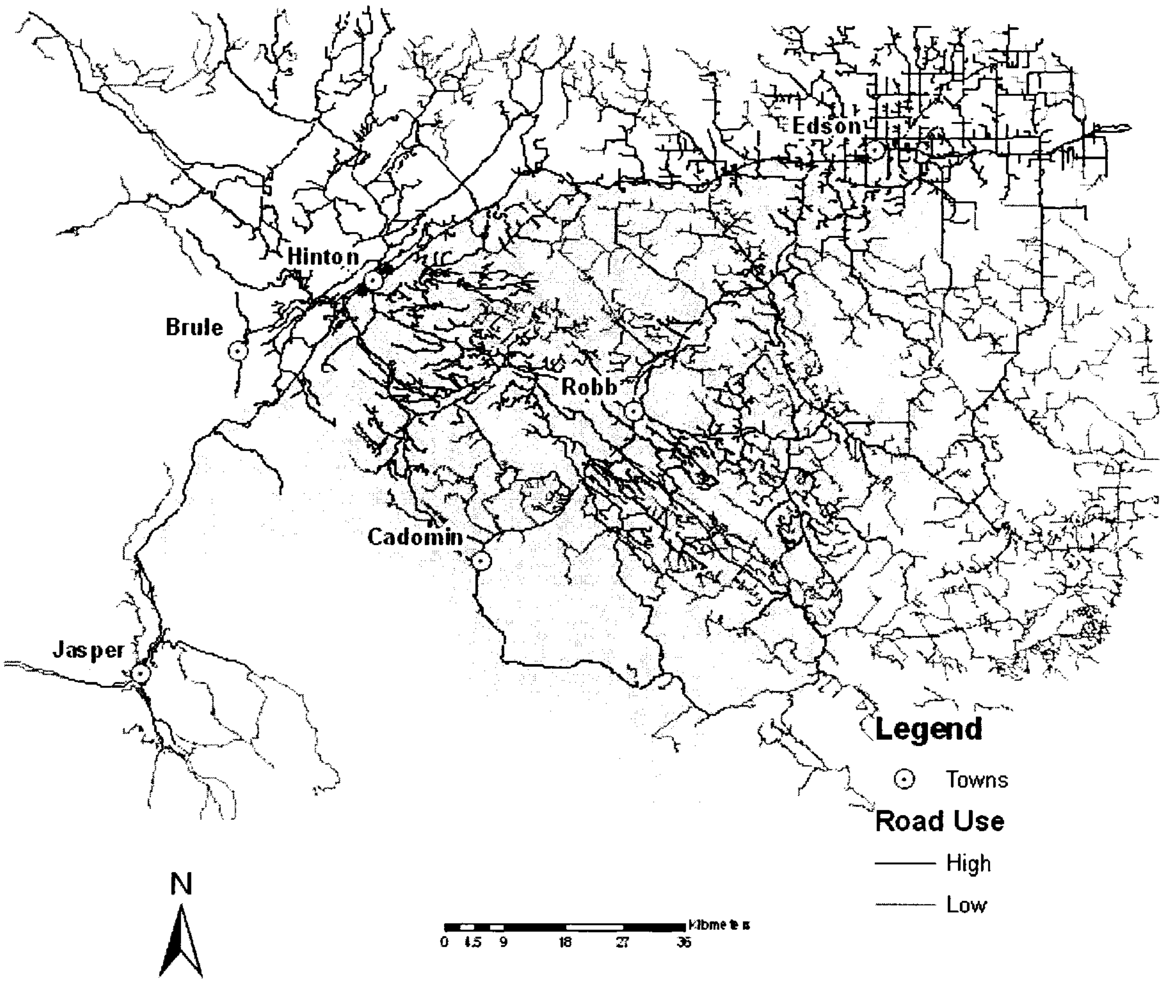

Figure B-5. The final road usage model created by combining modelled human use by forestry, oil & gas, recreational users, and campers.

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