UNIVERSITY OF CALGARY

A Conservation Biology Approach to Management of Grizzly Bears in Banff National Park, Alberta.

by

Michael L. Gibeau

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

DEGREE OF DOCTOR OF PHILOSOPHY

RESOURCES AND THE ENVIRONMENT PROGRAM

CALGARY, ALBERTA

APRIL 2000

0-612-49496-9

ABSTRACT

I examined movement patterns of adult female grizzly bears (*Ursus arctos*) in the Bow River Watershed, Alberta. Intensive movement data showed that habituated adult female bears did not take advantage of higher quality habitats in the same manner as wary bears. The combination of habituated bears using lower quality habitats and demonstrating higher movement rates suggests less energy available for growth and reproduction. Bears within an area of restricted human access used higher quality habitat and traveled less than bears in unregulated areas. I document the permeability of several highways in a landscape where human presence is widespread. One highway with 24 hour, year-round high traffic volumes served as a total barrier for adult female movement and a filtered barrier for males. Traffic volume appeared to be a key variable in highway permeability. Significant potential currently exists for permanent habitat and population fragmentation to occur along the Trans Canada Highway. I document the degree and magnitude of grizzly bear responses as a function of multiple interacting variables based on observed distances to roads, trails and development features. Bears were found closer to trails during the human inactive period when within high quality habitat and further from trails when distant from high quality habitat. Female bears remained further than males from paved roads regardless of the habitat quality or time of day. My data indicated an inverse relationship between the sexes in response to vehicles and traffic noise compared to the response to human settlement and encountering people. I developed a predictive GIS-based model of adult female grizzly bear security areas in the Central Canadian Rocky Mountains. Forty eight percent of the land surface area of the

Banff, Yoho, and Kootenay National Parks were unsuitable for grizzly bears, primarily because of rock and ice. This is unfortunate because it is assumed that these national parks form productive core refugia for grizzly bears. Management of access and development are key to grizzly bear persistence in the region. An adaptive management approach, bringing in new knowledge of grizzly bear response to human activity, will be crucial, to support population connectivity and habitat security.

ACKNOWLEDGMENTS

A very successful research project would not have been possible without the dedication of field biologists B. Benn, M. Jalkotzy, C. Mamo, C. Morgan, C. Mueller, J. Paczkowski, H. Robinson, J. Saher, S. Stevens, S. Stotyn, J. Theberge, M. Urquhart, and J. Wittingham. Their efforts were augmented through the volunteer support of K. Barkman, C. Campbell, P. Hoffer, L. Homstol, and M. Lacroix. Assistance in coordination of field staff was provided by A. Dibb, S. Donelon, T. Hurd and C. White. Trapping was conducted by R. Leblanc, C. Mamo, R. Riddell, and I. Ross. Veterinary care was provided by Dr. T. Shury. Several Alberta Fish and Wildlife Officers, Banff National Park Wardens and Peter Lougheed Park Rangers all provided invaluable safety backup and field assistance during trapping. The Banff Park Warden Service and Kananaskis Country Park Rangers provided logistical support through all stages of monitoring. Exemplary flying skills were provided by Alpine Helicopters of Canmore and fixed wing pilot M. Dupuis of Wildlife Observation Air Services. S. Jevons, J. Slemko, and J. Wierzchowski provided GIS and computer technical support. C. Kelly provided much needed editing.

The Eastern Slopes Grizzly Bear Steering Committee helped implement and guided this research. All steering committee participants contribute either money, time or both toward the objectives. Through the Steering Committee, governments, industry, business and conservation groups work together to support this and other research components (www.canadianrockies.net/grizzly). Finally, I thank my supervisory committee for the support, encouragement and critical review of this project.

DEDICATION

This work is dedicated to Emilie and Patrick, for it is their generation that will either reap the benefits of our labor or endure the consequences of our failures.

This work would not have been possible if not for Cindy's patience, perseverance and steadfast love.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

BACKGROUND AND CONTEXT FOR THE RESEARCH

A variety of development pressures in the Central Canadian Rocky Mountains are currently accelerating habitat fragmentation, displacement and mortality of large carnivores including grizzly bears. The result is loss of connectivity as well as potential loss of viability for large carnivore metapopulations. As demands on the land increase, the cumulative effects from individually minor, yet collectively significant, uses occurring over space and time continue to mount.

Many scientists now recognize that human activity is so prevalent today that ignoring it is now not only almost impossible, but would result in excluding from consideration one of the dominant components in modern biological communities (Primack 1992). Given the existing and proposed human development in the Central Rockies area, multiple human-related impacts have been demonstrated to be a major issue especially for large carnivores (Noss et al. 1996, Mattson et al. 1996, Gibeau 1998). Thus, the process and factors which could lead to extirpation have begun (Shaffer 1981, Gilpin and Soule 1986).

Recent advances in our understanding of conservation biology, metapopulation dynamics and landscape ecology have focused our concern on the long term viability of large carnivores. As the landscape becomes ever increasingly human dominated, we incrementally impinge on a population's ability to acquire needed resources. The challenge ahead lies in trying to understand the process and not just understanding the population (J. Weaver pers. comm.)

One of the primary concerns with high levels of human presence is loss of habitat effectiveness which could have an influence on carrying capacity, hence recruitment and survivorship. This may have a more subtle but at least as profound an impact on animal populations as direct mortalities. Comparing spatial and temporal preference for, or avoidance of, different distributions of human activities may also give insights into levels of habitat alienation. In addition, one of the key factors in metapopulation persistence is dispersal (Hansson 1991). Chance of extirpation from a number of stochastic forces increases with loss of connectivity and associated fragmentation (see Hanski and Gilpin 1991 for overview). The effects of fragmentation have emerged as one of the important topics of the science of landscape ecology (Forman and Godron 1986).

In this study, I address the issues of habitat alienation and landscape fragmentation, through a detailed research program focusing on grizzly bears. This species requires immediate attention because of its lack of resilience in the face of change (Weaver et al. 1996). My focus on grizzly bears is viewed as one component nested within a much larger research agenda. That agenda seeks to apply a large carnivore conservation strategy to the Rocky Mountain Park Complex as outlined by World Wildlife Fund (Dueck 1990, Paquet and Hackman1995). Ultimately, if managers can identify principles concerning responses to certain human activities, they will be better able to predict and thus avoid impacts (Gutzwiller 1991).

Several different factors contributed to a growing concern for grizzly bears in Alberta. In 1990 the province of Alberta released its grizzly bear management plan (Nagy and Gunson 1990). This document clearly showed not only historic declines of grizzly bears in the province, but over hunting, especially during 1980-1988. In 1992 the Federal government enacted the Canadian Environmental Assessment Act which broadened the scope of traditional environmental assessment to consider the cumulative effects of developments at a landscape scale. The following year (1993) the Alberta Environmental Protection and Enhancement Act passed. It also included a provision for assessing the cumulative impacts of development proposals. Research based in Yoho and Kootenay national parks showed that individual grizzly bears may enter four different management jurisdictions in a year (Raine and Riddell 1991). Herrero (1994) suggested that grizzly bear populations in Canadian national parks by themselves were probably all too small for a high probability of long term persistence, and therefore integrated management with surrounding provincial or territorial lands would be required. These and other factors all demonstrated that grizzly bears would become a focal species for cumulative effects assessment (Herrero et al. 1998).

Because of the species' biological characteristics, grizzly bears recover slowly if at all from population declines, and only if mortality factors have been brought under control (Mattson et al. 1996). These biological characteristics are part of the reason why human activities can have such a significant impact on grizzly bears. Whether land is managed as parks, commercial forests or privately, management practices must respond to the grizzlies' needs if these bears are to survive. There is an urgent need for scientific data on grizzly bears to help land managers better understand the affects of human activities on this species. Previous research has focused on the effects of roads and road density on grizzly populations (IGBC 1998 and references therein). Until now, little research has been devoted to the effects of non-motorized, tourism-oriented activities on grizzly bears.

The overall goal of my research was to understand how access to resources and encounters with humans, influence grizzly bears. Specific research objectives included:

1. To detect spatial and temporal activity patterns of bears given various levels of human influences.
2. Determine how the distribution of human influences affects a bear's ability to use the landscape.
3. Determine if sufficient habitat connectivity exists to allow bears access to resources.
4. Determine what, if any adjustments to human activities would give bears better access to resources.
5. Suggest management alternatives for integrating land uses compatible with bear habitat needs for the study area.

The Bow River Watershed within the Central Rockies Ecosystem was chosen as the primary study area (Figure 1). This is 11,400 km^2 of mountainous terrain 50-180 km west of Calgary, in southwestern Alberta. The area includes a portion of Banff National Park (BNP) and adjacent Alberta Provincial lands known as Kananaskis Country. Neither jurisdiction allows grizzly bear hunting although bears are exposed to some hunting outside the Bow River Watershed. Differing agency mandates oversee preservation, industrial tourism, recreation, forestry, oil and gas extraction, mining and stock grazing. Native councils, towns and municipalities, commercial developers and

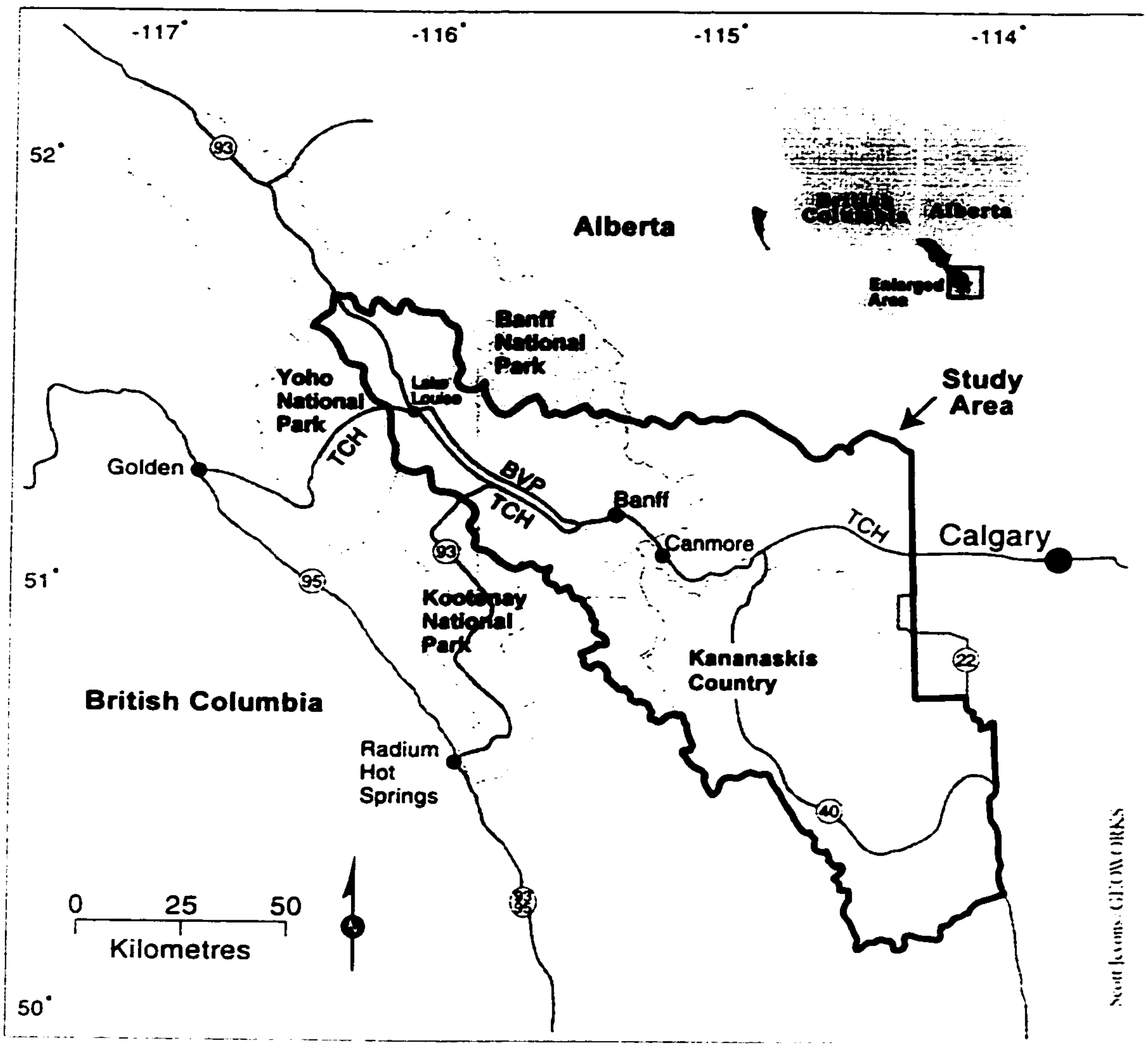

Figure 1. The study area, highlighting the Bow River Watershed within the Central Rockies Ecosystem.

residential owners diversify land administration even further. The combination of a highly developed transportation system and elaborate infrastructure makes this one of the most human dominated landscapes in the world where a population of grizzly bears still survives.

Between 1994-1998 I used radio telemetry to gather information on individual grizzly bears during the non-denning season. Radio-collared individuals provided information on movements, home range, habitat use and reactions to human activity. These bears were monitored from the air and ground wherever they went and my budget permitted. Aerial monitoring gave infrequent, but relatively unbiased location data. This facilitated understanding of home range, movements and habitat use. Ground-based telemetry allowed intensive monitoring of grizzly bear activities related to developments such as towns, highways, campgrounds and trails. A detailed description of capture and monitoring methods are documented in Gibeau and Herrero (1995), Stevens et al. (1999) and at www.canadianrockies.net/grizzly. While this research did not concentrate on population ecology parameters, I also gathered basic demographic information following Eberhardt et al. (1994) and Hovey and McLellan (1994) to enhance and strengthen overall study findings.

CHAPTER ONE: MOVEMENT PATTERNS OF FEMALE GRIZZLY BEARS IN A LANDSCAPE WITH EXTENSIVE TOURISM

ABSTRACT

I examined movement patterns of adult female grizzly bears (*Ursus arctos*) in the Bow River Watershed where the combination of a highly developed transportation system and elaborate infrastructure makes it one of the most intensively developed landscapes in the world where a grizzly bear population still survives. I used 385 daily movement distances from 17 adult female bears for this analysis. I found no difference in adult female movement rate between the traditional day versus night, but substantial difference when dividing the data by when humans were most active. This supports the contention that differences in use patterns are attributable to human activity. Consistent differences in movement rates between wary and habituated adult females, although not statistically significant, further suggested the influence of humans. My intensive movement data showed that habituated adult female bears were not able to take advantage of higher quality habitats in the same manner that wary bears were. The combination of habituated bears using lower quality habitats and demonstrating higher movement rates suggests less energy available for growth and reproduction. Bears within an area of restricted human access used higher quality habitat and traveled less than bears in unregulated areas. Providing security allows bears access to the highest quality habitats, without competition from humans, thus maximizing the reproductive potential of the population. Identification of security areas and limiting human access to

these areas should receive the highest priority for habitat conservation of grizzly bears in the Bow River Watershed and the Central Canadian Rocky Mountains.

INTRODUCTION

It is important to understand whether human activity affects spatial and temporal activity patterns of bears, because displacement into sub-optimal habitats or reduced feeding efficiency can affect the net energy available for growth and reproduction (MacHutchon et al. 1998). Research focused on breeding age female grizzly bears. This segment of the population is most critical to population viability (Knight and Eberhardt 1985, Harris 1986) but is also one of the segments most vulnerable to displacement and/or habituation to people (Mattson et al. 1987, Mattson 1990). Human-caused displacement of bears from important foraging areas can result in reduction of habitat effectiveness and carrying capacity (Gibeau 1998). Habituation, the progressive waning of a response to a neutral stimulus (Thorpe 1956), allows some bears to take advantage of near-human environments, however, it may increase the chances of a bear being removed from the population because of human safety concerns (Meagher and Fowler 1989). Habituation in a national park setting can also be dangerous for people, and has been associated with some bear-caused human fatalities (Herrero 1985).

On Alaskan salmon streams, Olson (1993) and Olson et al. (1997) determined that the degree of tolerance of people better predicted the spatial and seasonal patterns of individual bear use than did the more traditional categories of age, sex, and maternal status. Their work demonstrated that non-habituated adult grizzly bears reduced activity at an Alaskan salmon stream in response to an extended lodge season. In contrast, habituated adult bear activity remained similar among years. Understanding female grizzly bear movement patterns is important for managing human activities to minimize their impacts on bears.

I documented daily movement distances of adult female grizzly bears as part of a larger research project investigating the effects of human development on grizzlies. I test whether differences in daily movement are correlated with the level of human access, habituation or habitat quality.

STUDY AREA

The primary study area encompassed the Bow River Watershed from its headwaters to approximately where it meets the prairies. This is 11,400 km^2 of mountainous terrain 50-180 km west of Calgary, in southwestern Alberta. This area includes a portion of Banff National Park (BNP) and adjacent Alberta Provincial lands known as Kananaskis Country. Neither jurisdiction allows grizzly bear hunting although bears are exposed to some hunting outside the Bow River Watershed. Differing agency mandates oversee preservation, industrial tourism, recreation, forestry, oil and gas extraction, mining and stock grazing. Native councils, towns and municipalities, commercial developers and residential owners diversify land administration even further.

People access the region using primarily the Trans Canada Highway, a major transcontinental transportation route, that bisects the study area east to west. Several high speed, two lane paved roads serve as arterial transportation routes. Numerous two lane paved secondary roads complete the transportation system through most of the low elevation valleys. I know of no other area within occupied grizzly bear habitat in North

America that has such an extensive network of high speed, high volume highways.

Human presence is widespread both within and outside of BNP. Three towns, Banff, Lake Louise and Canmore are world-renowned tourist destinations that attract approximately four million visitors annually. Developments, in addition to the towns that support tourism and industry, include a transcontinental railway, numerous hotels, campgrounds and picnic areas, 5 golf courses, 5 downhill ski facilities and an extensive network of hiking, biking and equestrian trails. The combination of a well-developed transportation system and elaborate infrastructure make the Bow River Watershed one of the most intensively developed landscapes in the world where grizzly bears still survive.

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

METHODS

Between 1994 and 1998 I captured and radio-marked grizzly bears in the Bow River Watershed, Alberta (Stevens et al. 1999) and monitored their movements. Individuals were equipped with either a conventional VHF radio collar (Lotek Engineering, Newmarket, Ontario) or a VHF ear tag transmitter (Advanced Telemetry Systems, Isanti, Minnesota). All radio collars were fitted with a breakaway cotton spacer (Hellgren et al. 1988) to ensure that collars would not be worn permanently.

I searched for collared bears at least once per week from the air, weather permitting, using a portable receiver, a right-left switchbox and paired 3-element yagi antennae attached to a Bell Jet Ranger III helicopter; or paired 2-element H antennae attached to a STOL equipped Cessna 337 Skymaster. Aerial tracking followed the techniques of Mech (1983). Aerial fixes were established from an aircraft mounted GPS unit and later transformed to UTM coordinates (North American Datum 1927) using the Geocalc Program (Blue Marble Graphics 1993). I also located bears from the ground opportunistically on a daily basis using a portable receiver, roof mounted omni-directional antenna and 3-element hand-held yagi antenna. Workers used either the loudest signal method or nulls (Springer 1979) to determine bearings from two or more positions (Nams and Boutin 1991). Bearings were plotted on 1:50,000 scale topographic maps with bear locations recorded to the nearest 100 m using the Universal Transverse Mercator (UTM) grid coordinate system. In addition to systematic radio tracking, I conducted periodic 24-hour monitoring of individual animals at hourly intervals to obtain daily movement patterns. Through testing with radio collars placed in known locations I recorded an average telemetry error of 150 m. Radio locations were supplemented by occasional direct observation or reports from the public.

I used both air and ground radio telemetry data from individual adult females to establish daily movement distance. Telemetry data were imported into a geographic information system (GIS) using MapInfo Professional® software (MapInfo Corporation, Troy, New York, USA) for analysis. I calculated daily movement distance (midnight to midnight) for individual female bears by measuring the largest linear distance of >2 radio locations per day. This measurement does not reflect total distance traveled over the course of a day which may be much greater. I also subdivided the data set and measured distance traveled based upon: 1) equal periods where the majority of time was during daylight conditions, hereafter called day (08:00-20:00) versus where the majority of time was during darkness, hereafter called night (20:00-0:800); and 2) differences in hours of peak human activity both on the highways and trail system (Parks Canada unpublished data) being human active (08:00-17:00) versus human inactive (17:00-0:800) periods. Based on field experience (M. Gibeau and C. Mamo pers. observation) I then assigned a level of habituation to each female bear. I used a two-tier (wary and habituated) classification scheme based on definitions by Herrero (1985:51). There were no food-conditioned bears in our sample.

Following Mattson et al. (1992) "bears that were known to exhibit considerable tolerance of humans were considered to be habituated. These bears remained in an area despite close approach of humans, or operated in areas near humans without apparent caution. The tendency of a bear to range near roads or developments by itself was not a basis for concluding that the animal was habituated". Several bears maintained ranges near humans but did not exhibit the close-range tolerance of humans that is considered to be characteristic of human habituation.

A more refined analysis of individual daily movement used a subset of data with >10 radio locations per day. Using program CALHOME (Kie et al. 1996), I calculated total distance moved and minimum convex polygons (MCP) to spatially define each daily movement event. I then used GIS (MapInfo® Corporation, Troy, New York, and Idrisi®, Clark Univ., Worcester, MA) to summarize each of the MCP in terms of their landscape characteristics: 1) habitat quality, 2) compactness ratio, 3) road density, and 4) total access density.

Landscape Characteristics

In the absence of a habitat suitability map for the study area I derived surrogate habitat values using Landsat Thematic Mapper satellite images transformed into a greenness band using the tasseled cap transformation (Crist and Cicone 1984, Manley et al 1992). Mace et al. (1999) found a strong selection by grizzly bears for areas of high greenness. I categorized the image into 12 classes of increasing greenness as an indicator of grizzly bear habitat. Use and expected values for each greenness class calculated from my aerial telemetry data set indicated that the 4 highest classes were used more than expected based on availability ($P = 0.0002$). These 4 classes were combined into a single map layer to represent preferred or high habitat quality. Several different metrics of habitat quality were used in preliminary tests including raw greenness score, variability in habitat quality, and distance to high quality habitat. I found the most predictive variable to be the percent of high quality habitat within a 1.5 km radius of a radio location (an area that roughly corresponded to an average female daily movement distance in my study area).

Compactness ratio (Eastman 1997) is a measure of the shape of a polygon compared to the most compact shape of the same size, a circle. Compactness ratio (Cr) was determined using the following formula:

$$Cr = SQRT(Ap/Ac)$$

where SQRT is the square root function, Ap = the area of the polygon being calculated, and Ac = the area of a circle having the same perimeter as that of the polygon being calculated. The smaller the Cr the closer the shape of the polygon to a perfect circle.

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

Analysis

I used summary statistics (SPSS 1998) as the basis for distance comparisons. A Mann-Whitney U statistic was used to test for differences between wary and habituated bears as an initial screening procedure. An unbalanced, multivariate analysis of variance (MANOVA) was used to test for differences in movement distance among habituation class, daily, day versus night, and human active versus human inactive movement distances.

For the more refined analysis of daily MCP events, I initially divided the data set by the level of human activity. I used the Spray River valley (250 km^2) as a control area where human use has been restricted to less than 30 parties per month since 1992. This control area was used to compare restricted human access to all other areas with unregulated access. Less high quality habitat was available in the restricted area than in unregulated areas ($P < 0.001$). I treated the level of habituation and the restricted area as factors and tested their relationship with landscape characteristics and average distances traveled by the bears using an unbalanced, multi variate analysis of variance

(MANOVA). Significance was accepted at $P < 0.05$. The assumption of equal variances was met for the telemetry data set.

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

RESULTS

I collected 385 daily movement distances from 17 adult female grizzly bears during the study. Slightly more than 60 % ($n = 237$) of the daily movement distances recorded were from wary females ($n = 12$) while the remainder ($n = 148$) were from females classified as habituated ($n = 5$).

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

No significant difference was detected in daily distance traveled ($P = 0.191$, power 0.275) between wary and habituated bears ($\bar{x} = 3.2$ km, SE = 0.12 km). I chose to continue with the distinction between wary and habituated bears given that the statistical power indicated a high probability of committing a Type II error and separation may provide biologically meaningful insights (Cherry 1998, Johnson 1999). Evidence is strong from other research that there are differences between wary and habituated bears (Jope 1985, Herrero 1985, Mattson et al. 1992).

I also found no significant difference in distance traveled ($F_{3,252} = 1.18$, $P = 0.279$, power = 0.191) between day (08:00-20:00) and night (20:00-08:00). There were however, significant differences in distance traveled ($F_{3,207} = 9.247$, $P = 0.003$) when the data set was divided between the human active period (08:00-17:00) and the human inactive period (17:00-08:00). Bears moved less during the human active period (1.3 km) than during the human inactive period (1.9 km). Differences were also detected in distance traveled between wary and habituated bears (Fig 1), although they were not statistically significant.

I identified 42 daily events with sufficient sample sizes ($\bar{x} = 16$ radio telemetry locations in 24 hours) from 10 different adult female bears to construct MCP's. Wary bears ($n = 7$) contributed 24 daily events whereas habituated bears ($n = 3$) contributed 18 events. Ten events from 2 bears (both classified as wary) were within the control area where human activity is restricted.

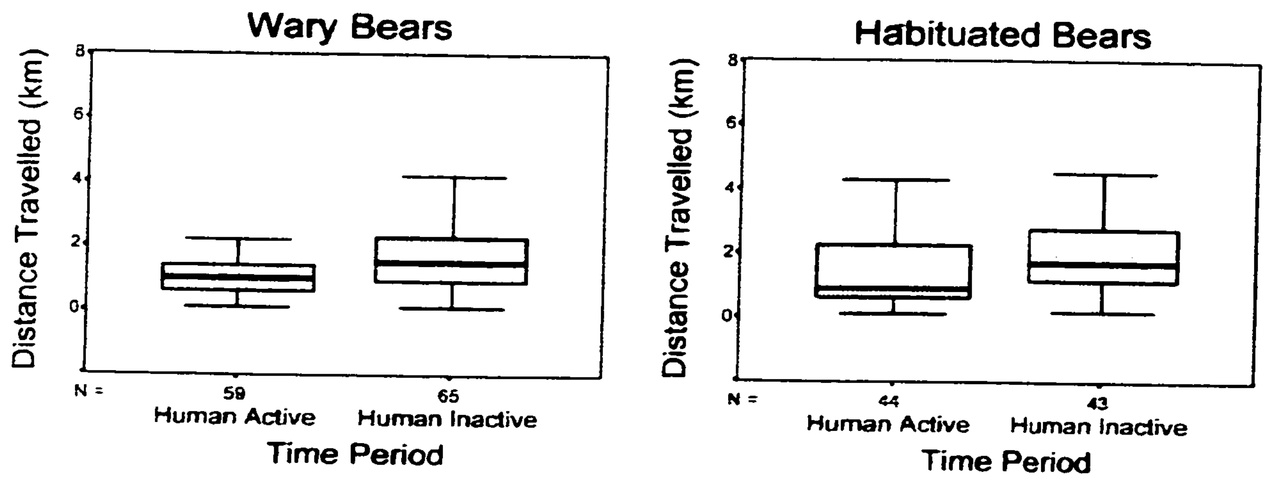

Figure 1. Box and whisker plots of distance traveled by time period for wary and habituated adult female grizzly bear in the Bow River Watershed, Alberta, 1994-1998. The box indicates the median, 25% and 75% quartiles and whiskers are the largest values that are not outliers.

In comparisons between the area of restricted human access and areas of unregulated human access, significant differences were detected in proximity to high quality habitat ($F_{2,39} = 4.42$, $P = 0.007$), compactness ratio ($F_{2,39} = 5.71$, $P = 0.022$), total access density ($F_{2,39} = 15.14$, $P < 0.001$) and distance traveled ($F_{2,39} = 4.42$, $P = 0.042$). MCP's for bears within the restricted area had a higher percentage of high quality habitat within a 1.5 km radius (10%) than MCP's for bears in unregulated areas (6%). The compactness ratio of MCP's within the restricted area was smaller than in unregulated areas. Total access density in the vicinity of MCP's in the restricted area (0.45 km/km^2) was less than MCP's in unregulated areas (2.1 km/km^2). Average total distance traveled within MCP's in the restricted area (4.0 km) was less than total distance traveled within MCP's in unregulated areas (6.5 km).

Significant differences were also detected in the sample of daily MCP events between wary and habituated bears for proximity to high quality habitat ($F_{2,39} = 26.36$, $P < 0.001$) and road density ($F_{2,39} = 10.37$, $P = 0.003$). MCP's for wary bears had a higher percentage of high quality habitat within a 1.5 km radius (18%) than MCP's for habituated bears (5%) (Fig 2). Average road density in the vicinity of MCP's from wary bears was less (0.0 km/km^2) than MCP's from habituated bears (1.1 km/km^2).

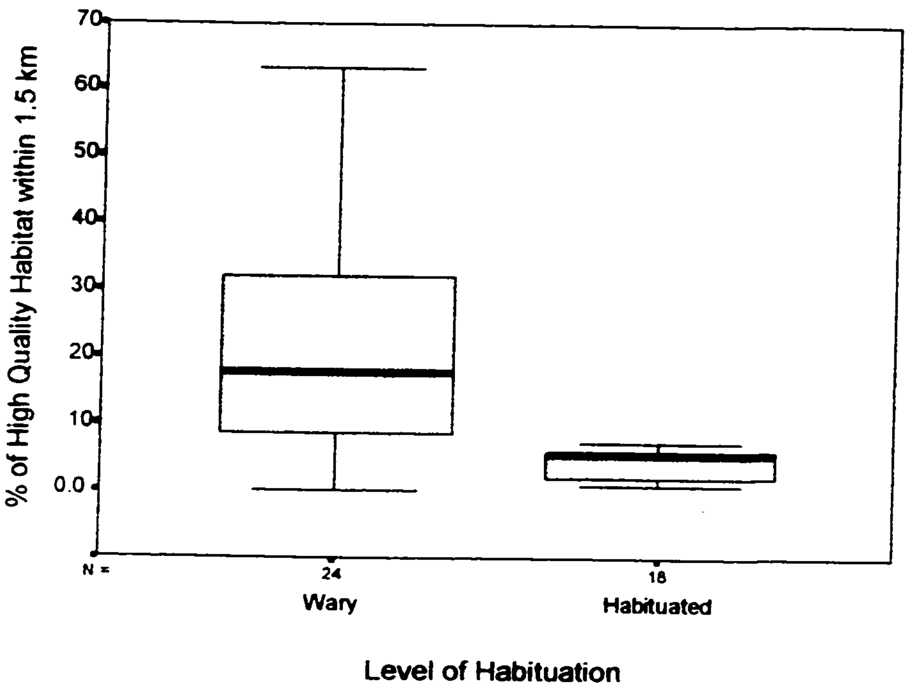

Figure 2. Box and whisker plot of the range of use of high quality habitat for wary and habituated adult female grizzly bear in the Bow River Watershed, Alberta, 1994-1998. The box indicates the median, 25% and 75% quartiles and whiskers are the largest values that are not outliers.

Discriminant function analysis for wary versus habituated bears produced a 78.6% cross-validated correct classification rate. Wilk's Lambda was low (0.49) denoting relatively high discriminating power. The high canonical correlation coefficient (0.71) indicated the model discriminated well between the groups. The structure matrix revealed the percentage of high quality habitat within a 1.5 km radius (-0.618) contributed most to the discriminant function. The negative sign indicated that habituated bears are found within a lower percentage of high quality habitat. The second most important variable was total access density (0.311) and thirdly, compactness ratio (0.284). Results of the standardized canonical function coefficients were similar. Based on the analysis, the most important landscape characteristics for wary bears were: 1) high percentage of high quality habitat within a 1.5 km radius, 2) low total access density, and 3) low compactness ratio.

DISCUSSION

I found no difference in bear movement rate for adult females between the conventional division of day versus night. However, I detected substantial difference when dividing the data by when humans were active (Fig. 1). This is consistent with the findings of Olson et al. (1997) that differences in use patterns are attributable to human activity. Consistent differences in movement rates between wary and habituated adult females (Fig. 1), although not statistically significant, further suggested an influence of humans. Another apparent influence was observed in my intensive movement data which showed that habituated adult female bears were not able to take advantage of higher quality habitats (Fig. 2) in the same manner that wary bears were. The combination of habituated bears using lower quality habitats and demonstrating higher movement rates has obvious implications for the net energy available for growth and reproduction.

While these implications on fitness and reproduction are most acute for habituated bears they are not limited to this subset of the population. Although the sample is small, movement patterns of the two adult females within the control area also demonstrated an impact of human activity. Bears within the area of restricted human access used higher quality habitat and traveled less than bears in unregulated areas despite the fact that less high quality habitat was available in the restricted area. The lower compactness ratio in the restricted area suggests that bears used the landscape more adeptly.

While it is obvious that total access density would be lower in the control area than unregulated areas, the differences were large (0.45 km/km^2 versus 2.1 km/km^2). This is because, for the most part, there are few places in the Bow River watershed that do not have some kind of human access. Even more dramatic were the differences in road density between areas used by wary and habituated bears.

Overall, both wary and habituated adult female grizzly bears were affected by human presence as evidenced by my discriminant function analysis. In the relative absence of humans, wary bears were characterized by more efficient use of higher quality habitats with less movement. Increased human presence eroded this habitat optimization to a point where habituated bears traveled further in sub-optimal habitats. Females that have access to predictable and high value foods such as meat and berries attain greater adult size, mature earlier and have larger litters than those with access only to foods with low nutritional value such as roots (Hilderbrand et al. 1999, Mattson et al. 1999, Nagy and Haroldson 1989, Rogers 1977).

Daily activity patterns of grizzly bears have been found to vary widely. Some studies have found grizzly bears to be diurnal (Stemlock and Dean 1983, Wenum 1998, MacHutchon 1998). Others have found grizzly bears to be more crepuscular (Harting 1985, Gunther 1990, McCann 1991). Several authors have suggested this variability is due to grizzly bear's ability to alter their temporal and spatial activity patterns in response to human activity. One study (MacHutchon 1998) found variation with age and sex classes as well as level of human activity. Mattson (1990) believed that response to human activity is a function of several factors including the nature and extent of historical interactions with humans, availability of human foods, demographics and size of the population, and distribution of habitats. Given this multitude of variables we might expect that all bears end up responding to human activity somewhere along the continuum between extreme wariness and habituated behavior.

MANAGEMENT IMPLICATIONS

Adult females are the reproductive engine of grizzly bear populations, and their success is the key to long term population persistence. A population's resilience is determined by the resilience of the reproductively most important cohort, adult females. Providing adult female grizzly bears with the highest level of protection possible should be a management priority. Managing human impacts on individual grizzly bears and the population is key to this provision.

My findings reinforce those of Mattson (1993) in emphasizing the importance of security areas where female grizzly bears can meet their energetic requirements relatively free from encounters with humans. Security areas help to reduce the incidence of habituated bears, bears killed out of self-defense, and bears removed by management agencies because of unacceptable behavior.

Providing security allows bears access to the highest quality habitats without competition from humans, thus maximizing the reproductive potential of the population. Identification of security areas and limiting human access to these areas should receive the highest priority for habitat conservation of grizzly bears in the Bow River Watershed and the Central Canadian Rocky Mountains.

CHAPTER TWO: EFFECTS OF HIGHWAYS ON GRIZZLY BEAR MOVEMENT IN THE BOW RIVER WATERSHED, ALBERTA.

ABSTRACT

No information exists to evaluate the effects of high-speed, high-volume highways on grizzly bear movement. I document the permeability of several highways to a grizzly bear population in a landscape where human presence is widespread. One highway with 24-hour, year-round high traffic volumes served as an effective barrier for adult female movement and a filtered-barrier for males. Traffic volume appeared to be a key variable in the permeability of highways for grizzly bears. Highway crossings by grizzly bears were concentrated in specific locations and occurred during night as well as day. Zones of high frequency road crossings in my study area were characterized by lower than average total access density, closer to a major drainage, more rugged terrain and higher quality habitat. Significant potential currently exists for permanent habitat and population fragmentation to occur along the Trans Canada Highway. An adaptive management approach will be crucial, with population connectivity being of paramount importance, as we continue to gain knowledge of grizzly bear response to highways.

INTRODUCTION

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

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

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

STUDY AREA

The study area encompassed the Bow River Watershed from its headwaters to approximately where it meets the prairies. This is 11,400 km^2 of mountainous terrain 50-180 km west of Calgary, in southwestern Alberta. This area includes a portion of Banff National Park (BNP) and adjacent Alberta Provincial lands known as Kananaskis Country. Neither jurisdiction allows grizzly bear hunting although bears are exposed to some hunting outside the Bow River Watershed. Differing agency mandates oversee preservation, industrial tourism, recreation, forestry, oil and gas extraction, mining and stock grazing. Native councils, towns and municipalities, commercial developers and residential owners diversify land administration even further.

Human presence is widespread both within and outside of BNP. Three towns, Banff, Lake Louise and Canmore are international tourist destinations that attract approximately four million visitors annually. Developments in addition to the towns that support the tourism industry include numerous hotels, campgrounds and picnic areas, 5 golf courses, 5 downhill ski facilities and an extensive network of hiking, biking and equestrian trails.

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

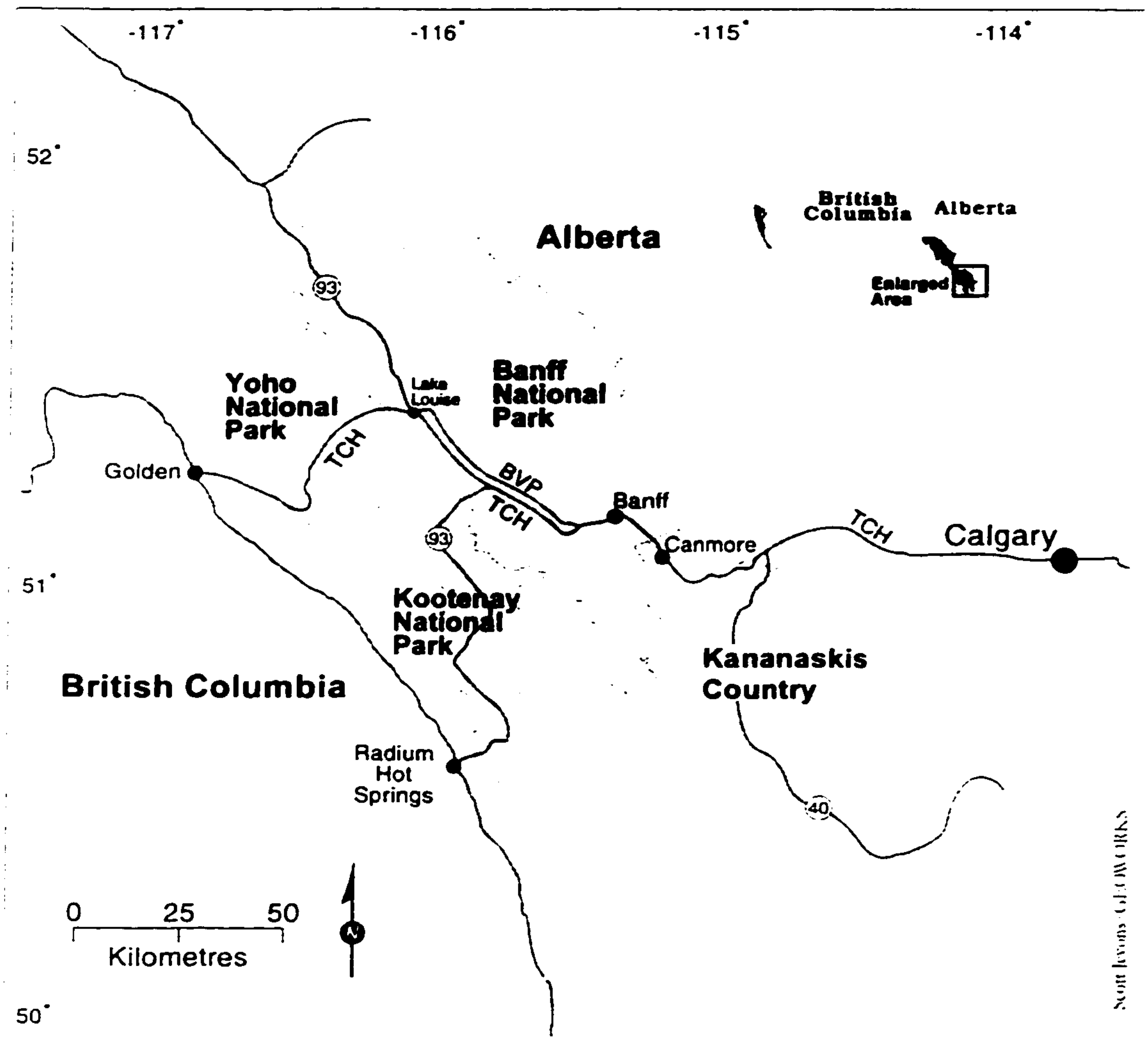

Figure 1. Network of high-speed, high-volume highways in the Central Canadian Rocky Mountains.

access the region using primarily the Trans Canada Highway (TCH), a major transcontinental transportation route, that bisects the study area east to west. It is a 4-lane divided highway through most of the study area with a summer (June - September) average traffic volume of 21,000 vehicles per day (Parks Canada, unpubl. data) and an observed average speed of 110-115 km/hr (Royal Canadian Mounted Police pers. comm). Thirty-five kilometers of this busy freeway have not yet been upgraded to a 4-lane divided highway along the western edge of the study area. Forty-five km of the TCH through BNP have been fenced to keep wildlife off the roadway. Wildlife crossing structures have been placed throughout the fenced section to facilitate movement across the highway (Clevenger and Waltho 2000). The remaining 40 km of the TCH along the eastern portion of the study area is a 4-lane divided highway but without a wildlife fence.

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

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

METHODS

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

For this analysis I used several subsets of the telemetry data (described below) to avoid biases of over sampling and to maximize independence between telemetry locations (Hurlbert 1984) required for some analyses.

Highway Crossings

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

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

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

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

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

where r_i is the distance from the highway to the location occurring before the bear crossed the highway, d_i is the distance between sequential locations, et_i is the time elapsed between sequential locations, and t_i is the time of the location before the bear crossed the highway.

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

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

Crossing Location Attributes

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

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

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

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

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

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

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

Analysis

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

< 0.05. The assumption of equal variances was met for the telemetry data set.

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

RESULTS

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

Highway Crossings

Three adult males, 2 subadult males, and 1 subadult female crossed the TCH during the 5 year period. Both subadult males were habituated and ultimately removed from the population. The subadult female was also habituated but was not removed.

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

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

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

In Kananaskis Country, 3 adult males, 5 adult females, 1 subadult male, and 2 subadult females crossed Highway 40. Two adult males, 2 adult females, 1 subadult male and 1 subadult female crossed the BVP. Both subadults are the bears that also crossed the TCH. One adult female and 1 subadult male crossed Highway 93, although these were the only bears in my sample in that vicinity.

There was a total of 33 crossings by 6 bears on the TCH for a median of 1.5 crossings per bear. Two bears crossed Highway 93, 17 times for a median of 8.5 crossings per bear. On Highway 40 there was a median of 12.0 crossings per bear, while on the BVP the median was 6.0. One adult male accounted for 66% of all TCH crossings. Of the four highways, the TCH formed a home range boundary for 6 adult females, while Highway 93 bordered the home range of one adult female.

Road density within the composite female home range was 0.16 km/km². Total access density within the composite female home range was 1.30 km/km². Road density within the composite male home range was 0.44 km/km². Total access density within the composite male home range was 1.54 km/km².

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

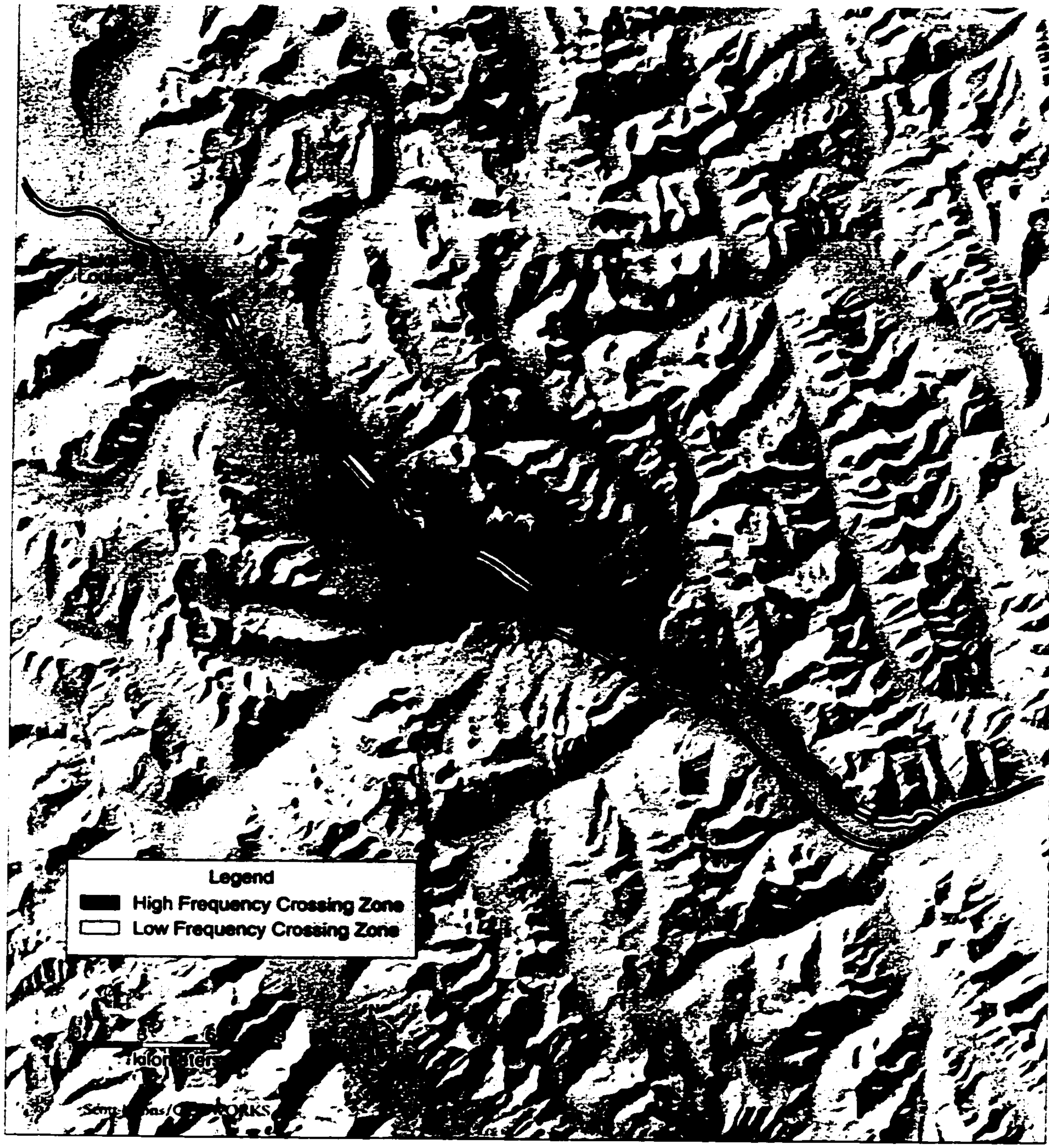

Figure 2. Grizzly bear highway crossing zones along the Bow Valley Parkway, Alberta, 1994-1998.

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

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

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

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

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

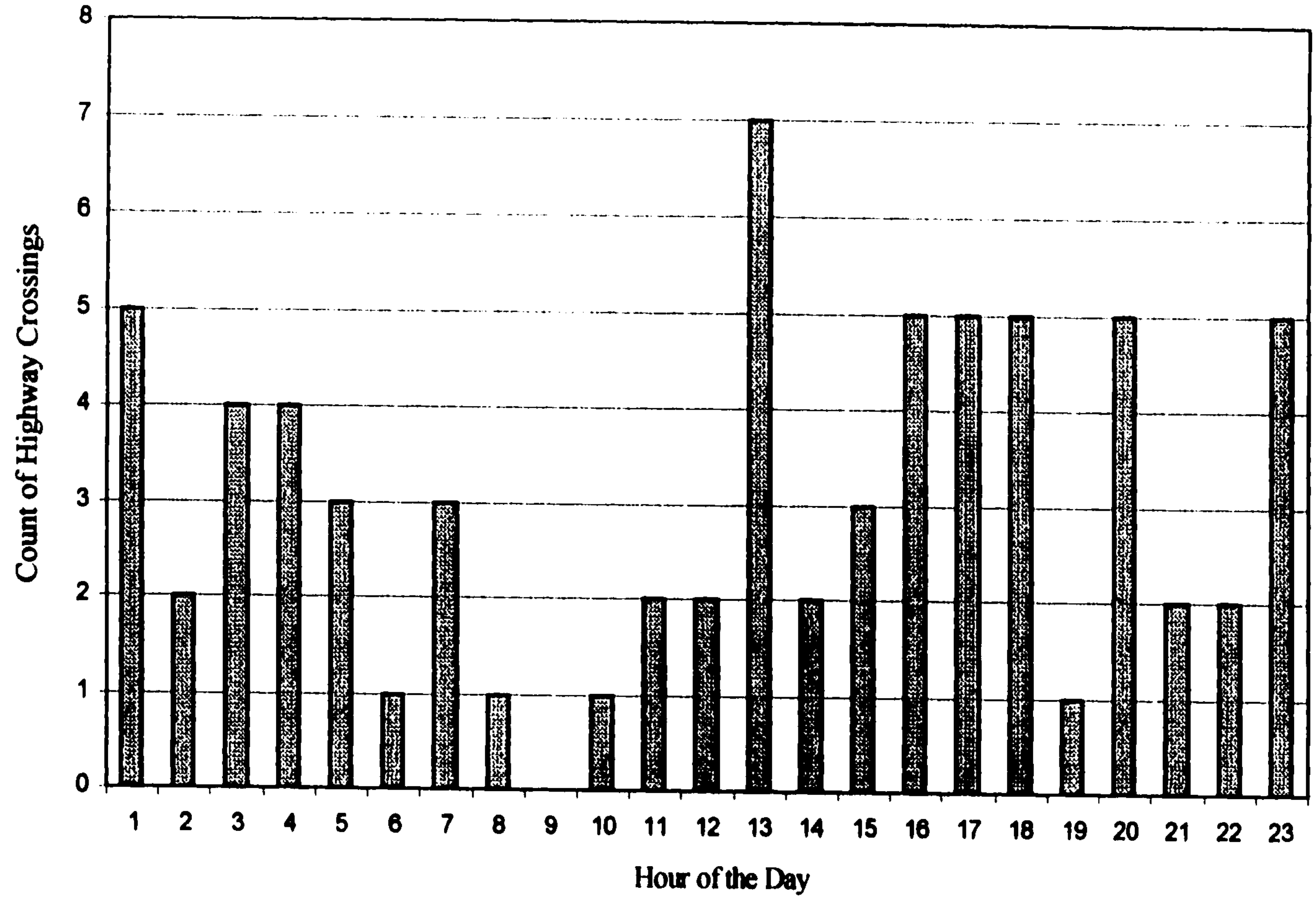

Figure 4. Timing of grizzly bear highway crossings for the Bow Valley Parkway and Highway 40, Alberta, 1994-1998.

Crossing Location Attributes

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

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

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

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

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

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

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

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

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

DISCUSSION

The relative crossing index of bears along the four highways indicated that the TCH was the least permeable for grizzly bears (Table 1). The facts that no radio marked adult females crossed this major highway during the study (Gibeau and Herrero 1999), and two-thirds of the crossings were by one adult male, are of the utmost concern. Black bears responded similarly to a high-speed highway in North Carolina by crossing only 14 times ($n = 9$ bears) in 4 years and one bear was killed while attempting to cross (Beringer et al. 1990). Highway 40 had the highest number of crossings per bear. This can be partially explained by the fact that the recorded Highway 40 traffic volume is most likely overestimated as a large proportion of the vehicles do not constitute through-traffic (P. Kilburn, Alberta Transportation and Utilities pers. comm.).

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

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

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

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

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

MANAGEMENT IMPLICATIONS

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

Permeability was significantly compromised for grizzly bears along the TCH even though this highway had 3 different configurations in the study area (40 kilometers of 4-lane no wildlife fence, 45 kilometers of 4-lane with a wildlife fence, and 35 kilometers of 2-lane). This leads me to believe that traffic volume appears to be a key variable in the permeability of highways for grizzly bears. The higher the traffic volume the less likely a bear will cross the highway. Management agencies in the Bow River Watershed now find themselves in a particularly difficult position with respect to maintaining a contiguous grizzly bear population in the Central Canadian Rocky Mountains. My results, along with home range analysis (Gibeau and Herrero 1999), suggest that the TCH both inside and outside of Banff National Park is a barrier to female grizzly bear movement, and a filtered barrier to male movement. The implications of a movement barrier are unknown, however it certainly points to the initial stages of islandization. Given grizzly bear's large home ranges, significant potential currently exists for permanent habitat and population fragmentation to occur. Management agencies must maintain access to high quality habitat, especially for adult females.

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

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

CHAPTER THREE: GRIZZLY BEAR RESPONSE TO HUMAN DEVELOPMENT AND ACTIVITIES IN THE BOW RIVER WATERSHED, ALBERTA.

ABSTRACT

Few studies have reported the effects of multiple human activities on grizzly bears. Unlike most grizzly bear studies that report specific avoidance distances to various human developments from analysis of resource selection, I document the degree and magnitude of grizzly bear responses as a function of multiple interacting variables based on observed median distances to roads, trails and development features in a landscape where human presence is widespread. Female grizzly bears remained further than males from paved roads regardless of the habitat quality or time of day. Males were found closer to paved roads when within or adjacent to high quality habitat and during the period of least human activity. The combination of traffic volume and highway configuration, however, overrides a bear's attraction to high quality habitats for high-speed, high-volume, highways. High human presence underlies the apparent unwillingness of most grizzly bears to use habitats near busy transportation corridors. This avoidance behavior is strongest in the adult segment of the population. Bears were found closer to trails during the human inactive period when within high quality habitat and further from trails when distant to high quality habitat. My data indicated an inverse relationship between the sexes in response to vehicles and traffic noise compared to the response to human settlement and encountering people. Female bears were found further

away than males in relation to vehicles and traffic noise, yet found closer than males to human settlement and places where people may be encountered. Those males that were more willing to exploit high quality habitat near roads used both cover and darkness as part of their adaptive strategy. Adult females were the most risk-averse cohort, choosing to avoid humans instead of seeking out high quality habitats. Adult female grizzly bears were influenced most by human activities and development. Management agencies must maintain access to high quality habitat, especially for adult females, and create new opportunities to support the reproductive potential of the population.

INTRODUCTION

Many wildlife populations have been reduced to small fractions of their former size during modern times due to anthropogenic pressures such as habitat loss and overexploitation. This phenomenon is increasing in Canada. Alberta has an expanding economy based significantly on the development of natural resources such as agriculture, oil and gas, forestry and nature-based tourism. Individual grizzly bears, having large home ranges, increasingly come into contact with all of these activities. Herrero (1994) showed that grizzly bear populations in Canadian national parks by themselves were probably all too small to have a high probability of long term persistence, and therefore integrated management with surrounding provincial or territorial lands would be required. Within the boundaries of Banff, Yoho and Kootenay National Parks, research by Gibeau (1998) showed that habitat effectiveness was significantly compromised by development. Whether land is managed as parks, commercial forests or privately, management practices must respond to the grizzlies' needs if these bears are to survive.

There is an urgent need for scientific data to help land managers better understand the effects of human activities on grizzly bears.

The response of grizzly bears to humans has been the focus of much research within the last 15 years. Most of these studies, however, have focused on one type of human activity such as roads (McLellan and Shackleton 1988, Mace et al. 1996), forestry or other industrial activity (Archibald et al. 1987, McLellan 1990), recreation (Jope 1985, Gunther 1990, Olson et al. 1990, Mace and Waller 1996), or facilities (Mattson et al. 1987, Reinhart and Mattson 1990). Few studies have reported the effects of multiple human activities (Mattson et al. 1987, McLellan and Shackleton 1989a, Kasworm and Manley 1990) and then, only using univariate analysis.

I document the distance of grizzly bears to different human activities and development features based on sex, age class and habitat quality in a landscape where human presence is widespread. The Bow River Watershed is one of the most intensively developed landscapes in the world where a grizzly bear population still survives. In this setting, grizzly bears may not be able to avoid humans and still find requisite resources. Using radio telemetry information, I tested the hypothesis that grizzly bears do not differ in their response to roads, trails, and major development features.

STUDY AREA

The study area encompassed the Bow River Watershed from its headwaters to approximately where it meets the prairies. This is 11,400 km^2 of mountainous terrain 50-180 km west of Calgary (a city of 800,000 people) in southwestern Alberta. This area includes a portion of Banff National Park (BNP) and adjacent Alberta Provincial lands known as Kananaskis Country. Neither jurisdiction allows grizzly bear hunting although bears are exposed to some hunting outside the Bow River Watershed. Differing agency mandates oversee preservation, industrial tourism, recreation, forestry, oil and gas extraction, mining and stock grazing. Native councils, towns and municipalities, commercial developers and residential owners diversify land administration even further.

Human presence is widespread both within and outside of BNP. Three towns, Banff, Lake Louise and Canmore are world-renowned tourist destinations that attract approximately four million visitors annually. Developments in addition to the towns that support the tourism industry include a multitude of hotels, campgrounds and picnic areas, 5 golf courses, 5 downhill ski facilities and an extensive network of hiking, biking and equestrian trails.

People access the region using primarily the Trans Canada Highway (TCH), a major transcontinental transportation route, that bisects the study area. It is a high-speed, high-volume (21,000 vehicles per day, summer average daily traffic volume; Parks Canada, unpubl. data), 4-lane divided highway through much of the study area. Forty-five km of the TCH through BNP has been fenced to keep wildlife off the road surface. Several high-speed, 2-lane paved roads serve as arterial transportation routes. Numerous 2-lane paved secondary roads complete the transportation system through most of the low elevation valleys. Traffic volumes on these arterial and secondary paved roads are high during the day (>300 vehicles per hour) but low at night (<50 vehicles per hour) which is significantly different than the TCH (Gibeau and Herrero 1998). There are few gravel roads in the study area.

Topographic features include rugged mountain slopes, steep-sided ravines, and flat valley bottoms. The climate is continental with long, cold winters and short, cool summers. The aspect and elevation of the mountainous topography modifies climate somewhat. Topography, soil, and local climate strongly influence plant communities. The landscape can be classified into major ecoregions: montane (1,300 to 1,600 m), subalpine (1,600 to 2,300 m) and alpine (2,300+ m). The montane region is dominated by dry grasslands, wet shrubland and forests of Lodgepole pine (*Pinus contorta*), Douglas-fir (*Pseudotsuga menziesii*), white spruce (*Picea glauca*) and aspen (*Populus tremuloides*). Subalpine areas are forested with mature stands of lodgepole pine, Engelman spruce (*Picea engelmanii*), subalpine fir (*Abies lasiocarpa*) and subalpine larch (*Larix lyallii*) interspersed by areas of wetland shrub. A mosaic of low shrubs and herbs characterize alpine areas.

METHODS

Between 1994 and 1998 I captured, radio-marked and monitored grizzly bears in the Bow River Watershed, Alberta. Individuals were equipped with either a conventional radio collar (Lotek Engineering, Newmarket, Ontario) or an ear tag transmitter (Advanced Telemetry Systems, Isanti, Minnesota). All radio collars were fitted with a breakaway cotton spacer (Hellgren et al. 1988) to ensure that collars would not be worn permanently. I located bears from the ground opportunistically on a daily basis using a portable receiver, roof mounted omni-directional antenna and 3-element hand-held yagi antenna. Workers used either the loudest signal method or nulls (Springer 1979) to determine bearings from 2 or more positions (Nams and Boutin 1991). Bearings were plotted on 1:50,000 scale topographic maps with bear locations recorded to the nearest 100 m using the Universal Transverse Mercator (UTM) grid coordinate system. Through testing with radio collars placed in known locations I recorded an average telemetry error of 150 m. Radio locations were supplemented by occasional direct observation or reports from the public.

I searched for collared bears at least once per week from the air, weather permitting, using a portable receiver, a right-left switchbox, and paired 3-element Yagi antennae attached to a Bell Jet Ranger III helicopter or paired 2-element H antennae attached to a STOL equipped Cessna 337 Skymaster. Aerial tracking followed the techniques of Mech (1983). Aerial fixes were established from an aircraft mounted GPS unit and later transformed to UTM coordinates (North American Datum 1927) using the Geocalc Program (Blue Marble Graphics 1993). In addition to systematic radio tracking, I conducted periodic 24-hour monitoring of individual animals at hourly intervals to obtain daily movement patterns.

I used both air and ground radio telemetry data consisting of one relocation per day to avoid biases of over sampling and maximize independence between telemetry locations (Hurlbert 1984). Ground-based telemetry data can be biased in some cases towards only where workers can travel. In this analysis, however, I rely upon ground-based telemetry data because the analysis is specific to areas where workers could travel and sample sizes are larger than the aerial data set. Relocations were categorized by: (1) sex; (2) age: adult (>5 years old) and subadult; (3) season: preberry (den emergence through 15 July) and berry (16 July through den entrance); (4) differences in hours of peak human activity both on the highways and trail system (Parks Canada unpublished data) being human active (08:00-17:00) versus human inactive (17:00-0:800) periods; (5) distance to high quality habitat: within (<150 m, which is consistent with telemetry error), adjacent (150-300 m) or distant (>300 m). Telemetry data were imported into geographic information system (GIS) maps using MapInfo Professional® software(MapInfo Corporation, Troy, New York, USA) for analysis.

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

The percentage of available vegetative cover was calculated for each 30 m pixel within the study area based on classified Landsat Thematic Mapper satellite images using a moving-window routine. I chose a 1.5 km radius as a moving-window size which approximates the average daily feeding radius of an adult female grizzly bear in my study area. The resulting GIS map provided a measure of the percent cover in the vicinity of each telemetry location.

I quantified human presence using the most recent data of human activity across the region (Gibeau 1998). These GIS maps categorized vector, point and polygon data of all motorized and non-motorized human developments and facilities into high (>100) and low (< 100) users per month (USDA Forest Service 1990, Gibeau 1998) based on visitation records and expert opinion. These data became the basis for measuring the distance of telemetry locations to various human developments and features. I categorized human use by: (1) Trans Canada Highway, (2) high use paved roads, (3) high use trails, and (4) high use features (campgrounds, lodges, picnic area, etc.). Although there were several low use trails within the study area, most were located in association with either the TCH or a high use paved road. Any attempt to partition out the effects of low use trails was masked by these other roadways. There were too few gravel roads, low use roads, and low use features for meaningful analysis.

Analysis

The nearest distance (>1 m) to each of the above 4 human use categories was calculated in a raster format with a 50 m pixel size using Idrisi® (Clark Univ., Worcester, MA) GIS software for each telemetry location. The resulting spreadsheet provided distances to four types of human uses, and percent cover for every telemetry location categorized by sex, age, season, time of day, and habitat quality. For comparison, I generated a stratified systematic sample of 2765 random points and calculated the nearest distance to each of the four human use categories for these locations as well.

Analysis of the distance data was complicated by the rugged mountainous topography. Distance measurements did not take into account intervening mountain ranges, therefore I had to impose distance limits to avoid measurements that were in fact in adjacent mountain valleys. I found the average distance between ridge tops for the major valleys in the Bow River Watershed to be 6.5 km. Therefore, I used half that distance (3.25 km) as a maximum to give a high probability that measurements were within the same mountain valley.

I used a Mann-Whitney U statistic to test whether the aerial and ground telemetry data sets, and the stratified systematic sample of random points, came from the same population. An unbalanced analysis of variance (ANOVA) was used to test both main effects and interactions among sex, age, season, distance to high habitat quality, and time of day for the measured distances to each of the four types of human uses. Profile plots were used to visualize the relationship between variables using estimated marginal means. Significance was accepted at $P < 0.05$. The assumption of equal variance was met for the aerial telemetry data set.

RESULTS

I collected 4,359 daily telemetry locations from 49 grizzly bears (15 adult male, 7 subadult male, 19 adult female, 8 subadult female) during the study. Slightly more than half of the locations were obtained from the ground ($n = 2,471$, 57%) compared to aerial locations ($n = 1,888$). There were significant differences between the aerial and ground telemetry data sets ($P = 0.002$) in observed distances to high use paved roads, high use trails and high use features; however, not for the TCH ($P = 0.101$). Although the ground-based telemetry data was statistically different from the aerial data set, I report and interpret ground-based results because the analysis is specific to areas where workers could travel and ground based telemetry may provide further biologically meaningful insights (Cherry 1998, Johnson 1999). Significant differences also existed between the aerial data set and the stratified systematic random sample in observed distances to the TCH ($P = 0.011$), high use paved roads ($P = 0.004$), high use trails ($P < 0.001$) and high use features ($P = 0.025$). Reported results are from the aerial telemetry data set, except where I specifically denote the ground-based data was used.

Differences between the percent cover around telemetry locations (56%) and the random sample (22%) were evident ($P < 0.001$). While not statistically significant, males tended to use cover more (67%) than females (52%). Again, while no statistical significance was detected, adult males used cover more (68%) than subadult males (56%). Adult (52%) and subadult (58%) females had similar use of cover.

The distribution of distance measurements for most of the four types of human uses was found to be non-normal. However, the similar shapes of the distributions (symmetric to slightly right-skewed) resulted in the variables having similar variances (verified by the Levene's tests of the homogeneity of variance). Results of statistical tests were the same with both the original values and transformed values to normalize the data. Given the robustness of the chosen statistical tool (ANOVA) to the departures from normality and the need to maintain a clarity, I present results of original values. The corrected model for each of the four types of human uses was significant ($P < 0.025$). Due to model complexity, three and four way interactions were not considered. I also report median distances to various human developments and activities as they provide a better measure of central tendency than means when data are skewed (Table 1).

Table 1. Median distance (m) to human developments measured from aerial telemetry locations of grizzly bears in the Bow River Watershed, Alberta, 1994-1998.

	Stratified random sample	Both Sexes	Males								Females							
						Time period [a]		High quality habitat						Time period [a]		High quality habitat		
			All males	Adult	Subadult	Human active	Human inactive	Within	Adjacent	Distant	All females	Adult	Subadult	Human active	Human inactive	Within	Adjacent	Distant
TCH	1432	1966	1741	1810	649*	1626	1166	905*	1134	1999	2148	2331	2071*	2185	2007	2294	2040*	2199*
Paved roads	1193	850	781	771	828	583	391	618	320*	951	900	951	800	604	566	868	943	1050*
High use Trails	1031	750	747	701	889	901	860	781	570	989	750	743	849	500	550	743	919	1145
Features	1791	1748	1602	1603	1521	1259	1204	1471	2022	2438	1808	1834	1550	894	604	1697	1692	1978

[a] ground-based data set
* small sample size (< 30 locations)

TCH

I detected significant differences in distance from the TCH between sexes ($F_{7, 121} = 17.21$, $P < 0.001$). The average female grizzly bear distance from the TCH was greater than that for males or the random sample (Table 1). Differences between the sexes were also seen when I analyzed the proximity of high quality habitat ($F_{24, 90} = 5.24$, $P = 0.024$). Females were located further than random from the TCH whether within, adjacent to, or distant from high quality habitat. Males, on the other hand, were found closer than random to the TCH when within or adjacent to high quality habitat but further than random when distant from high quality habitat (Table 1).

Clear differences were found between sex and age class in the ground-based data set ($F_{7, 739} = 60.30$, $P < 0.001$). While both subadult and adult females and adult males were found further away from the TCH than random, subadult males were much closer to the TCH (Table 1). The aerial data set characterized an almost identical pattern although no statistical significance was detected ($F_{7, 121} = 2.58$, $P = 0.111$, power = 0.357).

The ground data set also depicted differences between the sexes and time periods ($F_{15, 731} = 73.02$, $P < 0.001$). Females remained further from the TCH than random during both the human active and human inactive periods. Although males were further away than random during the human active period, they were closer than random during the human inactive period. I did not have a sample of night time locations to test the aerial data set.

High Use Paved Roads

No statistical difference was detected between female and male distances to high use paved roads ($F_{7, 496} = 0.20$, $P = 0.657$, power = 0.073) although both sexes were both closer than random (Table 1). Conclusions from the aerial data set may not be reliable because of the high probability of committing a Type II error, given that the statistical power indicated little chance of detecting a difference due to the small sample. Similar to the TCH findings, the same pattern of differences between the sexes depending upon the proximity of high quality habitat, was again evident with high use paved roads. Females remained much further from high use paved roads whether within, adjacent to, or distant from high quality habitat. Males on the other hand, were found much closer than random to high use paved roads when within or adjacent to high quality habitat, but further away from high use paved roads when distant from high quality habitat (Table 1). This relationship was statistically significant only in the ground data set ($F_{47, 1736} = 18.88$, $P < 0.001$).

Differences were also seen between the sexes and time periods ($F_{15, 1829} = 14.65$, $P < 0.001$). Females were further from high use paved roads during the human active and human inactive periods than males. Males were further from high use paved roads during the human active period, but closer during the human inactive period (Table 1).

High Use Trails

No statistical difference was detected between female and male distances to high use trails ($F_{7, 1561} = 0.07$, $P = 0.784$, power = 0.059) although both sexes were both closer than random (Table 1). Although not statistically significant ($F_{40, 1264} = 2.31$, $P = 0.100$, power = 0.470), bear use in association with high use trails also depended upon the proximity of high quality habitat. In both cases, conclusions from the aerial data set may not be reliable because of the high probability of committing a Type II error, given that the statistical power indicated little chance of detecting a difference due to the small sample. Female bears within or adjacent to high quality habitat were closer to high use trails than if distant from high quality habitat. Males were also closer to trails when within or adjacent to high quality habitat than when they were distant from high quality habitat (Table 1). The ground telemetry data set confirmed the same pattern and was highly significant ($F_{46, 1999} = 33.55$, $P < 0.001$).

A significant difference was detected in distance to high use trails between the sexes and time periods ($F_{15, 2254} = 13.18$, $P < 0.001$). Females were closer than males to high use trails during both the human active and human inactive periods (Table 1). Overall, there was a trend for bears to be further away from developments during human active periods and closer during the human inactive period when the proximity of high quality habitat is accounted for (Figure 1c).

High Use Features

While not significantly different ($F_{7, 794} = 0.05$, $P = 0.815$, power = 0.056), female distance to high use features was further than that of males or random (Table 1). Again, conclusions from the aerial data set may not be reliable because of the high probability of committing a Type II error, given that the statistical power indicated little chance of detecting a difference due to the small sample. Significant differences between the sexes and time period were apparent depending upon the proximity of high quality habitat ($F_{33,}$

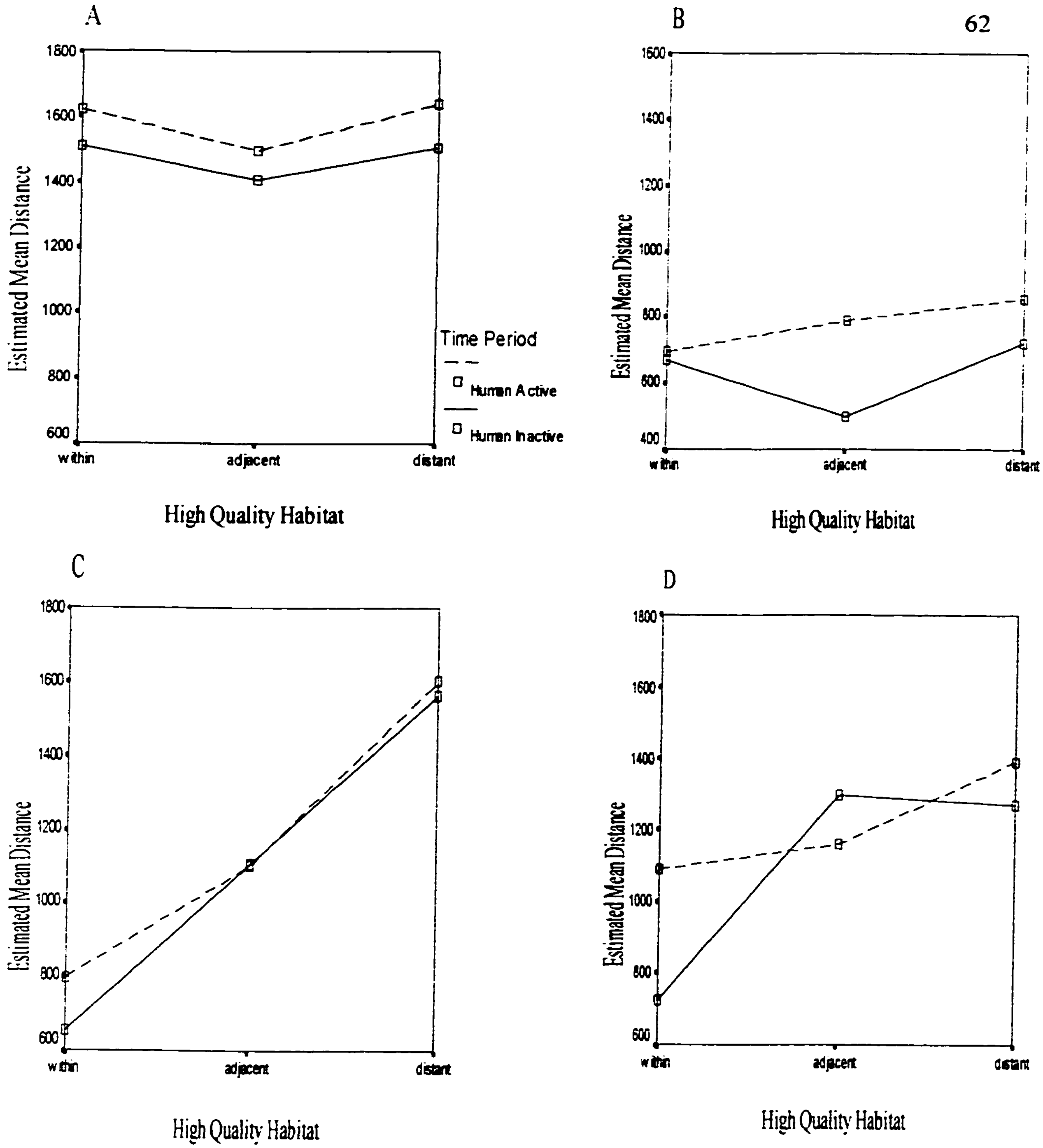

Figure 1. Profile plots of the interaction between high quality habitat and time period for (A) TCH, (B) high use paved roads, (C) high use trails, and (D) high use features, for grizzly bears in the Bow River Watershed, Alberta, 1994-1998.

$_{665}$ = 6.21, P = 0.013). Females were found closer to features than random when within or adjacent to high quality habitat, but further than random when distant from high quality habitat. Males, on the other hand, were similar to random when within or adjacent to high quality habitat but much further than random when distant from high quality habitat (Table 1). The same pattern is seen in the ground based data set although the differences between the sexes are much more pronounced ($F_{47, 1756} = 9.21$, $P < 0.001$).

Although no statistical significance was detected in the aerial data set between the age classes and distance to features ($F_{7, 794} = 1.42$, $P = 0.234$, power = 0.221), a highly significant pattern is evident in the ground data set ($F_{7, 1958} = 33.32$, $P < 0.001$). Adults were found further away from features, while subadults were closer to features (Table 1).

The ground data set also depicted differences in distance to features between the sexes ($F_{7, 1958} = 44.50$, $P < 0.001$). Females were closer to features than males during both the human active and human inactive period. Males remained some distance from features during both the human active and human inactive periods (Table 1). Generally, bears were found closer to high use features when within high quality habitat and when humans were inactive (Fig 1d).

With all four types of human developments I found some differences between the two seasons; however, I found statistical significance only in distance from features ($F_{7, 794} = 4.80$, $P = 0.029$). While no consistent pattern emerged, a weak trend of the data depicted subadults closer to human development in preberry season than berry season, while the opposite was true for adults. It seems likely that any observed variation in seasonal distance to human developments would be related to seasonal changes in food value arising from the progression of plant phenology.

DISCUSSION

Wildlife response to humans and our activities occur in context, and in differing magnitudes in differing contexts (Whittaker and Knight 1998). Wildlife also behave differently in different locations and during different activities, and the learned outcomes of all these interactions affect subsequent interactions (Gilbert 1989). Unlike most grizzly bear studies that have reported specific avoidance distances from various human developments from analysis of resource selection (Archibald et al. 1987, Mattson et al. 1987, McLellan and Shackleton 1988, Kasworm and Manley 1990, Mace and Waller 1996, Mace et al. 1996), I have documented the degree and magnitude of grizzly bear responses as a function of multiple interacting variables based on observed median distances to roads, trails and development features. My data establish correlations, not causal relationships between various human stimuli and observed grizzly bear locations. I make inferences about causality and grizzly bear response based upon my data and relevant literature.

One important yet confounding variable, both in the literature and within my data, was the level of habituation (Whittaker and Knight 1998) of some individuals. Habituation may permit some bears to exploit habitats near roads, trails and developments, especially if human use is spatially and temporally predictable (Tracey 1977, Jope 1985, Herrero 1985, McLellan and Shackleton 1989a, Olson et al. 1990). Several studies have suggested there are differences among sex, age and reproductive classes in the likelihood and level of habituation to humans (Olson et al. 1990, Mattson 1990). My observations on responses of grizzly bears to various human developments reflect some of these differences, even though the majority of study bears were not considered habituated.

Social structure may also have a bearing on spatial distribution of a bear population. In Yellowstone National Park, Mattson et al. (1987) demonstrated that cohorts of subordinate bears were found in poorer-quality habitats near developments, displaced by more dominant classes, particularly adult males. McLellan and Shackleton (1988) also determined that adult males used remote areas whereas adult females and some subadults used areas closer to roads. While my results pointed to differential use by sex and age, I was unable to determine whether this distribution is a natural phenomenon or the result of intense competition for space with humans.

Of the four types of human developments I investigated, the TCH was avoided most by grizzly bears. Female bears avoided the busy freeway regardless of the habitat quality or time of day. Males, and especially subadult males, were found closer to the TCH when within or adjacent to high quality habitat and during the human inactive period. These observed responses may not be solely due to the TCH, but to the higher overall human access density associated with the valley system that includes the TCH. Greater use of cover by males may be part of the strategy used to take advantage of high quality habitat near roads.

Several authors believe that grizzly bears become accustomed to predictable occurrences (Herrero 1985, Jope 1985), including traffic (McLellan and Shackleton

1989b) although my results have suggested otherwise for high-speed, high-volume highways. There is a point when the combination of traffic volume and highway configuration overrides a bear's attraction to high quality habitats. The population as a whole displayed little variation in its response to the TCH whether within, adjacent to, or distant from high quality habitat (Fig. 1a). Between 1994 and 1998 not a single radio collared adult female bear crossed the TCH and only 2 radio collared males regularly crossed (Chapter 3). One habituated subadult female did cross the TCH. After 5 years of research I conclude that the TCH is a barrier to adult female grizzly bear movement and a significant filter to males.

The same pattern of grizzly bear response to paved roads was seen as to the TCH, although both sexes were found closer than a random pattern would predict. Females remained further than males from paved roads regardless of the habitat quality or time of day. Males were found closer to paved roads when within or adjacent to high quality habitat and during the human inactive period.

Avoidance of roads has been documented by Tracey (1977), Harding and Nagy (1980), Archibald et al. (1987), Mattson et al. (1987), McLellan and Shackleton (1988), Kasworm and Manley (1990), and Mace et al.(1996). I too documented bears further away from roads when distant from high quality habitat which I interpret as avoidance behavior. In this environment, however, bears were found closer to paved roads than would be predicted, presumably to acquire high quality food resources. High quality habitat is a strong attractant. Mace et al. (1996) demonstrated that avoidance of roadside buffers by grizzly bears generally increased with traffic levels and road densities, but bears did use important habitats adjacent to roads with low to moderate traffic levels. This neutral use, or positive selection toward habitats near roads implied that important habitat resources occurred near roads in their study area also.

Unlike paved roads that were located in valley bottoms and good quality habitats, high use trails were widely distributed throughout all types of habitats within the study area. Bears were found closer to trails during the human inactive period when within high quality habitat and further from trails when distant from high quality habitat (Fig 1c). In the Swan Mountains Montana, Mace and Waller (1996) concluded that grizzly bears using hiking trails have become negatively conditioned to human activity and that they minimized their interaction with recreationalists by spatially avoiding high use areas. My data suggest the same pattern in the absence of high quality habitat.

Kasworm and Manley (1990) reported that, overall, grizzlies were displaced less by trails than by roads. My results suggest otherwise for this study area. My observed avoidance of high use trails when distant from high quality habitat may be a reflection of a greater opportunity for bears to select high quality habitat in the relative absence of humans. In my study area, grizzly bears may not have the opportunity to truly "avoid" paved roads without forfeiting access to much of the high quality habitats.

Grizzly bears displayed more complex responses to development features. While distance measurements were not as great as for the TCH, bear response to high use features were still double those of paved roads or high use trails. Females, and especially subadult females, were found closer to features when within or adjacent to high quality habitat and during the human inactive period. Males, on the other hand, remained further away from features regardless of habitat quality or time of day.

Bears were more willing to take advantage of high quality habitat near features while humans were inactive. While this trend was evident throughout all types of human developments, it was most pronounced in association with features (Fig 1d). Mattson et al. (1987) and Reinhart and Mattson (1990) found that habitats were substantially under used especially during the day near town-sites and recreational developments depending upon the season, food and development. My results were consistent with others in that grizzly bears were more likely to use roads, trails and human facilities at night or when unoccupied (Harting 1985, Nadeau 1987, McLellan and Shackleton 1988, Gunther 1990).

My data indicate an inverse relationship between the sexes in response to vehicles and traffic noise (TCH and paved roads) compared to the response to human settlement and encountering people (high use trails and features). Female bears were found further away than males in relation to vehicles and traffic noise, yet found closer than males to human settlement and places where people may be encountered. I was unable to determine whether this was a result of dominance hierarchy, but females were less willing to take advantage of the high quality habitats that were in roaded valley bottoms. This displacement into sub-optimal habitats and/or reduced feeding efficiency may affect net energy intake and reproductive output.

I conclude from my observations, and the literature, that there were significant differences in grizzly bear response to roads, trails and major development features categorized by sex, age class, proximity of high quality habitat and time of day. High human presence underlies the unwillingness of most grizzly bears to use habitats near busy transportation corridors. This avoidance behavior was strongest in the adult segment of the population where I believe males selected for high quality habitats and an absence of humans. Those males that were more willing to exploit high quality habitat near roads, used both cover and darkness as part of their adaptive strategy. Adult females were the most risk averse cohort, choosing to avoid humans instead of seeking out the highest quality habitats. Adult females selected areas with a high degree of security for raising cubs (Gibeau and Herrero 1999), which in some cases also meant avoiding adult males. With the safest and highest quality habitats taken up by adult males and resident females, subordinate bears including some adult females were forced to use sub-optimal habitats including those with high human presence. My data demonstrated that subadults were almost always closer to humans than adults were. Unable to successfully compete elsewhere, these bears were relegated to using habitats close to people and developments. While in the proximity of humans some of these bears may become habituated to people. While these habituated bears appear to successfully use habitats near humans, they are also most likely to die at the hands of humans (Mattson et al. 1992, McLellan et al. 1999).

MANAGEMENT IMPLICATIONS

Research from Yellowstone National Park demonstrated that avoidance of roads and developments by grizzly bears probably resulted in adult females in poorer condition and consequently, higher mortality rates and lower fecundity for the cohort (Mattson et al. 1987). Mace et al. (1996) also found that spatial avoidance of roads increased and survival decreased as traffic levels, road densities and human settlement increased.

Given these findings from other grizzly bear ecosystems, management agencies in the Bow River Watershed are challenged to maintain a contiguous grizzly bear population in the Central Canadian Rocky Mountains. In an era when humans are having a significant influence upon the landscape, even within areas considered to be refugia, agency managers need to apply tools to assist in delineation and planning of important and productive sites for bears. The key to this is managing human impacts on individual grizzly bears and the population.

The reproductive potential of any population resides in the adult female cohort. In a landscape as intensely developed as the Bow River Watershed, adult female grizzly bears are influenced most by human activities and development. This is most acute in association with the TCH, where adult females not only have compromised access to the highest quality habitat in the region, but also face an almost impenetrable barrier to movement. The implications of such a barrier are unknown. However, it certainly points to the initial stages of islandization. Management agencies must maintain access to high quality habitat, especially for adult female bears, and create new opportunities to support the reproductive potential of the population.

The future of any population is found in the subadult cohort. In the Bow River Watershed, subadult grizzly bears are predisposed to interact with humans. This increased exposure to humans translates into a greater danger of being killed by humans. Every effort must be made to maintain and encourage wary behavior in vulnerable individuals and cohorts.

Many of the management techniques needed to maintain population viability are known from experiences in the United States and Canada, and need only to be applied and refined in this study area (Herrero et al 1986, Gunther 1995, Schirokauer and Boyd 1998). These include seasonal restrictions on human use of high quality habitat, locating trails and facilities away from such habitat and managing habituation. The need to control human access and to restrict development has been acknowledged in Banff National Park and to a lesser extent in Kananaskis Country, although the mechanisms for doing so are under development (Herrero et al. In press). Strict control of human access can be achieved by applying seasonal area closures, seasonal trail closures, day use only restrictions, travel limited to mid day only and restrictions on party size. In the end, the most difficult aspect of making real gains in grizzly bear conservation may be mustering the social and political will to implement change.

CHAPTER FOUR: MANAGING FOR GRIZZLY BEAR SECURITY AREAS IN BANFF NATIONAL PARK AND THE CENTRAL CANADIAN ROCKY MOUNTAINS.

ABSTRACT

The need for security areas in which grizzly bears (*Ursus arctos*) may rarely encounter humans and maintain wary behavior, is not explicitly addressed by cumulative effect modeling (CEM). In addition, CEM does not assess the value to bears of small areas left between zones of human disturbance. I developed and tested a predictive GIS based model of adult female grizzly bear security areas in the Central Canadian Rocky Mountains to provide agency planners with a tool that addresses these shortfalls. My study area included 4 major jurisdictions: Alberta provincial lands, British Columbia provincial lands, Kananaskis Country improvement district in Alberta, and National Park lands in both provinces. Starting with the total land base in each jurisdiction, I progressively removed areas of unsuitable habitat (e.g., rock and ice), habitat within 500 m of high human use (>100 human visits per month), and areas of insufficient size based on an average daily feeding radius (polygons < 9 km^2). I identified the remaining lands as secure areas. Using radio telemetry, I then tested the hypothesis that female grizzly bear use of security areas differs from use of the landscape as a whole. Of the 4 jurisdictions in the Central Canadian Rocky Mountains, the largest percentage of secure habitat was on British Columbia provincial lands. Forty eight percent of the land surface area of the Banff, Yoho, and Kootenay National Parks are unsuitable for grizzly bears,

primarily because it is composed of rock and ice. This is unfortunate because it is assumed that these national parks form productive core refugia for grizzly bears. By reconstructing past human use and forecasting into the future for Banff National Park and Kananaskis Country I demonstrate progressive loss of security areas. I found that an average of 69% of the land within grizzly bear home ranges was secure using my sample of 28 radio-collared adult females. Resource selection indices from these bears demonstrated selection of security areas within their home ranges. Existing mortality and translocation data, combined with my findings of low security and high habitat fragmentation within some adult female home ranges, give quantitative substance to the assertion that grizzly bears in and around Banff National Park and Kananaskis Country exist in one of the most human-dominated landscapes where they still survive. Careful management of access and development are key to grizzly bear persistence in the region.

INTRODUCTION

As omnivores and apex predators, grizzly bears (*Ursus arctos*) possess little resiliency (Weaver et al. 1996) and are one of the first species to be lost from an area as a result of land development activities. The status of the grizzly bear population and habitat are indicators of ecological integrity in Banff, Yoho, and Kootenay National Parks and the significantly larger regional ecosystem, the Central Canadian Rocky Mountains, upon which grizzly bears depend. The combination of a bear's biological traits interacting with people's proclivity to develop and use grizzly bear habitat, usually results in compromised grizzly bear populations and habitat. By maintaining a healthy grizzly bear population, I suggest that most other elements and processes of the terrestrial ecosystem will also be maintained.

Typically in the past, aesthetically pleasing lands not suitable for other economic uses were set aside as reserves with little consideration for whether they provided high quality habitat for sensitive species. By default however, our National Parks have become the core refugia even though as Caughley (1994) points out, "species in trouble end up living not in the habitat most favorable to them, but in the habitat least favorable to the agent of decline". Such is the case with grizzly bears. As we close the twentieth century, managers are recognizing that the ability of our National Parks to support bears has been significantly reduced by widespread human presence (Gibeau 1998).

Human access is one of the most influential factors affecting grizzly bear habitat security (IGBC 1998). Although grizzly bear mortality can be regulated and influenced by changes in human attitudes, it seems unlikely that humans will tolerate much contact with animals like grizzly bears: first, because they directly compete with humans for space and foods (Mattson 1990), and second because interactions with them can be potentially hazardous (Herrero 1985). Thus, there is a strong case for preserving security areas where female grizzly bears will be relatively free from encounters with humans, where bears can meet their energetic requirements while at the same time choosing to avoid people (Mattson 1993). Such security areas would foster the wary behavior in grizzly bears that most managers consider desirable (Mattson 1993) given that habituated bears have a significantly elevated mortality risk (Mattson et al. 1992).

Since the development of a cumulative effects model (CEM) for grizzly bears in the mid-1980s (Weaver et al. 1987, USDA Forest Service 1990), there have been significant advances in understanding the management of grizzly bears and substantial accumulation of empirical data about their ecology (see Gibeau et al. 1996, Mattson et al. 1996, Weaver et al. 1996, Mace and Waller 1997, and references therein). However, the CEM does not explicitly address the need for habitat security whereby bears maintain wary behavior, nor does it assess the value of small areas left between zones of human disturbance. To address this problem, Mattson (1993) developed the idea of micro-scale security areas where bears can forage for 24-48 hours safe from human disturbance. Micro-security areas include a core zone (based on foraging radius) surrounded by a disturbance-free buffer zone (based on displacement distances).

The Interagency Grizzly Bear Committee (IGBC) in the United States has endorsed an approach for providing habitat security for grizzly bears at the larger scale of Bear Management Units (IGBC 1998). A BMU is a discrete area of contiguous habitat for management purposes that would also incorporate the year round needs of an adult female grizzly bear. Based on research by Mace and Waller (1997), interagency managers in the Northern Continental Divide grizzly bear ecosystem in northwest Montana have specified that > 68 % of a BMU be in secure status for several years (USDA Forest Service 1995). Security areas help to reduce the incidence of habituated bears, bears killed out of self-defense, and bears removed by management agencies because of unacceptable behavior.

In an era where humans are having a significant influence on the landscape, even within areas considered to be refugia, agency managers need effective tools to assist in delineation and planning of important and productive sites for bears. To that end, I develop a predictive model of security areas in the Central Canadian Rocky Mountains, where adult female grizzly bears will have a low human encounter rate based on an average daily feeding radius. I further test the hypothesis that female grizzly bear use of security areas differs from use of the landscape as a whole based on radio telemetry data.

STUDY AREA

The Central Canadian Rocky Mountains, with an area of roughly 41,000 km^2, straddles the continental divide of Alberta and British Columbia. Topographic features include rugged mountain slopes, steep-sided ravines, and flat valley bottoms. The climate is continental with long, cold winters and short, cool summers. The aspect and elevation of the mountainous topography modifies climate somewhat. Topography, soil, and local climate strongly influence plant communities. The landscape can be classified into major ecoregions: montane (1,300 to 1,600 m), subalpine (1,600 to 2,300 m) and alpine (2,300+ m). The montane region is dominated by dry grasslands, wet shrubland, and forests of Lodgepole pine (*Pinus contorta*), Douglas-fir (*Pseudotsuga menziesii*), white spruce (*Picea glauca*) and aspen (*Populus tremuloides*). Subalpine areas are forested with mature stands of lodgepole pine, Engelman spruce (*Picea engelmanii*), subalpine fir (*Abies lasiocarpa*), and subalpine larch (*Larix lyallii*) interspersed by areas of wetland shrub. A mosaic of low shrubs and herbs characterize alpine areas.

Management of the landscape is divided into 4 major governmental jurisdictions: (1) National Parks including, Banff, Yoho, and Kootenay; (2) British Columbia provincial lands, (3) Alberta provincial lands, and (4) Alberta's Kananaskis Country (Fig. 1). Differing agency mandates oversee preservation, tourism, forestry, oil and gas

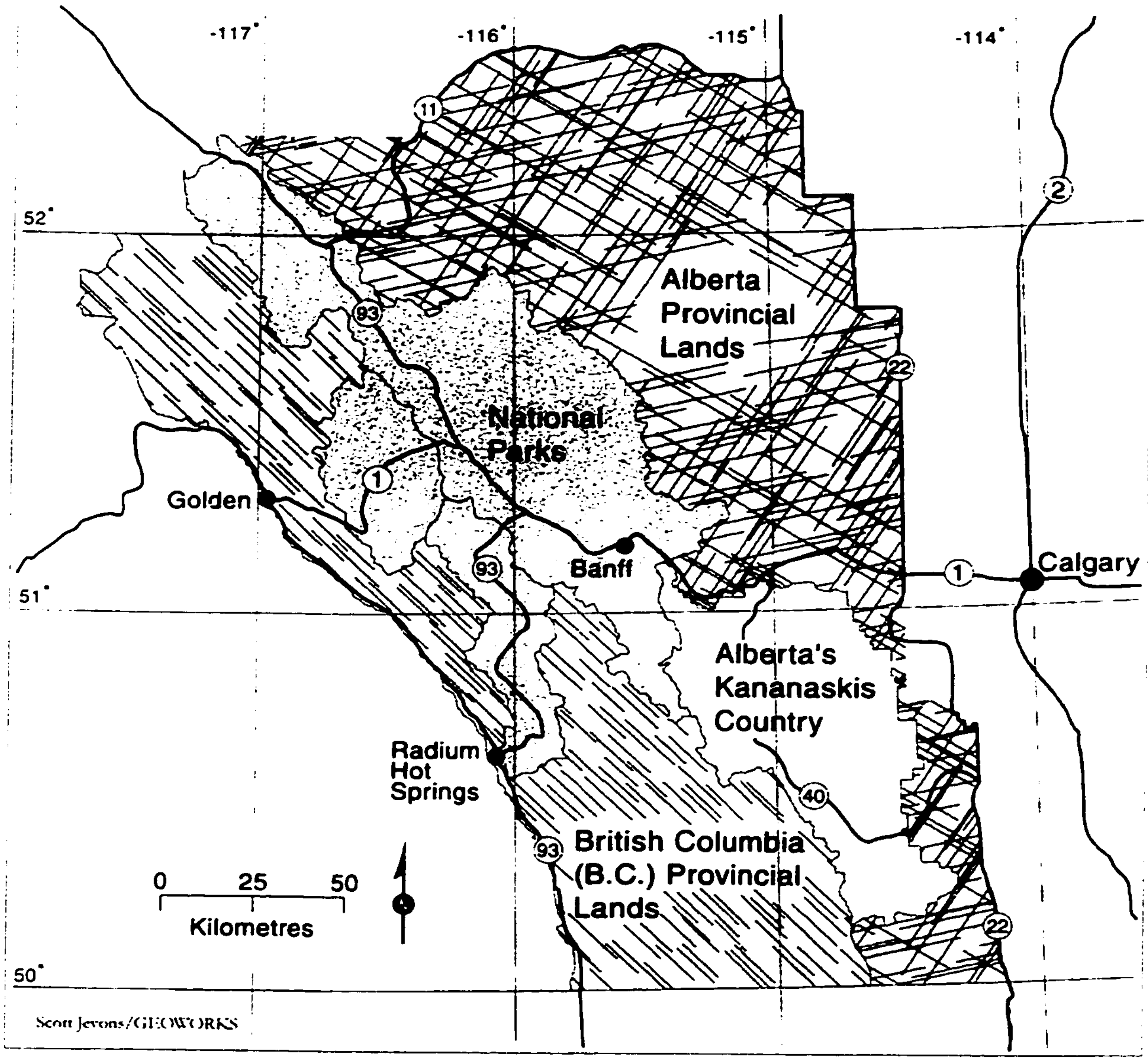

Figure 1. The Central Canadian Rocky Mountains divided into 4 major government jurisdictions: (1) National Parks including, Banff, Yoho, and Kootenay; (2) British Columbia provincial lands, (3) Alberta provincial lands, and (4) Kananaskis Country improvement district.

extraction, mining, agriculture, and stock grazing. Native councils, towns and municipalities, commercial developers and residential owners diversify land administration even further, making this one of the most intensively developed landscapes in the world where grizzly bears still survive.

METHODS

Much of the basis for security area analysis relies on defining the average daily foraging radius and subsequent daily area requirements for an adult female grizzly bear. I used a subset of radio telemetry data from intensive tracking of wary adult female bears gathered between 1994 - 1998 by the Eastern Slopes Grizzly Bear Project in the Central Canadian Rocky Mountains to establish a mean daily movement distance. These data were calculated from the largest linear distance of >2 relocations per day and do not reflect total distance traveled over the course of a day which may be much greater. The calculated average daily foraging radius among all bears sampled is one-half of the mean daily movement distance. Subsequently, the minimum daily area requirement is simply the area of a circle (πr^2) based on the daily foraging radius.

Multi-annual home range data for adult female grizzly bears based on radio-telemetry were obtained from the Eastern Slopes Bear Project east of the Continental Divide (N=19) and the concurrent West Slopes Bear Research Project (Woods et al. 1997) in a contiguous study area west of the Continental Divide (N=9).

Several types of geographic information were compiled for analysis in MapInfo Professional® (MapInfo Corp., Troy, NY) and Idrisi® (Clark Univ., Worcester, MA) GIS systems including:

1. Elevation - A 1:50,000 scale digital elevation model compiled from National Topographic System series maps was used to derive an elevation cut at 2500 m. That elevation was the upper limit of useful grizzly bear foraging through analysis of a grizzly bear habitat model (Kansas and Riddell 1995) for Banff, Yoho, and Kootenay National Parks. More than 99% of grizzly bear telemetry locations (n = 7380) between 1994 - 1998 from the Eastern Slopes Grizzly Bear Project were located below the 2500 m level.
2. Satellite image - A Landsat Thematic Mapper image was used to derive a layer representing vegetated area. The unsuitable areas of snow and ice, rock and bare soil, and water were reclassified out of the image leaving the area actually available to bears.
3. Human activity - Updated human activity data from Central Canadian Rocky Mountains used in a habitat effectiveness model (Gibeau 1998) formed the basis of this layer. The most recent data available from all 4 jurisdictions were compiled into a single map of human activity across the region. These maps categorized vector, point, and polygon data of all motorized roads, trails and facilities into high and low use (USDA Forest Service 1990, Gibeau 1998) based on visitation records and expert opinion. Any area receiving > 100 human visits per month during the active bear foraging season (May-October) was considered to be high use. These data became the basis for delineation of the types and intensity of human uses and their associated disturbance buffers. My mapping could not keep up with continued development, especially on Alberta provincial lands, therefore these maps only portray an absolute

minimum amount of human activity on the landscape. Historical human use maps for Kananaskis Country and Banff National Park were compiled from circa 1950 records and personal interviews (Banff-Bow Valley Study 1996). Future human activity projections for Kananaskis Country were based on a build out scenario from the existing recreational policy and a 6% visitor growth rate for Banff National Park roughly coinciding to the year 2020 (Banff-Bow Valley Study 1996). The major assumption of the human activity maps is that they accurately reflect human use at an ecosystem scale.

Analysis

The initial stage of GIS analysis was to remove areas from the landscape that were unsuitable for foraging for bears. This was accomplished by combining the vegetated cover map with the 2500 m elevation cut. All lands below 2500 m and vegetated were considered available lands for security areas.

Next, all high human use features for past, present, and future time periods were buffered by a 500m zone of influence following standards developed by the IGBC (1998). I consider this a minimum zone of human influence in comparison to research results from Yellowstone National Park (Mattson et al. 1987, Reinhart and Mattson 1990, Mattson et al. 1992, Green et al. 1997). Once the buffered high human use data were prepared, these files were imposed on the map of available/unsuitable lands. This removed all areas within the zone of influence from further consideration. Interim maps depicting habitat patches of all sizes were generated once the area of available landscape outside the zone of influence had been determined.

After removing unsuitable lands, and lands within 500 m of high human use, I eliminated all remaining polygons smaller than the minimum daily area requirement for an adult female grizzly. Based on this analysis, results were tabulated into 4 categories: 1) unsuitable landscape, 2) land base in security area, 3) land not secure due to high human use, 4) and land not secure due to small size. Historical and future scenarios for Kananaskis Country and Banff National Park were prepared in the same manner.

I used the program CALHOME (Kie et al. 1996) to calculate minimum convex polygon (MCP) home ranges for adult female grizzly bears. I chose the 99% MCP to measure potential female grizzly bear occupancy, excluding only extreme outliers. The home range polygons were then converted to GIS map layers. For each adult female home range I prepared a tabulation of the unsuitable landscape, land base in security area, land not secure due to high human use, and land not secure due to small size.

Comparison of the observed telemetry data from weekly aircraft relocations and the security analysis map provided use and expected values for evaluation of resource selection of security areas. In the context of this study, availability was defined as the home range of an individual animal. Both Johnson (1980), and White and Garrott (1990) point out that the home range of an animal already represents some prior selection because of territoriality or food resources. Availability of security differed for each individual bear depending on its home range configuration. This form of third-order selection (Johnson 1980) pertains to the use made of security areas within the home range. Radio telemetry data from each collared individual were overlaid onto the security analysis map to determine the proportions of security used and available within the home range.

The G-test for goodness of fit (Zar 1984) was employed to test the hypothesis that adult female grizzly bears use security areas in proportion to their availability. The G-test was selected because of the ability to partition between and among variables (Sokal and Rohlf 1981). The assumptions that all expected values be above 1 and no more than 20% be less than 5 were met (Zar 1984, Krebs 1989). Given that the goodness of fit test rejects the null hypothesis that use is equivalent to availability, the statistical test reviewed by Neu et al. (1974) and Byers et al. (1984) provided a method for further evaluation of resource selectivity (Alldredge and Ratti 1986, 1992, White and Garrot 1990). Bonferroni confidence intervals (Neu et al. 1974, McLean et al. 1998) led to conclusions about whether security areas were used more, in proportion to, or less than their availability.

I used Spearman correlation coefficients to investigate the degree of association between home range size, the proportion of the land base in security areas, and the amount of land not secure due to high human influence (SAS Inst. Inc., Cary, NC). Results of all statistical tests were considered significant at $P < 0.05$.

RESULTS

I analyzed 227 daily movement episodes from 16 wary adult female grizzly bears to produce a mean daily movement distance of 3.4 km (range 0.2-16.3 km, SE = 0.18 km). Subsequently, the calculated average daily foraging radius was 1.7 km with a 9.0 km^2 minimum daily area requirement.

Removal of rock, ice, water, and areas of bare soil from the analysis as well as an elevation cut of areas greater than 2500 m delineated available areas for grizzly bears. Forty eight percent of the National Park landscape was unsuitable for foraging for grizzly bears. This contrasts sharply with only 12% unsuitable on Alberta provincial lands, 21% unsuitable in Alberta's Kananaskis Country, and 27% unsuitable on British Columbia provincial lands.

Application of a minimum daily area requirement of 9.0 km^2 based on an adult female's daily foraging radius on a map of the available landscape defines security areas as well as land not secure due to human use, and land not secure due to size for each jurisdiction in the Central Canadian Rocky Mountains (Fig. 2). Alberta's Kananaskis Country, with an intensive recreation mandate, had the greatest percentage of its land base (40%) not secure due to human use. Alberta provincial lands followed closely behind with 33%, British Columbia provincial lands 28%, and National Parks 25%. The percentage of land base where adult female grizzly bears will have a low probability of encounters with people (secure) is a function of the amount of productive land available to a bear and the extent of high human influence.

By reconstructing past human use and forecasting into the future for Kananaskis Country and Banff National Park I demonstrated progressive loss of security areas starting with the 1950's, through the present, and continuing into the future (Fig 3). The average size of secure habitat patches in Banff National Park ranged from 218 km^2 in the 1950's, to 56 km^2 currently, and finally 43 km^2 in the future. Corresponding to the decrease in patch size I found an increase in the number of patches from 13 historically, to 39, both currently and into in the future. The same pattern existed throughout

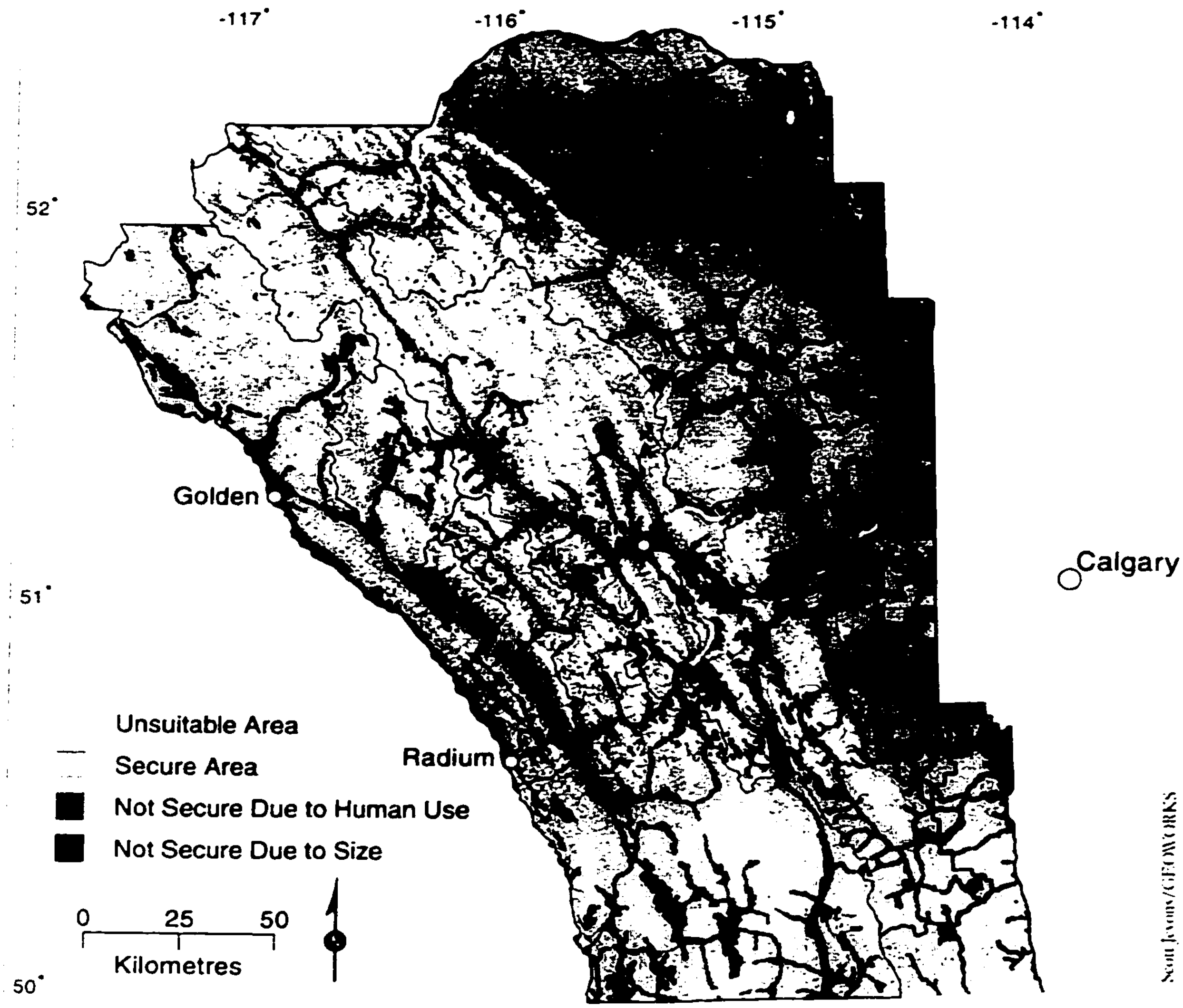

Figure 2. The Central Canadian Rocky Mountains categorized by security area classes.

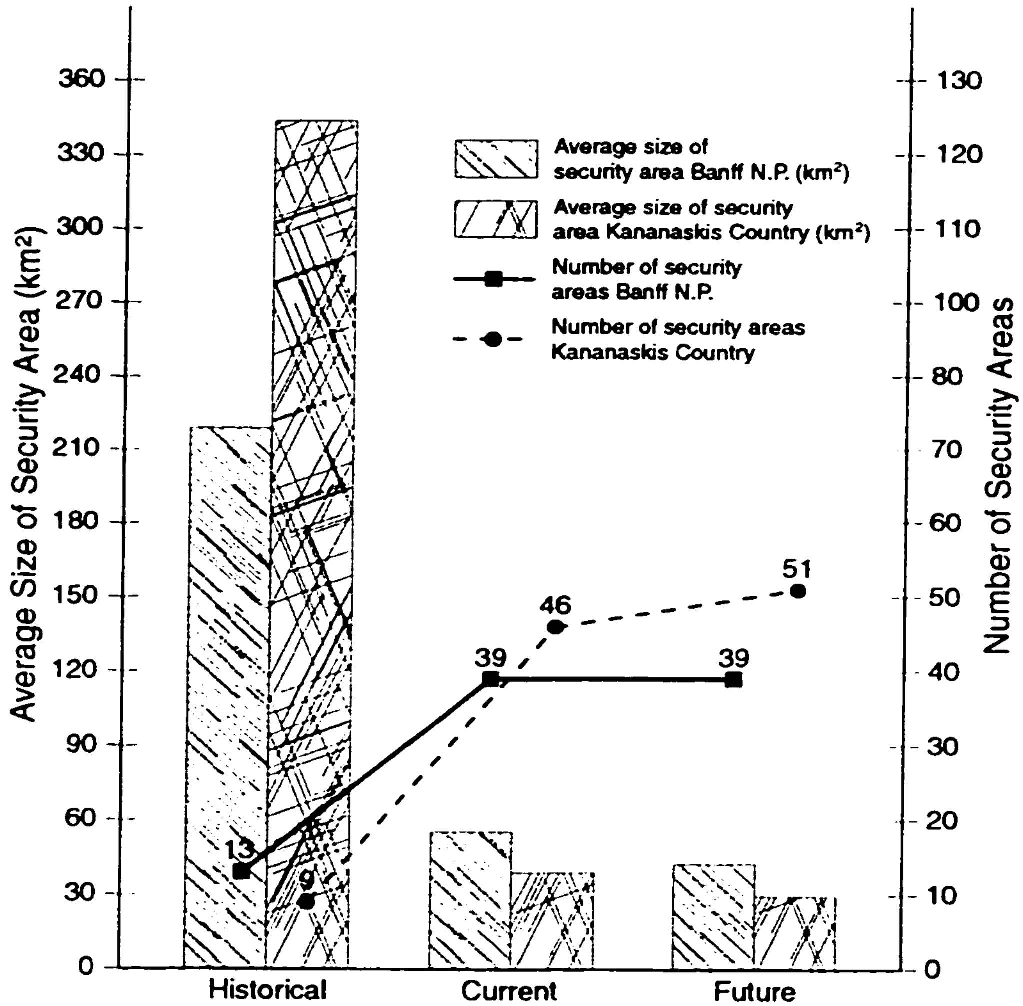

Figure 3. Average size and number of grizzly bear security areas over time for Banff National Park and Kananaskis Country.

Kananaskis Country. Fragmentation and insularization of habitat within both jurisdictions was evident, and accompanied by a loss in the ability to foster the wary behavior in grizzly bears that most managers consider desirable.

My model identified an average of 69% (range 32-100%, SE = 4.2%) of the available land within individual home ranges of adult female grizzly bears as secure (Table 1). Bears with the highest degree of human influence within their home ranges tended to have the least security (bears 24, 26, 47). Several bears had lower than average security despite average or lower than average human influence due to a high percentage of land not secure because the remaining potentially secure areas were too small (bears 18, 41, 61).

Individual G-tests for goodness of fit were significant ($P < 0.01$) for 26 of 28 bears, rejecting the hypothesis that adult female grizzly bears use security areas in proportion to their availability. Further evaluation of resource selection using Bonferroni confidence intervals indicated that 18 of 26 bears used secure areas more than expected. Six bears used secure areas in proportion to availablity, while only 2 bears used secure areas less than expected. One of the 2 bears that used secure areas less than expected was habituated to human presence (M. Gibeau, personal observation).

The proportion of the land base in security areas was negatively correlated with both home range size (Spearman's = -0.559, $P < 0.01$), and the amount of land not secure due to high human influence (Spearman's = -0.556, $P < 0.01$). This association between security and home range size demonstrates that smaller home ranges tend to be more secure.

Table 1. Percent of the available land base in security classes for 28 adult female grizzly bears in the Central Canadian Rocky Mountains.

Bear *ID*	Home Range *(Km2)*	Secure	Not Secure Due To Human Use	Not Secure Due To Small Size
ES17	111	55	39	7
ES18	236	38	42	20
ES24	279	32	57	11
ES26	427	46	46	8
ES28	307	72	21	7
ES30	268	59	38	3
ES31	79	50	41	10
ES32	328	53	37	10
ES33	218	67	29	4
ES36	617	60	28	12
ES37	884	53	40	7
ES40	206	84	12	4
ES41	189	67	17	16
ES46	321	67	29	4
ES47	245	34	60	7
ES55	180	52	36	12
ES57	282	73	27	0
ES61	232	50	34	16
ES62	150	63	34	3
WS35	49	81	9	10
WS42	131	81	6	13
WS44	220	100	0	0
WS71	78	100	0	0
WS74	35	100	0	0
WS282	78	99	0	1
WS284	59	99	0	1
WS289	109	99	0	1
WS295	37	100	0	0

DISCUSSION

My results quantitatively characterized grizzly bear habitat at the landscape level for the Central Canadian Rocky Mountains. This area supports a grizzly bear population which I assume has a significant degree of genetic exchange within it, and some degree of isolation from populations north and south. Four major, different land use jurisdictions were found in the area. Each has a unique land base, different general management policies, and different grizzly bear management. A large percentage (48%) of the land surface area of one jurisdiction, the combined national parks (Banff, Kootenay and Yoho) in my study area, was unsuitable for grizzly bears, primarily because it is composed of rock and ice. This is unfortunate because it has been assumed that these national parks form productive core refugia for difficult to maintain species such as grizzly bears. In the Alberta provincial lands portion of the Central Canadian Rocky Mountains, the percentage of unsuitable land was much less (12%), indicating more productive land, but conflicts with multiple human uses are predicted to increase. British Columbia provincial lands also have less unsuitable land (27%) than National Parks but there too, multiple human uses are expected to rise.

The concept of secure habitat, an area where an adult female grizzly bear can meet its daily foraging needs with a low probability of disturbance by people, was central to my research. Mattson et al. (1992) found that grizzly bears with access to secure habitat maintained desirable wary behavior, had low probabilities of becoming habituated or food-conditioned, and had significantly less mortality than did non-wary adult females. Resource selection indices from my sample of radio collared individuals substantiated that adult female grizzly bears selected security areas, or at least avoided areas that were not secure.

My results characterized habitat security at the adult female grizzly bears' home range level, and on average at the landscape level. For 28 adult female bears throughout the region, an average of 69% of the home range was secure. Female bears within Banff National Park, however, averaged only 60% security within their home ranges. Although female bears in Banff National Park currently have less secure habitat than average, it is probably more predictable into the future, and recent policy changes project modest increases in security (Parks Canada 1997).

The largest percentage of secure habitat within a jurisdiction was on British Columbia provincial lands (68%). Alberta's Kananaskis Country, with 52% secure habitat, and Alberta provincial lands (63%) did not meet the current target level of 68% considered to be adequate security set by the USDA Forest Service (1995) in the Northern Continental Divide grizzly bear ecosystem in northwest Montana. Kananaskis Country, dedicated primarily to recreation and resource development, also had the largest percentage of land in the zone of human influence. Because this area is also dedicated to maintaining all wildlife populations, conflict of objectives occurs and could increase. Only the combined National Parks (68%) and British Columbia provincial lands (68%) met the USDA's target level. A more refined analysis of Banff National Park however, revealed that only 12 of 27 bear management units (48%) exceed target levels (Eastern Slopes Project, unpublished data).

These results give quantitative substance to the assertion that grizzly bears in and around Banff National Park and Kananaskis Country exist in one of the most human-dominated landscapes where they still survive. This was also demonstrated in the habitat effectiveness model applied to Banff, Yoho, and Kootenay National Parks (Gibeau 1998). The effect of these levels of development has been high grizzly bear mortality, even in Banff National Park, and especially in the female cohort, during the 1970s and into the 1980s (Benn 1998). A correlate of Banff National Park having the lowest percentage of its lands not secure due to high human use was that between 1971-1996, 95 out of 107 mortalities occurred in the zone of human influence. Outside of the National Parks, Benn (1998) found within the Alberta and British Columbia portions of the study area that 89% of 172, and 71% of 303 human-caused mortalities were within the zone of human influence. This gives further support to the function of secure habitat in buffering grizzly bears from mortality.

Time series security area analysis (which included only Banff National Park and Kananaskis Country) clearly demonstrated the decreasing size over time of relatively undisturbed habitat units. This habitat fragmentation has occurred throughout Banff National Park and Kananaskis Country, but is dramatic in the Bow River Valley. The decreasing size of security areas was paralleled by a significant decrease in total amount of security area available throughout Banff National Park and Kananaskis Country.

I can surmise, but cannot conclusively demonstrate, that compromised habitat security and habitat fragmentation are having demographic effects by decreasing grizzly bear population size and possibly, long-term population viability. Doak (1995) reached a similar conclusion regarding the linkage between habitat degradation and potential population depression in the Yellowstone ecosystem. I cannot demonstrate demographic and viability effects because baseline data from the past do not exist. However, existing mortality and translocation data, combined with my findings of low security and high habitat fragmentation within adult female home ranges, present converging evidence for grizzly bear population decline across the region.

MANAGEMENT IMPLICATIONS

In the past, habitat effectiveness modeling was the primary tool used to measure the impact of humans activities on bears (USDA Forest Service 1990, Gibeau 1998). The model provided managers with a broad scale measure of the quality and quantity of a bear's foraging opportunities when human activities were taken into account. The model fell short, however, in providing managers with a measure of the human encounter rate and mortality risk that researchers consider equally important as foraging opportunities for population persistence. Security area analysis now provides managers with a measure of the human encounter rate for adult female grizzly bears, at a much more refined scale than the habitat effectiveness model. Security areas help to reduce the incidence of habituated bears, bears killed out of self-defense, and bears killed by management agencies because of unacceptable behavior.

Management agencies in southern Canada now realize that grizzly bears require special consideration to maintain healthy populations. Many of the management prescriptions required are known from experiences in the United States and need only to be applied and refined in southern Canada. Much of this experience can be summarized, arguably, into management of human access (IGBC 1998).

The need to control human access has been acknowledged in Banff National Park, although the mechanisms for doing so are not fully apparent. Management strategies such as those employed in Denali National Park (Schirokauer and Boyd 1998) and Yellowstone National Park (Gunther 1994, 1998) have proven successful. Strict control of human access has been achieved through seasonal area closures, seasonal trail closures, day-use only restrictions, travel limited to mid-day only, and restrictions on party size. For example, in Yellowstone's Pelican Valley bear management area the "area is closed April 1 through July 3. From July 4 through November 10, the area is open to day-use only between the hours of 9 a.m. and 7 p.m" (Gunther 1998:3). The explicit acknowledgment to manage areas for grizzly bear security has been the key to their success (NPS 1982).

To facilitate use by bears, these security areas of no, or low human use should remain in place for some period of time. Access management guidelines adopted by the IGBC (1998) stipulate that once established and effective, security areas should remain in place for at least 10 years. In my opinion however, given grizzly bear's long life span, this duration must be measured in generations and not merely in calendar years.

The National Parks by themselves will not sustain a regional grizzly bear population. Some of the best chances for grizzly bear persistence come from outside National Parks (McLellan et al. 1999) and hence a cooperative and coordinated management approach is critical. The nucleus of an interagency grizzly bear planning committee has been formed in the Canadian Rockies, although its existence seems tenuous without continued commitment from all jurisdictions. There is a clear need for complementary management guidelines that provide security for grizzly bears as they cross jurisdictional boundaries.

Although the concept of providing security areas appears logical and relatively straight forward, perhaps the most challenging steps ahead will be implementation of new management prescriptions to achieve security for grizzly bears. We as humans have never been particularly accepting of land use policy that restricts individual rights and privileges. In the end, grizzly bears may prove to be the ultimate challenge in whether man can coexist with nature.

CHAPTER FIVE : A CONSERVATION BIOLOGY APPROACH TO MANAGEMENT

As we enter the new millennium the science of conservation biology offers a new approach to managing our natural heritage. Born in the 1980's out of concern for the basic issue of eroding biological diversity (Soule 1986), conservation biology has matured to include more than genetic, species, and ecosystem integrity. This expanded definition of biological diversity emphasizes both the processes (e.g., inbreeding, genetic drift, mortality, dispersal, nutrient cycling, succession and disturbance) and the interactions (e.g., coevolution, predation and competition) that play crucial roles in maintaining biological diversity (Beissinger 1990, Noss 1990). Although conservation biology does not encompass all conservation issues, it complements forestry, wildlife management and fisheries management as the newest player in the area of applied ecology (Temple et al. 1988).

Conservation biology has 2 goals: first, to investigate human impacts on species richness and second, to develop practical approaches to prevent the extirpation of species (Soule 1986). Meffe and Carroll (1994) suggest "the false dichotomy of pure and applied research is finally breaking down, as academic researchers and resource managers have joined intellects, experience and perspectives to address local to global conservation problems". This collaboration is evident not just in the biological sciences but also in social sciences, economics and political sciences where many of the real advances or losses in conservation will occur.

Soule (1985) identified conservation biology as a "crisis discipline" acknowledging that decisions and action are often taken without complete knowledge. This is not the way that most scientists are trained, however. In traditional sciences the most persuasive evidence to justify a claim of progress is replication of the results of controlled experiments and development of broad explanatory theories. However, according to Meffe and Viederman (1995) because conservation biology is so young, the proper balance between basic and applied science is still being sought. Unlike many other areas of science, conservation biology is also "mission oriented" (Soule 1986); its goal clearly is to conserve natural ecosystems and biological processes. It is in this context that conservation biology is said to be a value-laden science (Soule 1985).

The science of conservation biology does more than rigorously apply the scientific method. Conservation biologists believe they need to act on scientific finding to inform the planning and policy process. Primack (1993) encapsulates the concept saying, "conservation biologists have to be willing to express an opinion based on available evidence, accepted theory, comparable examples and informed judgment". Ultimately, conservation biologists must assist managers and the public in setting goals and integrating ecologically compatible land uses in a given area. Craighead (1998) pointed out that the wildlife profession in general has been doing this for many years. He goes on to suggest that science alone will not suffice. "As professionals we don't just study or manage animals, we attempt to make changes that scientific value judgements indicate as desirable or necessary".

One underpinning of conservation biology that may go undetected by some is a fundamental shift in ethics. Much of modern conservation biology has grown from, and is guided by Aldo Leopold's land ethic (Meffe and Carroll 1994, Noss and Cooperrider 1994). It is these shifts in ethics which bring about new paradigms. In describing the theory of social change regarding scientific paradigms, Kuhn (1970, as cited in Gunderson et al. 1995) distinguished the alternations between long periods of normal science and sudden scientific revolutions leading to a paradigm shift. Upon reflection, Noss and Cooperrider (1994) state, "we think it is now obvious that our greatest limitation has been philosophical. Past approaches were heavily anthropocentric, utilitarian, reductionist, shortsighted, and arrogantly faithful to technology".

Brunner and Clark (1996) suggest that a new paradigm is emerging out of the science of conservation biology that is the basis for conservation advances on the ground. This evolving paradigm is ecosystem management, and has come about through recent changes in social aspirations (Golley 1993, Burroughs and Clark 1995) as well as acceptance by conservation biologists and some practitioners of natural resource management (Jensen and Bourgeron 1994, Stanley 1995). There are problems with the concept, however, because ecosystem management is not just a technical problem (Gerlach and Bengston 1994, Brunner and Clark 1996).

Ecosystem management is only one goal in an arena of multiple, conflicting societal agendas. Under these circumstances the goal of a management decision becomes ambiguous because it must integrate multiple, often incompatible or incommensurable goals (Brunner and Clark 1996). The function of ecosystem management, Brunner and Clark (1996) emphasize, "is not to evaluate action alternatives as if the decision problems were merely technical but to guide a collective and continuing evolution process that can reduce ambiguities and uncertainties and improve alternatives through the comparative evaluation of practical experience".

This is not a new concept and is nothing more than learning by doing (Walters and Holling 1990), where practitioners in the adaptive management of ecosystems exploit such opportunities to learn from field experience (Holling 1978, Walters 1986, Clark 1993, 1995; Gunderson et al. 1995). The priority is to evolve improvements in principles of conservation biology through reflection on the experience that follows decision and action (Brunner and Clark 1996).

The success or failure of an adaptive management approach in any specific context relies on several basic tenets. Management must be viewed as an experiment by designing "probes" (Walters and Holling 1990) or "prototypes" (Brunner and Clark 1996) that will update our understanding. Individual and institutional learning is paramount (Clark 1993), however, it is difficult (Michael 1995) and very often slow (Clark 1995, Primm and Clark 1996, Mattson et al. 1996). All public decisions are made in the relatively irrational arena of politics (Lasswell 1971). It is therefore important to understand the policy process, and scientists' role in framing and clarifying policy questions (Primm and Clark 1996).

The ultimate test of any applied research program will be if scientific findings are used to inform either policy process or management practices. Over the years, grizzly bears have become one of the vehicles for carnivore conservation policy reform. Biologically, grizzly bears possess much less resilience than many other large carnivores (see Weaver et al. 1996 for a synthesis). Because of conservation needs we are forced to plan and act in a large landscape context. Socially, more than any other North American animal, the grizzly bear may remind us of ourselves (Kellert et al. 1996). Grizzly bears are one of the few animals that underscore the inadequacy of our present protected area system (Herrero 1994). Hence, there is a much broader foundation than just science to hold grizzly bears in some esteem. Managers and practitioners can, and have used grizzly bears to exemplify the concepts of sound ecosystem management (Grumbine 1994) and rally support for inter-jurisdictional cooperation and management (Mattson et al. 1996, Press et al. 1996, Primm 1996). Grizzly bears have also proven to be one of our biggest challenges in policy formulation (MacCracken and O'Laughlin 1998).

Managers need to keep wildlife impacts to acceptable levels by modifying the factors that influence the nature, frequency and magnitude of responses (Knight and Cole 1991). These factors are type of activity, timing, location, frequency, predictability and the characteristics of the species being disturbed. Managers can control human impacts by manipulating these factors. Although my research was not designed explicitly as a behavioral study, an understanding of both proximate and ultimate behavioral factors in grizzly bear ecology are the underpinnings of both the management implications and recommendations. Some of the most important contributions to recovery of threatened populations come from placing animal behavior in context (Beissinger 1997). In the end however, it may be human behavior that dictates whether grizzly bears continue to remain part of the landscape.

CHAPTER SIX: MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

I have documented some of the effects of human development on grizzly bears in one of the most highly developed landscapes in the world where the species still exists. Even with this level of human presence upon the landscape, the national parks, and in particular Banff, are still considered the core refugia within the region. Long term species persistence is, and will continue to be, inextricably linked to management within the core refugia. Banff National Park has acknowledged this responsibility with supportive new direction in its 1997 Management Plan, although the mechanisms for translating policy into action are not fully apparent yet. Management implications and recommendations as a result of this work further substantiate and reinforce earlier recommendations made to the Banff Bow Valley Task Force (Gibeau et al.1996). In making them, I also draw upon other research findings including mortality (Benn 1998), as of yet unpublished reproduction data (Gibeau and Herrero 1999), and a habitat and population viability assessment (Herrero et al. 2000). Although management implications and recommendations are made specifically for Banff National Park, much of the supporting data were collected, analyzed and interpreted in the broader context of the Bow River Watershed and the Central Rocky Mountains.

Management implication 1: Substantial grizzly bear habitat loss has occurred because of human development and activities within the Bow River Watershed, both within and outside Banff National Park.

Because of the species' biological characteristics, grizzly bears recover slowly if at all from population declines, and only if negative mortality factors have been brought under control. These characteristics are part of the reason why human activities can have such a significant impact on grizzly bears. Grizzly bears must be able to move widely and safely throughout their home ranges to access seasonally available resources.

Assessment of habitat effectiveness (Gibeau 1998), movement patterns (Chapter 1), and grizzly bear response (Chapter 3), demonstrate significant spatial avoidance of requisite resources due to humans. The combination of habituated bears using lower quality habitats and demonstrating higher movement rates suggests less energy available for growth and reproduction. Adult female bears within an area of restricted human access used higher quality habitat and traveled less than bears in unregulated areas. Bears were found closer to trails during the human inactive period when within high quality habitat and further from trails when distant from high quality habitat. Female bears remained further than males from paved roads regardless of the habitat quality or time of day. This suggests that substantial habitat loss has occurred in tandem with human development and activities. In my judgment this loss has decreased the carrying capacity of Banff National Park for grizzly bears. Managing human developments and activities as well as mortality will be key to maintaining a viable grizzly bear population. This is especially vital along important movement areas which give certain grizzly bears access to different watersheds isolated by mountain ranges (Chapter 2).

Recommendation 1a: Prepare human access management plans for each of the Carnivore Management Units in Banff National Park. The objective of the plans would be to systematically increase habitat effectiveness for grizzly bears. This can be done by:

(1) restricting use of, or relocating some trails and roads

(2) regulating timing of use, and

(3) limiting or disallowing overnight use of some areas.

Priority should be given to areas having good quality grizzly bear habitat, and human use or developments whose impacts could be lessened through management actions. Increasing habitat effectiveness will also promote connectivity across the Trans Canada Highway (see Management implication 2) and provide security for female bears (see Management implication 3). Particular attention should be given to preventing further erosion of habitat effectiveness and security especially in high quality habitats where highly suitable seasonal grizzly bear habitat exists.

Recommendation 1b: Continue with an aggressive prescribed fire program to restore more natural habitat and increase habitat suitability (quality) for grizzly bears. Fire suppression policies have probably significantly decreased habitat productivity for ungulates and grizzly bears (Hamer and Herrero 1987). The use of fire can enhance grizzly bear habitat quality. Female grizzly bears that have access to predictable and high value foods such as meat and berries attain greater adult size, mature earlier and have larger litters than those with access only to foods with low nutritional value such as roots (Hilderbrand et al. 1999, Mattson et al. 1999, Nagy and Haroldson 1989, Rogers 1977).

Human access to this habitat must be managed to encourage grizzly bear use. For example, the Sawback burn now provides high quality seasonal foods for bears but high human access density in the Bow Valley limits grizzly bear use of those resources (see Management implication 2).

Management implication 2: The Trans-Canada Highway has a profound effect on grizzly bear habitat use and movement, causing significant habitat fragmentation.

Habitat fragmentation and physical barriers pose what many conservation ecologists consider the greatest risk to maintaining species diversity (Wilcox & Murphy 1985, Ralls et al. 1986, Servheen and Sandstrom 1993, Dale et al. 1994, Mills and Smouse 1994, Forman & Alexander 1998). Both traffic volumes (Chapter 2) and habitat alienation (Chapter 3) make the Trans Canada Highway and the Bow River Valley an extremely hostile environment for grizzly bears. This is most acute for adult females where they not only have compromised access to some of the highest quality habitat in the region but also face an almost impenetrable barrier to movement.

Since grizzly bears have large home ranges, a perilous potential currently exists for habitat and population fragmentation (Chapter 2). After five years of data collection, no adult female grizzly bears have crossed the Trans Canada Highway (Gibeau and Herrero 1999). This is not solely due to traffic volumes, however. Female bears from my study were found on average to be > 2000 m from the Trans Canada Highway (Chapter 3) in part from all the other human activity in the Bow Valley. Even with all the effort expended on highway crossing structures, the question remains as to how grizzly bears will work through human activities and developments to get to the mouth of these structures in order that they may cross the highway. While little may be able to be done to reduce traffic volumes on the Trans Canada Highway, reducing human access density will allow bears better access in the valley.

Recommendation 2a: Reduce human access density adjacent to the Trans Canada Highway by controlling timing and volume of human use. Voluntary use restrictions have proven not to be successful in the case of both hikers at Carrot Creek and vehicles along the Bow Valley Parkway during the spring (Parks Canada unpublished data). Because of non-compliance, Parks Canada is now forced to take more immutable action. Some suggestions are:

1) Physically gate the Bow Valley Parkway between the Five Mile Bridge and Johnson Canyon to enforce the spring time closure. Serious consideration must be given to the use of public transportation only on this section of the Bow Valley Parkway for the summer months. Examples of successful comparable systems include Denali National Park in Alaska, Shark Valley in the Florida Everglades and The Maroon Belles in Colorado.
2) Further discourage trail use in the Bow Valley by removing the trailhead parking lots at Carrot Creek, Bourgeau Lake, Castle Warden Station and Baker Creek.

Recommendation 2b: Performance criteria for grizzly bears crossing the Trans Canada

Highway need to be established based on expert judgment and research data. Monitoring of crossing rates and applying an adaptive management approach will be essential until performance criteria are reached. Overall, a substantial budget will be required to achieve an acceptable level of grizzly bear highway crossings.

Management implication 3: Habituation, especially in the female component of the population, does not provide competitive advantage to individual bears.

In Yellowstone National Park, humans killed habituated adult female grizzly bears 3.8 times more often than non-habituated adult females (Mattson et al. 1992). In Banff National Park, extensive development sets the scene for conflicts between grizzlies and people. This situation helps explain the growing problem with habituated grizzly bears (Chapter 1) and with grizzly bear mortalities classified as problem wildlife (Benn 1998). Grizzly bears are finding fewer and fewer opportunities to meet their daily and yearly needs without association with people (Chapter 4). Projection of proposed development and use trends into the future showed grizzly bear habitat being fractionated into ever smaller non-disturbed units thus further stressing individuals and the population. The situation may get worse as older adult females, who have had many years to adjust to changing land uses, are replaced by young females who have to develop home ranges without long term knowledge of resources or human influences on the landscape. Fundamental to maintaining a wary, healthy grizzly bear population is managing habituation (Chapter 1) and food-conditioning in Banff National Park. This is an enormous challenge, however, because of the preconceived expectation that National Parks are recreation areas for millions of people.

Recommendation 3a: Establish areas managed specifically for grizzly bear security through human access restrictions similar to the program in place in Yellowstone National Park (Gunther 1998). Three areas of overlapping adult female grizzly bear home ranges (Gibeau and Herrero 1999) in need of immediate designation are:

1) The area surrounding Spray Lakes including the Middle Spray Valley, Lower Bryant Creek and the Upper Spray River.
2) Northeast of the village of Lake Louise including Corral Creek, Baker Creek, Oyster Creek, Skoki, Little Pipestone and Pipestone River.
3) Flints Park, Upper Panther River, Sawback Creek and the Cascade River complex.

Recommendation 3b: Provide funding and resources to continue, and expand, comprehensive and intensive management of grizzly bears in areas used by both bears and humans including techniques such as aversive conditioning of habituated bears. This cannot be an ad hoc approach as a delicate balance is sought between attracting bears to use the Bow Valley (see Management implication 2) while also preventing habituation. Aversive conditioning is a means of potentially addressing habituation but meets with varying success. However, it should only be viewed as treating a symptom that will have a more permanent solution through redesigning the nature of human use in the area where habituation is occurring.

Management implication 4: Converging evidence suggests the grizzly bear population in the Bow River Watershed, both within and outside Banff National Park, is significantly to severely stressed.

The status of grizzly bears in the Bow River Watershed and the surrounding ecosystem can be viewed as an indicator of regional ecological integrity. This is because grizzly bears are a species with little resilience. Adult female grizzly bears are influenced disproportionately more than other cohorts by human activity (Chapters 1, 2 and 3). Because of large home ranges, low population density and a very low reproductive rate, grizzly bears are easy to remove from any area. These biological characteristics have led to grizzly bears being classified as a vulnerable species nationally and as a species at risk (blue listed) in Alberta (Gibeau et al. 1996). A habitat and population viability assessment for this region (Herrero et al. 2000) predicts population declines for Banff National Park and Kananaskis Country. Grizzly bear mortality management is fundamental to population persistence. Benn (1998) documented a high female mortality rate for Banff National Park and it is possible that the grizzly bear population may not yet have recovered from this numerical population depression. Lag effects are probable with low reproductive rates and especially if subsequent mortality is concentrated in the female cohort.

Recommendation 4a: Because of documented population stresses, management of grizzly bears in Banff National Park must become more conservative. The precautionary principle ought to be the new paradigm. The burden of proof regarding the potential impacts of development should shift to the proponent to prove there would be no significant local or cumulative effect on grizzly bears. Banff National Park has an opportunity to be more proactive instead of waiting for endangered species legislation.

Management implication 5: Grizzly bears must be managed at a regional scale.

National parks by themselves are too small to support a viable population of grizzly bears. A significantly larger area will need to be managed with grizzly bear population viability as an objective (Chapter 2 and 4). The current model that conservation biologists agree is essential for protecting a regions' biological diversity starts with a protected core. A strongly protected area is surrounded by buffer zones where integrated management occurs. Special attention is paid to linkage zones that join together core habitat throughout the region (Chapter 2). To implement such a model in the Central Rocky Mountains would require a dramatically increased level of interagency, multi-stakeholder cooperation.

Recommendation 5a: Implement an interagency mortality/removal monitoring system for the Central Rockies Ecosystem which brings together data from Parks Canada, and the provinces of Alberta and British Columbia. Annual summaries must be published.

Regional targets for total allowable human-caused mortality should be established on a jurisdictional basis based on the best available demographic data.

Recommendation 5b: Re-establish an inter-provincial, federal, and international, multi-stakeholder group with significant responsibilities for strategic management of grizzly bears at a regional scale. Decision makers must be at the table to effect change. Supporting that group of decision makers, a group of technical experts and local managers can bring information into the decision making process. This model has worked for grizzly bear recovery in other ecosystems (IGBC 1998).

Recommendation 5c: Adopt a learning by doing philosophy through the posing and testing of formal research hypotheses. An adaptive management approach needs to be more fully integrated into the decision making process in Banff National Park. Improvements are made through analysis and reflection on the experience that follows decision and action.

Recommendation 5d: Ongoing monitoring and research linking habitat quality, effectiveness and security with population viability should be supported. Equally important will be social science research to integrate the human dimension into an adaptive management approach. This two prong focus could contribute significantly to more science-based management. This evolving knowledge needs to be integrated formally and regularly into regional policy and planning decisions.

LITERATURE CITED

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

Alldredge, J. R., and J. T. Ratti. 1992. Further comparison of some statistical techniques for analysis of resource selection. Journal of Wildlife Management. 56:1-9.

Alldredge, J. R., and J. T. Ratti. 1986. Comparison of some statistical techniques for analysis of resource selection. Journal of Wildlife Management. 50:157-165.

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

Banff-Bow Valley Study. 1996. Banff-Bow Valley: At the crossroads. Technical report of the Banff-Bow Valley Task Force. Prepared for Minister of Canadian Heritage, Ottawa, Ontario, Canada.

Beissinger, S. R. 1997. Integrating behavior into conservation biology: Potentials and limitations. Pages 23-47 *In* J. R. Clemmons and R. Bucholz, (editors). Behavioral approaches to conservation in the wild. Cambridge University Press, Cambridge, United Kingdom.

Beissinger, S. R. 1990. On the limits and direction of conservation biology. BioScience 40:456-457.

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

Benn, B. 1998. Grizzly bear mortality in the Central Rockies Ecosystem, Canada. Masters Degree Project. Faculty of Environmental Design, University of Calgary, Alberta, Canada.

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

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

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

Brunner, R. D., and T. W. Clark. 1997. A practice-based approach to ecosystem management. Conservation Biology 11:48-58.

Burroughs, R. H., and T. W. Clark. 1995. Ecosystem management: A comparison of Greater Yellowstone and Georges Bank. Environmental Management 19:649-663.

Byers, C. R., R. K. Steinhorst, and P. R. Krausman, 1984. Clarification of a technique for analysis of utilization-availability data. Journal of Wildlife Management. 48:1050-1053.

Caughley, G. 1994. Directions in conservation biology. Journal of Animal Ecology 63:215-244.

Cherry, S. 1998. Statistical tests in publications of The Wildlife Society. Wildlife Society Bulletin 26:947-953.

Clark, T. W. 1995. Learning as a strategy for improving endangered species conservation. Endangered Species Update 13:5-23.

Clark, T. W. 1993. Creating and using knowledge for species and ecosystem conservation. Perspectives in Biology and Medicine 36:497-525.

Clevenger, A. P. and N. Waltho. 2000. Attributes influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14: In press.

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

Craighead, J. J. 1998. Thinking like a mountain. Wildlife Society Bulletin 26:908-910.

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

Dale, V. H., S. M. Pearson, H. L. Offerman, and R. V. O'Neill. 1994. Relating patterns of land-use change to faunal biodiversity in the Central Amazon. Conservation Biology 8:1027-1036.

Doak, D. F. 1995. Source-sink models and the problem of habitat degradation: General models and applications to the Yellowstone grizzly. Conservation Biology 9:1370-1379.

Dueck, H. A. 1990. Carnivore conservation: A proposal for the Canadian Rockies. MEDes Project, University of Calgary, Alberta, Canada.

Eastman, J. R. 1997. Idrisi for Windows, User's Manual. Clark University, Worcester, MA., USA.

Eberhardt, L. L., B. M. Blanchard and R. R. Knight. 1994. Population trends of the Yellowstone grizzly bear as estimated from reproductive and survival rates. Canadian Journal of Zoology 72:360-363.

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

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

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

Forman, R. T. T, and M. Godron. 1986. Landscape ecology. J. Wiley and Sons, New York, New York, USA.

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

Gerlach, L. P., and D. N. Bengston. 1994. If ecosystem management is the solution, what's the problem. Journal of Forestry 92:18-21.

Gibeau, M. L. 1998. Grizzly bear habitat effectiveness model for Banff, Yoho, and Kootenay National Parks, Canada. Ursus 10:235-241.

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

Gibeau M. L., and S. Herrero. 1998. Roads, rails, and grizzly bears in the Bow River Valley, Alberta. Pages 104-108 *in* G. L. Evink (editor) Proceedings of the International Conference on Ecology and Transportation, Florida Dept. of Transportation, Tallahassee, Florida, USA.

Gibeau, M. L., and S. Herrero. 1995. Year 1 progress report. Eastern Slopes Grizzly Bear Project. University of Calgary, Alberta, Canada.

Gibeau, M. L., S. Herrero, J. L. Kansas, and B. Benn. 1996. Grizzly bear population and habitat status in Banff National Park: A report to the Banff Bow Valley Task Force by the Eastern Slopes Grizzly Bear Project. University of Calgary, Alberta, Canada.

Gilbert, B. K. 1989. Behavioral plasticity and bear-human conflicts. Pages 1-8 *in* Bear-People Conflicts. Proceedings of a Symposium on Management Strategies. Northwest Territories Department of Renewable Resources, Yellowknife, Canada.

Gilpin, M. and M. E. Soule. 1986. Minimum viable populations: processes of species extinction. Pages 19-34 *in* M. Soule, (editor) Conservation biology: the science of scarcity and diversity. Sinauer Assoc. Inc. Sunderland, Massachusetts, USA.

Golley, F. B. 1993. A history of the ecosystem concept in ecology. Yale University Press, New Haven, Connecticut, USA.

Green, G. I., D. J. Mattson and J. M. Peek. 1997. Spring feeding on ungulate carcasses by grizzly bears in Yellowstone National Park. Journal of Wildlife Management 61:1040-1055

Grumbine, R. E. 1994. What is ecosystem management? Conservation Biology 8:27-38.

Gunderson, L. H., C. S. Holling, and S. S. Light. (editors) 1995. Barriers and bridges to the renewal of ecosystems and institutions. Columbia University. Press, New York, USA.

Gunther, K. A. 1998. Bear management area program, Yellowstone National Park. Information paper No. BMO-5, Bear Management Office, Yellowstone National Park, Wyoming, USA.

Gunther, K. A. 1995. Bear management in Yellowstone National Park, 1960-93. International Conference on Bear Research and Management 9:549-560.

Gunther, K. A. 1994. Bear management in Yellowstone National Park, 1960-93. International Conference on Bear Research and Management 9:549-560.

Gunther, K. A. 1990. Visitor impact on grizzly bear activity in Pelican Valley, Yellowstone National Park. International Conference on Bear Research and Management 8:73-78.

Gutzwiller, K. J. 1991. Assessing recreational impacts on wildlife: The value and design of experiments. North American Wildlife and Natural Resources Conference 56:248-255.

Hamer, D. and S. Herrero. 1987. Wildfires influence on bear feeding ecology in Banff National Park, Alberta. International Conference on Bear Research and Management 7:179-186.

Hanski, I., and M. Gilpin. 1991. Metapopulation dynamics: brief history and conceptual domain. Pages 3-16 *in* M. Gilpin and I. Hanski (editors) Metapopulation dynamics: empirical and theoretical investigations. Academic Press, London, England.

Hansson, L. 1991. Dispersal and connectivity in metapopulations. Pages 89-103 *in* M. Gilpin and I. Hanski (editors) Metapopulation dynamics: empirical and theoretical investigations. Academic Press, London, England.

Harding, L., and J. A. Nagy. 1980. Responses of grizzly bears to hydrocarbon exploration on Richards Island, Northwest Territories, Canada. International Conference on Bear Research and Management 4 :277-280.

Harris, R. B. 1986. Grizzly bear population monitoring: current options and considerations. Misc. Publication No.45, Montana Forest and Conservation Experimental Station, University of Montana, Missoula, Montana, USA.

Harting, A. L. 1985. Relationships between activity patterns and foraging strategies of Yellowstone grizzly bears. M.S. Thesis. Montana State University, Bozeman, Montana, USA.

Hellgren, E. C., D. W. Carney, N. P. Garner and M. R. Vaughan. 1988. Use of breakaway cotton spacers on radio collars. Wildlife Society Bulletin 16:216-218.

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

Herrero, S. 1985. Bear attacks: Their causes and avoidance. Lyons and Burford, New York, New York, USA

Herrero, S., P. S. Miller and U. S. Seal. (editors) 2000. Population and habitat viability workshop for the grizzly bear of the Central Rockies Ecosystem (*Ursus arctos*). Eastern Slopes Grizzly Bear Project, University of Calgary, Alberta, Canada and Conservation Breeding Specialist Group, Apple Valley, Minnesota, USA.

Herrero, S., D. Poll, M. L. Gibeau, J. Kansas and B. Worbets. 1998. The eastern slopes grizzly bear project: Origins, organization and direction. Proceedings of the Canadian Council on Ecological Areas (CCEA), Calgary, Alberta, Canada.

Herrero, S., W. McCrory, and B. Pelchat. 1986. Using grizzly bear habitat evaluation to locate trails and campsites in Kananaskis Provincial Park. International Conference on Bear Research and Management 7:179-186.

Herrero, S., J. Roulet, and M. L. Gibeau. In press. Banff National Park: Science and policy in grizzly bear management. Ursus 12.

Hilderbrand, G. V., C. C. Schwartz, C. T. Robbins, M. E. Jacoby, T. A. Hanley, S. M. Arthur and C. Servheen. 1999. The importance of meat, particularly salmon, to body size, population productivity, and conservation of North American brown bears. Canadian Journal of Zoology 77:132-138.

Holling, C. S., (editor) 1978. Adaptive environmental assessment and management. Vol. 3. John Wiley, London, United Kingdom.

Hovey, F. W. and B. N. McLellan. 1996. Estimating population growth of grizzly bears from the Flathead River drainage using computer simulations of reproductive and survival rates. Canadian Journal of. Zoology 74:1409-1416.

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

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

Jensen, M. E., and P. S. Bourgeron (editors.) 1994. Volume II: Ecosystem management: Principles and applications. General technical report PNW-GTR-318. U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon, USA.

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

Johnson, D. H. 1999. The insignificance of statistical significance testing. Journal of Wildlife Management 63:763-772.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluation of resource preference. Ecology 61:65-71.

Jope, K. L. 1985. Implications of grizzly bear habituation to hikers. Wildlife Society Bulletin 13:32-37.

Kansas, J. L., and R. N. Riddell. 1995. Grizzly bear habitat model for the four contiguous mountain national parks: Second Iteration. Report for Canadian Parks Service, Calgary, Alberta, Canada.

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

Kellert, S. R., M. Black, C. Reid Rush, and A. J. Bath. 1996. Human culture and large carnivore conservation in North America. Conservation Biology 10:977-990.

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

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

Knight, R. L. and D. N. Cole. 1991. Effects of recreational activities on wildlife in wildlands. North American Wildlife and Natural Resources Conference 56:238-247.

Knight, R. R., and L.L. Eberhardt. 1985. Population dynamics of Yellowstone grizzly bears. Ecology 66(2):323-334.

Krebs, C. J. 1989. Ecological Methodology. Harper & Row, New York, New York, USA.

Kuhn, T. S. 1970. The structure of scientific revolutions. 2nd edition. University of Chicago Press, Chicago, Illinois, USA.

Lasswell, H. D. 1971. A pre-view of the policy sciences. Elsevier, New York, New York, USA.

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

MacCracken, J. G., and J. O'Laughlin 1998. Recovery policy on grizzly bears: an analysis of two positions. Wildlife Society Bulletin 26:899-907.

Mace, R. D., and J. S. Waller. 1997. Final report: grizzly bear ecology in the Swan Mountains. Montana Fish, Wildlife, and Parks Department, Helena, Montana, USA.

Mace, R. D., and J. S. Waller. 1996. Grizzly bear distribution and human conflicts in Jewel Basin hiking area, Swan Mountains, Montana. Wildlife Society Bulletin 24:461-467.

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

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

MacHutchon, A. G., S. Hemmer, H. Davis, and M. Gallagher. 1998. Temporal and spatial activity patterns among coastal bear populations. Ursus 10:539-546.

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

Mattson, D. J. 1993. Background and proposed standards for managing grizzly bear habitat security in the Yellowstone ecosystem. Cooperative Park Studies Unit report. University of Idaho, Moscow, Idaho, USA.

Mattson, D. J., 1990. Human impacts on bear habitat use. International Conference on Bear Research and Management 8:33-56.

Mattson, D., K. Barber, R. Maw and R. Renkin. 1999. Coefficients of productivity for Yellowstone's grizzly bear habitat. U.S.G.S. Forest & Rangeland Ecosystem Science Center, Corvallis, Oregon,USA.

Mattson, D. J., S. Herrero, R. G. Wright, and C. M. Pease. 1996. Science and management of Rocky Mountain grizzly bears. Conservation Biology 10:1013-1025.

Mattson, D. J., B.M. Blanchard, and R.R. Knight. 1992. Yellowstone grizzly bear mortality, human habituation, and whitebark pine seed crops. Journal of Wildlife Management 56:432-442.

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

McCann, R. K. 1991. Activity measures of free-ranging grizzly bears (Ursus arctos) in the Flathead drainage. M.S. Thesis, University of British Columbia, Vancouver, British Columbia, Canada.

McLean, S. A., M. A. Rumble, R. M. King, and W. L. Baker. 1998. Evaluation of resource selection methods with different definitions of availability. Journal of Wildlife Management. 62:793-801.

McLellan, B. 1990. Relationships between human industrial activity and grizzly bears. International Conference on Bear Research and Management 8:57-64.

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

McLellan, B. N., and D. M. Shackleton. 1989b. Grizzly bears and resource-extraction harvesting and road maintenance. Journal of Applied Ecology 26 :371-380.

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

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

Meagher, M. and S. Fowler. 1989. The consequences of protecting problem grizzly bears. Pages 141-144 *in* M. Bromley (editor) Bear-people conflicts: Proceedings of a symposium on management strategies. Northwest Territories Dept. Renewable Resources, Yellowknife, Northwest Territories, Canada.

Mech, L. D. 1983. Handbook of animal radio-tracking. University of Minnesota Press, Minneapolis, Minnesota, USA.

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

Meffe, G. K., and S. Viederman. 1995. Combining science and policy in conservation biology. Wildlife Society Bulletin 23:327-332.

Meffe, G. K., and C. R. Carroll. 1994. Principles of conservation biology. Sinauer Associates, Sunderland, Massachusetts., USA.

Michael, D. N. 1995. Barriers and bridges to learning in a turbulent human ecology. Pages 461-488 *In* Gunderson, L. H., C. S. Holling, and S. S. Light (editors) Barriers and Bridges to the renewal of ecosystems and institutions. Columbia University Press. New York, New York, USA.

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

Nadeau, M. S. 1987. Habitats, trail, and campground situations associated with human-grizzly confrontations in Glacier National Park, Montana. M.S. Thesis. University of Montana, Missoula, Montana, USA.

Nagy, J. A. and J. R. Gunson. 1990. Management plan for grizzly bears in Alberta. Alberta Fish and Wildlife Division, Edmonton, Alberta, Canada.

Nagy, J. A. S. and M. A. Haroldson. 1989. Comparison of some home range and population parameters among four grizzly bear populations in Canada. International Conference on Bear Research and Management 8:227-235.

Nams, V. O., and S. Boutin. 1991. What is wrong with error polygons? Journal of Wildlife Management 55:172-176.

National Parks Service (NPS). 1982. Final environmental impact statement, grizzly bear management program. U. S. Department of Interior, National Park Service, Yellowstone National Park, Wyoming, USA.

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

Neu, C. W., C. R. Byers, J. M. Peek, and V. Boy . 1974. A technique for analysis of utilization-availability data. Journal of Wildlife Management. 38:541-545.

Noss, R. F. 1990. Indicators for monitoring biodiversity: A hierarchical approach. Conservation Biology 4:355-364.

Noss, R. F., and A. Y. Cooperrider. 1994. Saving natures legacy: Protecting and restoring biodiversity. Island Press, Washington, D.C., USA.

Noss, R. F., H. B. Quigley, M. G. Hornocker, T. Merrill and P. C. Paquet. 1996. Conservation biology and carnivore conservation in the Rocky Mountains. Conservation Biology 10:949-963.

Olson, T. L. 1993. Resource partitioning among brown bears in Katmai National Park. MSc thesis, Utah State University, Logan, Utah, USA.

Olson, T. L., B. K. Gilbert, and R. C. Squibb. 1997. The effects of increasing human activity on brown bear use of an Alaska river. Biological Conservation 82:95-99.

Olson, T. L., B. K. Gilbert, and S. H. Fitkin. 1990. Brown bear and human activity at salmon streams in Katmai National Park, Alaska: Final report. Interagency agreement IA9700-7-8028. Utah State University, Logan, Utah, USA.

Paquet, P. C. and A. Hackman. 1995. Large carnivore conservation in the Rocky Mountains. A long term strategy for maintaining free-ranging and self-sustaining populations of carnivores. World Wildlife Fund Canada, Toronto, Ontario, Canada.

Parks Canada. 1997. Banff National Park Management Plan. Ministry of Canadian Heritage, Ottawa, Ontario, Canada.

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

Press, D., D. F. Doak, and P. Steinberg. 1996. The role of local government in the conservation of rare species. Conservation Biology 10:1538-1548.

Primack, R. B. 1993. Essentials of conservation biology. Sinauer Associates, Sunderland, Massachusetts, USA.

Primack, R. B. 1992. Tropical community dynamics and conservation biology. BioScience 42:818-820.

Primm, S. A. 1996. A pragmatic approach to grizzly bear conservation. Conservation Biology 10:1026-1035.

Primm, S. A., and T. W. Clark. 1996. Making sense of the policy process for carnivore conservation. Conservation Biology 10:1036-1045.

Raine, M. and R. Riddell. 1991. Grizzly bear research in Yoho and Kootenay National Parks. Canadian Parks Service Report, Calgary, Alberta, Canada.

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

Reinhart, D. P. and D. J. Mattson. 1990. Bear use of cutthroat trout spawning streams in Yellowstone National Park. International Conference on Bear Research and Management 8:343-350.

Rogers, L. L. 1977. Movements and social organization of black bears in northeastern Minnesota. Ph.D. Thesis. University of Minnesota, St. Paul, Minnesota, USA.

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

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

Schirokauer, D. W., and H. M. Boyd. 1998. Bear-human conflict management in Denali National Park and Preserve, 1982-94. Ursus 10:395-403.

Servheen, C., and P. Sandstrom. 1993. Ecosystem management and linkage zones for grizzly bears and other large carnivores in the northern Rocky Mountains in Montana and Idaho. Endangered Species Bulletin 18:310-313.

Shaffer, M. L. 1981. Minimum viable population sizes for species conservation. Bioscience 31:131-134.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry: the principle and practice of statistics in biological research. Second edition. W.H. Freeman, San Francisco, California, USA.

Soule, M. E. 1986. Conservation biology and the "real world" Pages 1-12 *In* M. E. Soule (editor) Conservation biology: The science of scarcity and diversity. Sinauer Associates, Sunderland, Massachusetts, USA.

Soule, M. E. 1985. What is conservation biology? Bioscience 35:727-734.

Springer, J. T. 1979. Some sources of bias and sampling error in radio triangulation. Journal of Wildlife Management 43:926-935.

SPSS. 1998. SPSS 8.0 for Windows. SPSS Inc., Chicago, Illinois, USA

Stanley, Jr., T. R. 1995. Ecosystem management and the arrogance of humanism. Conservation Biology 9:255-262.

Stemlock, J. J., and F. C. Dean. 1983. Brown bear activity and habitat use, Denali National Park - 1980. International Conference on Bear Research and Management. 6:155-167.

Stevens, S., C. Mamo, T. Shury, and M. L. Gibeau. 1999. Eastern slopes grizzly bear project capture program. Unpublished report for the Eastern Slopes Grizzly Bear

Project Steering Committee, University of Calgary, Alberta, Canada.

Temple, S. A., P. F. Brussard, E. G. Bolen, H. Salwasser, M. E. Soule, and J. G. Teer. 1988. What's so new about conservation biology? Transactions of the North American Wildlife and Natural Resources Conference 53:609-612.

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

Thorpe, W. H. 1956. Learning and instinct in animals. Harvard University Press. Cambridge, Massachusetts, USA.

Tracey, D. M. 1977. Reaction of wildlife to human activity along Mount McKinley National Park road. M.S. Thesis. University of Alaska, Fairbanks, Alaska, USA.

USDA Forest Service. 1995. Flathead National Forest plan amendment #19: Allowable sale quantity and objectives and standards for grizzly bear habitat management. USDA Forest Service, Kalispell, Montana, USA.

USDA Forest Service. 1990. CEM - A model for assessing effects on grizzly bears. USDA Forest Service, Missoula, Montana, USA.

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

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

Walters, C. J. 1986. Adaptive management of renewable resources. MacMillan Publishing Co., New York, New York, USA.

Walters, C. J., and C. S. Holling. 1990. Large-scale management experiments and learning by doing. Ecology 71: 2060-2068.

Weaver, J. L., P. C. Paquet, and L. F. Ruggerio. 1996. Resilience and conservation of large carnivores in the Rocky Mountains. Conservation Biology 10:1013-1025.

Weaver, J. L., R. E. F. Escano, and D. S. Winn. 1987. A framework for assessing cumulative effects on grizzly bears. North American Wildlife and Natural Resources Conference. 52:364-376.

Wenum, E. A. 1998. Activity patterns and time budgets of grizzly bears in the Swan Mountains of Montana. MSc Thesis, Montana State University, Bozeman, Montana, USA.

White, G. C., and R. A. Garrott. 1990. Analysis of wildlife radio-tracking data. Academic Press, San Diego, California, USA.

Whittaker, D. and R. L. Knight. 1998. Understanding wildlife response to humans. Wildlife Society Bulletin 26:312-317.

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

Woods, J. G., B. N. McLellan, D. Paetkau, M. Proctor, C. Strobeck. 1997. West Slopes Bear Research Project, Second Progress Report. Parks Canada, Revelstoke, British Columbia, Canada.

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

Zar, J. H. 1984. Biostatistical Analysis, Second edition. Prentice-Hall, Englewood Cliffs, New Jersey, USA.