10.3 RESOURCE SELECTION BY FEMALE GRIZZLY BEARS WITH CONSIDERATION TO HETEROGENEOUS LANDSCAPE PATTERN AND SCALE

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ABSTRACT

Although research suggests that many species perceive multiple scales, few studies have included a range of scale-dependent variables in studies regarding resource selection. We investigate the selection of such features for grizzly bears - a mobile species whose landscape selection could be influenced by landscape pattern. We investigate whether female grizzly bears in the eastern slopes region of the Alberta portion of the Central Rockies Ecosystem select resource characteristics and heterogeneous landscape patterns differently than available within home ranges when landscape patterns are measured at multiple scales simultaneously. Resource characteristics were measured in the 300-m diameter immediate-vicinity of bears, specifically vegetation, slope, aspect, elevation, proximity to edge, proximity to water, and proximity to human activity. Heterogeneous landscape patterns were measured in 300-m, 1.5-km, 3.0-km diameter windows, specifically vegetation diversity, vegetation dominance, terrain ruggedness, density of motorized access, and density of non-motorized access. We used logistic regression to calculate resource selection functions.
Female grizzly bears responded to environmental conditions beyond the immediate vicinity of 300 metres, frequently selecting heterogeneous landscape patterns at different scales, and simultaneously at several scales. We describe results for wary individuals during 2 seasons. All female bears selected pockets of low-density non-motorized access by humans at the 1.5-km scale, within larger 3.0-km areas of high-density non-motorized access by humans. For all female bears, relatively high diversity of vegetation types was selected at the 300-m scale in the preberry season, and selection for high diversity at the 1.5-km scale in the berry season. Homogeneous vegetation within the 300-m scale was never selected. Close proximity to edge was consistently selected. Wary females selected high levels of ruggedness at the broadest scales during both seasons. Also commonly selected were general-shrub, graminoid meadows, and avalanche paths, suggesting their general importance to female grizzlies. We recommend that resource selection studies incorporate variables at multiple scales.

Management along the eastern slopes should maintain vegetation edge and diversity of vegetation communities through the maintenance of disturbance regimes. Furthermore, management should attempt to minimize human disturbance in areas that have any or all of the following characteristics: are within 60 metres of vegetation edges, have high levels of vegetation diversity within 300-m and 1.5-km windows, consist of rugged terrain within broad 3.0-km areas, contain graminoid meadows and avalanche paths, or are close to riparian areas. To take into account habitat selected by grizzly bears levels of human access should be minimal in contiguous 1.5-km diameter areas that contain these habitat attributes. We recognize that competing land use pressures will often exist.

In applying seasonal resource selection functions to the eastern slopes landscape, we identified 4 geographic areas containing a concentration of high probability of adult female occurrence. These areas were: 1) around Lake Louise, 2) from the Red Deer River/Ya Ha Tinda area, south to and including the Burnt Timber drainage, 3) around Banff townsite, and 4) along the Canmore/Bow River corridor as far east as the Kananaskis River drainage and the Old Fort Creek drainage, and extending south to include the Wind Valley and the Evan-Thomas Recreation Area. We also identified numerous smaller pockets of high probability of female grizzly occurrence distributed throughout the study area but especially south of the Trans Canada Highway. Each of the 4 areas with a concentration of high probability of adult female use is a candidate for management that will allow for grizzly bear habitat use with minimal human-caused mortality risk. This will be challenging because of extensive human use in these areas.

INTRODUCTION

There is increasing interest and attention to the possibility that many species select resources at multiple scales (Senft et al. 1987, Otis 1998). Several studies have described the influence of scale upon resource selection for species of mammals, birds, and insects (With 1994, Wallace et al. 1995, Meyer et al. 1998, Clark et al. 1999, Naugle et al. 1999, Kerkhoff et al. 2000, Apps et al. 2001). However, most studies of grizzly bear ecology have investigated habitat use by describing attributes in the immediate environment only, for example within a few hundred metres of a bear location. Mace and Waller (1997) suggested that grizzly bears might perceive broad landscapes and multiple scales, one example being the selection of small microsites within broad cover types when foraging (Waller and Mace 1997). Recently Apps et al. (In press) found correlations of bear locations with ecological attributes at various coarse scales.

Proximity and juxtaposition of various landscape or resource characteristics also influence the distribution of individuals within a species (Milne et al. 1989, Dunning et al. 1992). Landscape pattern has not been frequently considered in wildlife studies (Otis 1998). The movements of a highly mobile species such as the grizzly bear might be influenced by the pattern of landscape attributes at different scales. Landscape pattern can be described by measuring the level of heterogeneity of various features (O'Neill et al. 1988). Because a landscape may appear homogeneous at one scale but heterogeneous at another (Musick and Grover 1991), the measurement of heterogeneity is dependent on spatial scale. Analysis of historical sightings of grizzly bears in Washington suggested that bears selected vegetation diversity within areas that were 550-m diameter (Agee et al. 1989). Otherwise, the selection of heterogeneous landscape patterns at various scales beyond the immediate vicinity of individual grizzly bears has not been thoroughly investigated.

Understanding resource selection by grizzly bears is one important component of management to ensure population persistence. In the eastern slopes of the Canadian Rocky Mountains in Alberta, as in other ecosystems, the survivorship and productivity of adult female grizzly bears are critical to population viability (Knight and Eberhardt 1985, Garshelis et al. 2005). Consequently, detailed knowledge of multi-scale resource requirements of female grizzlies might aid conservation of the species. In this paper, we investigate whether female grizzly bears in the eastern slopes region select resource characteristics and heterogeneous landscape patterns differently than available within home ranges when landscape patterns are measured at multiple scales simultaneously. The resource characteristics we measured were: vegetation, slope, aspect, elevation, proximity to edge, proximity to water, and proximity to human activity. Each of these variables was measured within a 300-m diameter window of bear and random locations. We defined landscape patterns as the level of vegetation diversity, vegetation dominance, terrain ruggedness, density of motorized access by humans, and density of non-motorized access by humans, measured at 3 scales (in 300-m, 1.5-km, 3.0-km diameter windows around bear and random locations).

This multiscale investigation provides information for land managers using a fine-filter approach. To support conservation of female grizzly bears, managers can preserve or manipulate the variables with which bear locations are correlated. In contrast, coarse-filter approaches would involve the management of variables that are correlated with bear range across large regions.

STUDY AREA

We conducted this research along the eastern slopes of the Alberta portion of the Central Rockies Ecosystem. This is part of the Continental Ranges of the Southern Rocky Mountains, part of the Eastern System of the Canadian Cordilleran region, located approximately 100 km west of Calgary, Alberta (Bostock 1970) (Figure 1). The study area was approximately 22,000 km^2, defined by the outermost movements of radio-collared grizzlies. In this chapter, we focus on adult females whose home ranges were located within the 11,400 km^2 area of the Bow River watershed (Gibeau and Herrero 2001) (Figure 1). Analysis was conducted within the home ranges of radio-collared females (Figure 2). Gibeau (2000) presents additional details regarding the Bow River watershed. Based on expected ecological similarity results were extrapolated to the larger 22,000 km^2 study area.

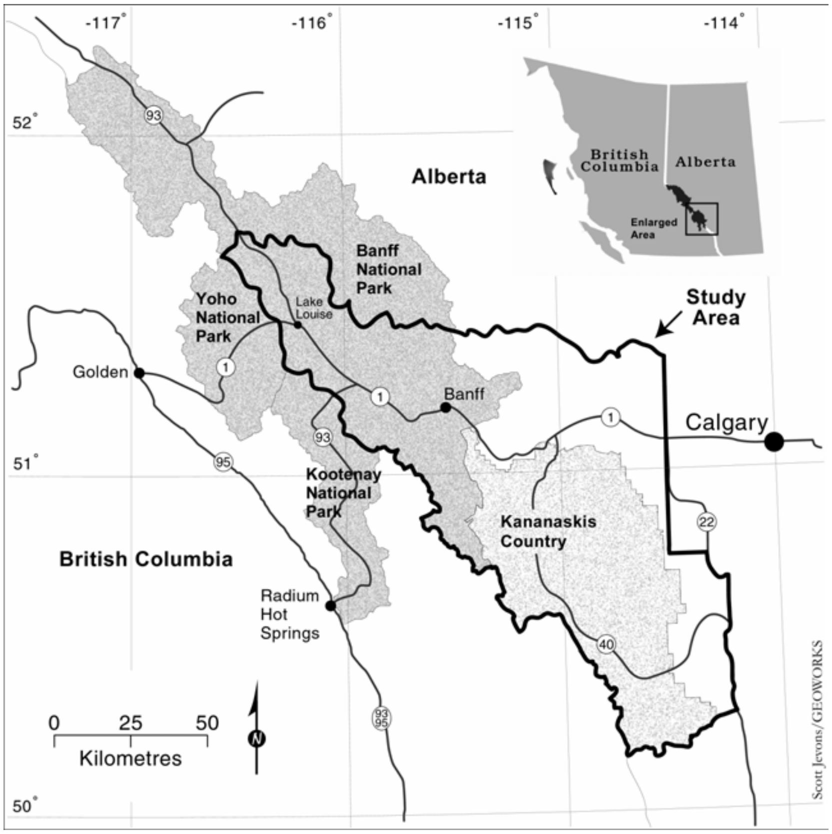

Figure 1. Study area, specifically the Bow Valley Watershed, and the surrounding region during 1994 to 1999. Human activity is illustrated by major transportation routes only.

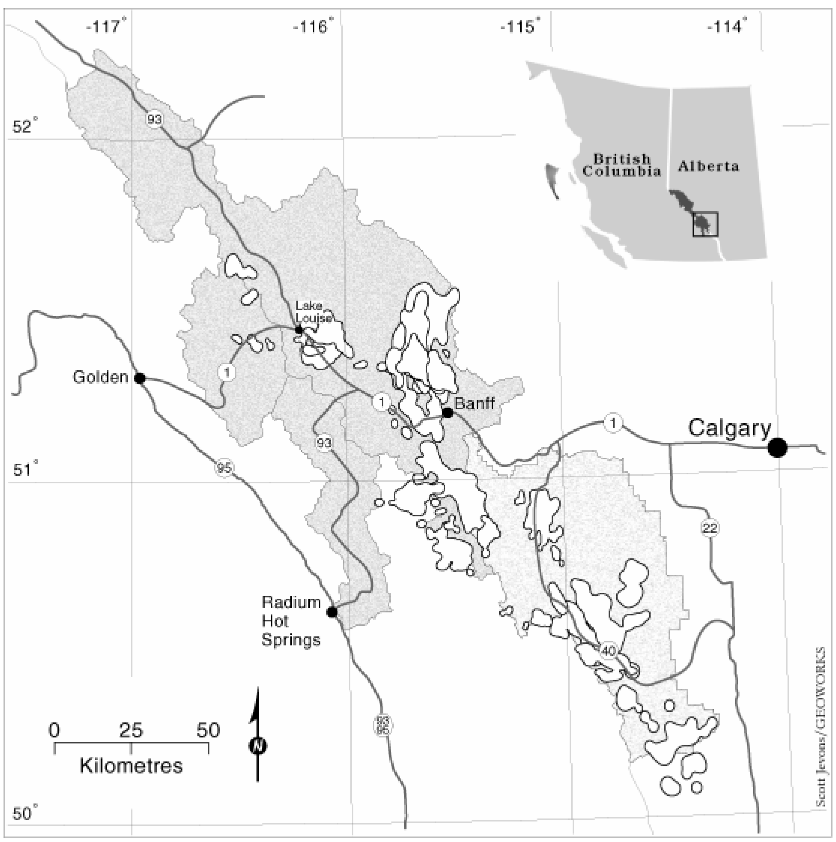

Figure 2. Composite home ranges, pooled across seasons and years, for individual female grizzly bears investigated in the study area from 1994 to 1999 (Theberge 2002).

METHODS

Telemetry and Data Collection

Grizzly bears were captured and radio collared in the study area between 1994 and 1999 (Stevens et al. 1999). Individuals were equipped with either a conventional VHF radio collar or ear tag transmitter. We only included aerial locations in the analysis to ensure that the spatial relationship between relocations was not influenced by limitations in access through mountainous terrain by observers. Aerial relocations were acquired (using the methods of Mech 1983) every 1 to 2 weeks during the daylight hours. Accuracy of air telemetry was estimated to be within 150 metres and was determined by testing with radio collars placed in known locations (Gibeau 2000). We assumed the aerial relocations were independent, and we screened them to ensure that locations were more than 24 hours apart. It is likely that an adult female grizzly bear can cross its home range in less than 24 hours (personal observation), and consequently has access to any location in its home range in that time frame. In later sections, we refer to relocations as bear locations or used locations.

The individuals included in this study were 14 adult female grizzly bears that were of reproductive age (> 6 years old) and that exhibited wary behaviour towards humans. Also investigated in the study, but not reported here, was resource selection of females with cubs-of-the-year and habituated female bears (Theberge 2002).

We classified individual bears into 2 behavioural approaches towards humans, wary and habituated, based on field observations (described in Gibeau 2000). Individual bears that exhibited tolerance towards humans were considered to be habituated (Mattson et al. 1992). For example, some habituated individuals in the eastern slopes study area approached people, used areas close to roads, and crossed highways more than wary individuals (Mueller 2001). Theberge (2002) analyzed habituated female bears separately from wary females to account for potentially different resource selection characteristics of each group, particularly in response to variables related to human presence. We assume that most jurisdictions prefer to manage landscapes to encourage survivorship of wary bears.

Female grizzlies used in this study were followed using telemetry relocations for 4 to 6 years. We pooled data for individual bears across years to maximize sample size, and stratified by 2 seasons.

We identified 2 seasons. The "preberry season" extended from den emergence, approximately the 1st of May, to 15th of July. We named the second season the "berry season", referring specifically to the summer during which many berry species were ripe, through to the late fall when berries were no longer available. The commencement of the "berry season" coincided with the emergence of buffaloberry (*Shepherdia canadensis*) generally around the 16th of July, and extended until after the buffaloberries were no longer available and the bears re-entered the dens around approximately the 31st of October (as is consistent with other research in this study area - Gibeau 2000, Mueller 2001). We identified these seasons to facilitate analysis of resource selection across time, because season had a significant effect on habitat selection in other studies (McLellan and Hovey 2001).

We estimated home ranges for each bear for each season using the 95% fixed kernel algorithm available in the software program KernelHR (Seaman et al. 1998).

To facilitate estimation of a resource selection function (RSF), we generated approximately 3,000 random locations inside each seasonal home range for each bear. Collectively, these random locations represent the relative availability of resource characteristics within the home ranges. In later sections, we refer to these randomly chosen locations as available locations.

Resource and Landscape Characteristics

We extracted resource characteristics for bear locations and random locations from digital data layers using a Geographic Information System (GIS) within the seasonal home ranges of each bear. Unless otherwise noted, all digital data layers were in raster format with 30-metre pixel resolution. For spatial analysis, we used the following software: MapInfo version 4.5 (MapInfo Corporation 1997), ArcView version 3.1 (ESRI 1998), and IDRISI 32 (Clark Labs 1999).

We measured 2 types of resource and landscape characteristics, and called them "immediate-variables" and "heterogeneity-variables". Immediate-variables were measured within an area 300-m in diameter surrounding bear and random locations, and included the variables slope, elevation, aspect, and vegetation type. The immediate-variables also included distance measures such as proximity to edge, proximity to water, and proximity to human access. Heterogeneity-variables described landscape patterns at 3 scales, specifically 300-m, 1.5-km, and 3.0-km diameters, and included density of motorized human access, density of non-motorized human access, vegetation diversity, vegetation dominance, and ruggedness. These heterogeneity-variables are scale-dependent. Scale is defined as a combination of grain, specifically the resolution of the data, and extent, specifically the dimensions of the study area (Turner et al. 1989). We investigated 3 scales (3.0-km, 1.5-km, and 300-m diameter) by holding the extent constant and changing the resolution. The broad 3.0-km scale reflects the average daily movement of adult female grizzly bears, which in the eastern slopes region is approximately 3.4 km covering an area of 9.0 km^2 (Hamer and Herrero 1983, Gibeau et al. 2001).

Immediate-Variables

Slope, elevation, and aspect of each random and bear location were extracted from a digital elevation model (Wierzchowski 2000) with a 30-metre resolution. For slope and elevation, we accounted for telemetry error by averaging the slope and elevation over an area 150-metres in radius (70,686 m^2). Averaging was conducted using a moving window routine in a raster-based GIS. We recorded slope in degrees, later dividing by 10 so that the odds ratios for the RSF could be interpreted as changes in probability in bear use given a change in slope of 10 degrees. We recorded elevation in metres, later dividing by 100 so that the odds ratios from the RSF could be interpreted as changes in probability of bear use given a change in elevation of 100 metres. We divided aspect into 5 classes (NE-facing, NW-facing, SE-facing, SW-facing, and flat). We accounted for telemetry error using a 300-metre diameter moving window routine where the dominant aspect type, the modal class, was assigned to each 30-metre pixel in the image.

Vegetation characteristics associated with each random and bear location were determined from a land cover layer derived from Landsat Thematic Mapper (TM) images taken in August 1995 and 1998 (Wierzchowski 2000). Originally, the land cover layer contained the following 7 classes: water, ice/ snow, rock/ soil, deciduous forest, graminoid, shrub, and conifer. Subsequently, we subdivided the latter 3 classes relative to their abiotic attributes (details provided below), resulting in the following classes: graminoid, steep-slope-avalanche-mix, general-shrub, shrub-SW-facing, general-conifer, and conifer-SW-facing. Consequently, our analysis examined 10 vegetation classes, also referred to as vegetation types. This subdivision made the classes more sensitive to understory vegetation that might be used by grizzly bears. We accounted for telemetry error using a 300-metre diameter moving window routine in which the dominant habitat type, the modal class, was assigned to each 30-metre pixel in the image (Mace et al. 1996).

Steep-slope-avalanche-mix (hereafter called avalanche) referred to areas with steep slopes (>30 degrees), high elevation (> 2300 metres), and high level of greenness reflectance (>35 raw score) in which the dominant vegetation type was graminoid meadows or shrub. Approximately 5% of this vegetation type classified in this manner also contained conifer trees. Nearly 40% of this vegetation type contained avalanche paths, but sometimes they also contained grass-shrub-conifer vegetation types that were in areas of high relief that have a strong likelihood of producing avalanches.

The conifer and shrub classes were subdivided by aspect and slope to delineate those vegetation types on south-west facing slopes with dry slopes where the production of grizzly bear foods might be substantial. In conifer forests, primary grizzly bear foods were buffaloberry, bearberry (*Arctostaphylos uva-ursi*), grass species, and ant larvae. In shrub fields, primary grizzly bear foods were buffaloberry, yellow hedysarum (*Hedysarum sulphurescens*), pink hedysarum (*H. alpinum*) and ant larvae (Hamer and Herrero 1983). Of specific interest were areas that faced 180-270° azimuth with slopes greater than 3 degrees. We subdivided the conifer and shrub classes by these slope and aspect criteria, and called the resulting classes shrub-SW-facing and conifer-SW-facing. Conifer forests on non-SW-facing slopes, including flat areas, were termed general-conifer. Similarly, shrub fields on non-SW-facing slopes, including flat areas, were termed general-shrub. In the analysis of the resource selection functions, we described bear use of classes within the categorical variables, specifically aspect and vegetation, relative to bear use of a "reference-category". We chose general-conifer as the reference-category for vegetation due to neutral selection of this vegetation type by the female grizzlies. We chose flat as the reference-category for aspect to facilitate comparison with other aspect classes.

The hydrology layer contained information from digital data, at 1: 50,000 scale, from the National Topographic System (see http://maps.nrcan.gc.ca/topographic.html), and base data from the Province of Alberta. The digital human use layer, at the 1: 50,000 scale, contained vector, point, and polygon data of motorized roads, trails and human facilities. The human use layer was created in 1998 and subsequently updated (Gibeau 2000). Both the vector hydrology and human use layers were rasterized at 30 metre resolution.

Several proximity measures were calculated for each bear and random location by measuring the straight-line distance (in metres) to the closest attribute, specifically distance to edge, water, and human access. Although the distances were measured in metres, we divided the data by 100 so that the odds ratios for the RSF could be interpreted as changes in probability of bear use given a change in distance of 100 metres. Edge referred to any boundary between vegetation types identified in the land cover layer. Water referred to permanent water bodies such as lakes, rivers and streams. Human access referred to linear features and nodes of human use, including the Trans-Canada Highway, railway, paved and unpaved roads, high and low use trails, and campgrounds.

Heterogeneity-Variables

Density of human access (km/km^2) was described for 2 types of human use, specifically motorized access and non-motorized access. Motorized access included roads capable of being driven on and railways. Non-motorized access included hiking trails. For both types of human activity, densities were measured within the home ranges in both 1.5-km diameter (1,767,146 m^2) and 3.0-km diameter (7,068,584 m^2) moving window routines.

Pattern of vegetation types was described using diversity and dominance indices (Turner et al. 1989) at 3 scales using moving window routines at 300-metre diameter, 1.5-km diameter, and a 3.0-km diameter. Diversity of vegetation types was calculated using the following equation:

$$H = -\Sigma \sum_{k=1}^{s} (P_k)*(\ln(P_k))$$

where P_k is the proportion of the kernel in vegetation type k, and s is the number of vegetation types observed (Turner 1989). Dominance measures the extent to which one or a few vegetation types dominate within 300-m, 1.5-km and 3.0-km analysis-windows,

$$D_o = H_{\max} + \sum^{s} (P_k)*(\ln(P_k))$$

where s is the number of vegetation types observed, P_k is the proportion vegetation type k in a given kernel, and $H_{\max}$ is ln(s) which is the maximum diversity when vegetation types occur in equal proportions (Turner 1989). We measured both diversity and dominance of vegetation types to aid in interpretation of the degree of heterogeneity that existed in analysis-windows. For example, areas with several vegetation types in relatively equal proportion to each other would be characterized by positive selection of diversity, and negative selection or non-significance of dominance. Conversely, if both diversity and dominance were positively selected, then one or two vegetation types dominated in area over the several other types present.

Variability in topography was described using a ruggedness index at 3 scales using moving window routines at 300-m, 1.5-km, and 3.0-km diameters. Ruggedness was calculated using the following equation:

$$TR = ((CDr)*(AVr)) / ((CDr)+(AVr))$$

where CD is the density of contour lines within a given kernel, AV is the variability of eight cardinal aspects within a given kernel, and r is the kernel size (300-m, 1.5-km, or 3.0-km diameter moving window) (Nellemann and Thomsen 1994, Gibeau 2000, Clevenger et al. 2002). Contour lines and aspects were obtained from a digital elevation model (Wierzchowski 2000) with a 30-m pixel resolution.

Building RSF Models

We utilized logistic regression to compare used and available resource characteristics, for wary and habituated bears during the 2 seasons. Multi-scale models were created for wary bears in the preberry and berry seasons.

We used logistic regression to differentiate used (telemetry) and available (random) resources in individual home ranges (Thomas and Taylor 1990, described as 'design III' in Manly et al. 1993) to model the relative probabilities of occurrence for adult female grizzly bears as a function of the combination of variables measured (Manly et al. 1993, Mace et al. 1996, Mace et al. 1999). Resource selection functions (RSFs) were defined as having the following form (see equation 8.7 from Manly et al. 1993: page 127):

$$w(x) = \exp(\beta_1 x_{k1} + \ldots \beta_p x_{kp})$$

where $w(x)$ is the RSF and $\beta_1 x_{k1} + \ldots \beta_p x_{kp}$ is the linear combination of characteristics of the available resource units. We used backward stepwise elimination, thereby removing variables when $p > 0.05$. We screened pairs of continuous variables for multicollinearity using the Spearman rank correlation coefficient. We removed one variable of a correlated pair if correlations were greater than 0.80. Correlations between 0.50 and 0.80 were investigated for domination of one variable over the other. If domination occurred, one variable of the pair was removed. We considered final models with $p \leq 0.05$ to be significant. We considered individual variables to be significant in the model when $p \leq 0.05$. Relative probabilities of bear occurrence were spatially displayed using ArcView 3.1.

Interpretation of Results

The odds ratio ($\exp(\beta)$) describes the relative probability of being in one group divided by the relative probability of being in the other group (the groups being bear or random location) (Manly et al. 1993, Tabachnick and Fidell 1996). The odds ratio is the increase (or decrease) in the odds of being in one outcome category given an increase in the value of the predictor by one unit (Tabachnick and Fidell 1996). For distance measures, we interpreted the odds ratio as the relative probability that a bear would use a location that is further away from a habitat attribute, such as a vegetation edge, given that 2 locations had identical habitat attributes except that one was further away than the other from the habitat attribute to which distances were measured. Similarly, for categorical variables, the odds ratio for each category is compared to reference-category (general-conifer and flat). For example, the odds ratio would express the relative probability that a bear would use a specific vegetation type in reference to the general-conifer reference-category. The direction of the relationship of the odds ratio was expressed as negative or positive. For heterogeneity indices, specifically diversity, dominance and ruggedness, we described the odds ratio only in the direction of the relationship, because it is difficult to interpret the increase of an index by one unit. Comparisons for odds ratios could only be made between the main effects for variables if the unit of measurement was the same (e.g. distance in metres, or ruggedness). However, for categorical variables (e.g. aspect and vegetation) comparisons could be made between sub-categories.

We also expressed the odds ratio in terms of percent change in the likelihood of selection. The "selection strength" of each variable is the percent change in the relative likelihood of selection given one unit of increase for continuous variables, or given the presence of a category compared to the reference-category. We excluded the following variables from analysis due to domination or multicollinearity: dominance (3.0-km and 1.5-km scales), ruggedness (1.5-km scale), density of non-motorized access (1.5-km scale), and proximity to humans.

To graphically illustrate the distribution of relative RSF values across the study area, the variable coefficients were applied to digital layers of the study area. Relative RSF values were transformed using natural logarithms, and classes of relative probability of bear occurrence were created based on standard deviations from the mean logarithmic relative RSF value.

RESULTS

Models in both seasons were significant (Preberry season: -2LL=3911.4, $\chi^2 = 878.5$, df=20, $p<0.001$, $N_{used}=396$, $N_{available}= 42652$; Berry season: -2LL=3913.4, $\chi^2 = 1791.5$, df=16, $p<0.001$, $N_{used}=410$, $N_{available}= 39459$). Detailed results are described in Theberge (2002, page 133, Table 4-7).

Resource selection is summarized to aid visual comparison between models at each scale (Figure 3). Selection or avoidance of categorical variables, vegetation and aspect, are in reference to the general-conifer and flat classes, respectively. Most of the heterogeneity-variables were selected by female grizzly bears. Several immediate-variables were selected.

Of the heterogeneity-variables in the preberry season, those at the 3.0-km scale dominated, with strong significance for ruggedness and density of non-motorized access ($p<0.0001$), and negative significance (avoidance) for density of motorized access (p=0.0001). Diversity at 3.0-km was also negatively significant (p=0.0160). Density of non-motorized access was negatively selected (avoided) at the 1.5-km scale (p<0.0001). Few heterogeneity-variables were significant at smaller scales.

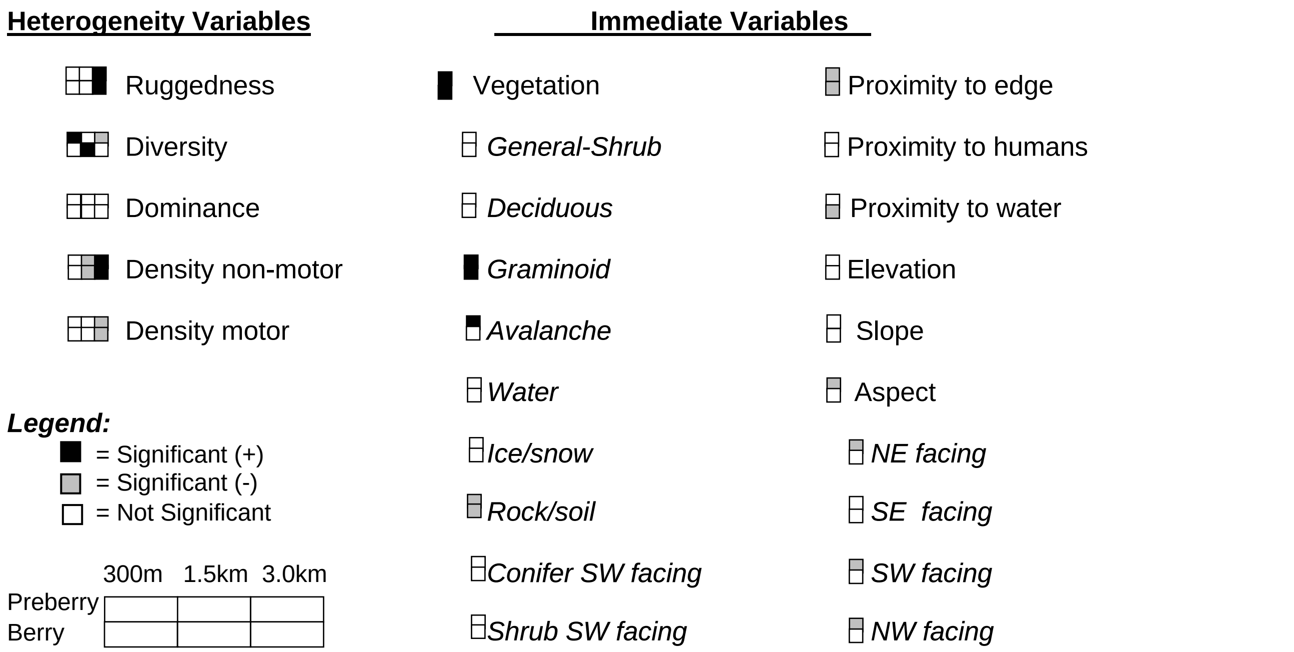

Figure 3. Comparative illustration of results from two seasonal multi-scale models investigating resource selection for wary female grizzly bears. Within each row of squares, each square represents the relationship of a variable to a specific seasonal model (see legend). Specifically, individual squares represent wary bears in the preberry season, and wary bears in the berry season. Significance was p $\leq$ 0.05. Additional details are provided in original dissertation (Theberge 2002, page 133).

During the berry season, wary bears selected many of the same heterogeneity-variables at the 3.0-km scale as in the preberry season. Compared to the preberry season at the 3.0-km scale, significance was comparably strong for both density of non-motorized access and motorized access (p<0.0001), but weaker for ruggedness (p=0.0208). At the 1.5-km scale, bears selected density of non-motorized access with strong significance (p<0.0001), and diversity with less significance (p=0.0249). Heterogeneity-variables were not selected at the 300-m scale. Dominance was not selected in either season. Relative probabilities of occurrence by adult female grizzly bears across the study area (Figures 4 and 5) illustrate that valley sides, valley bottoms, and especially valley bottom confluences, were likely to be used frequently. These areas tended to have relatively open montane or sub-alpine vegetation where human activity, such as trail or road building, has opened the tree canopy. Within these areas are pockets of higher probability of female grizzly occurrence. The spatial distribution of areas with the highest probability of occurrence varies between the two seasons but is somewhat similar (e.g. see inset of Figures 4 and 5).

Geographically defined areas that had a concentration of high probability of female grizzly occurrence were: 1) around Lake Louise, 2) from the Red Deer River/Ya Ha Tinda area, south to and including the Burnt Timber drainage, 3) around Banff townsite, and 4) along the Canmore/Bow River corridor as far east as the Kananaskis River drainage and the Old Fort Creek drainage, and extending south to include the Wind Valley and the Evan-Thomas Recreation Area. Also numerous smaller pockets of high probability of female grizzly occurrence were distributed throughout the study area but especially south of the Trans Canada Highway.

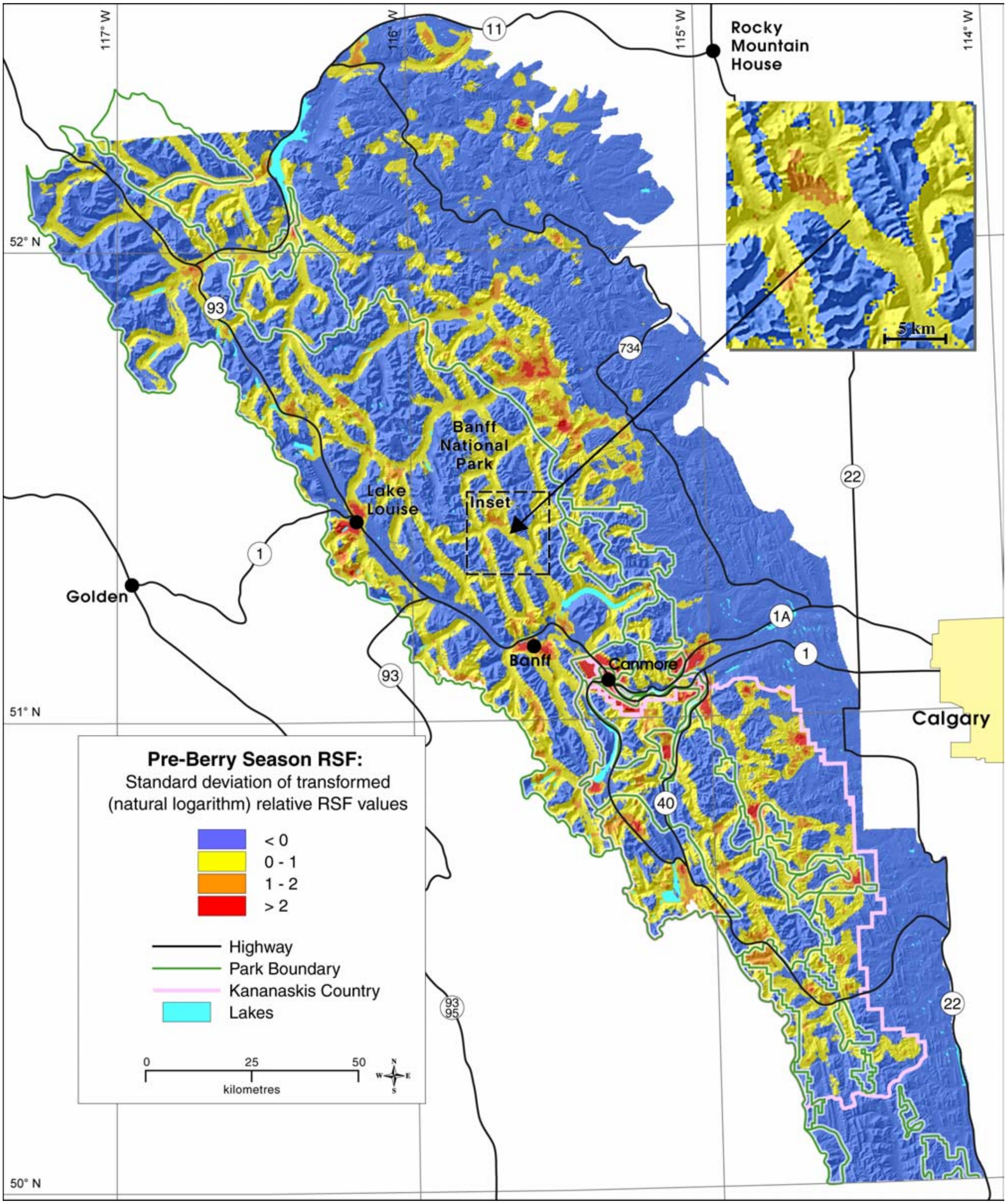

Figure 4. Relative probability of occurrence of adult female grizzly bears in the preberry season during 1994 to 1999 in the eastern slopes of the Canadian Rocky Mountains. Based on resource selection functions from Theberge (2002).

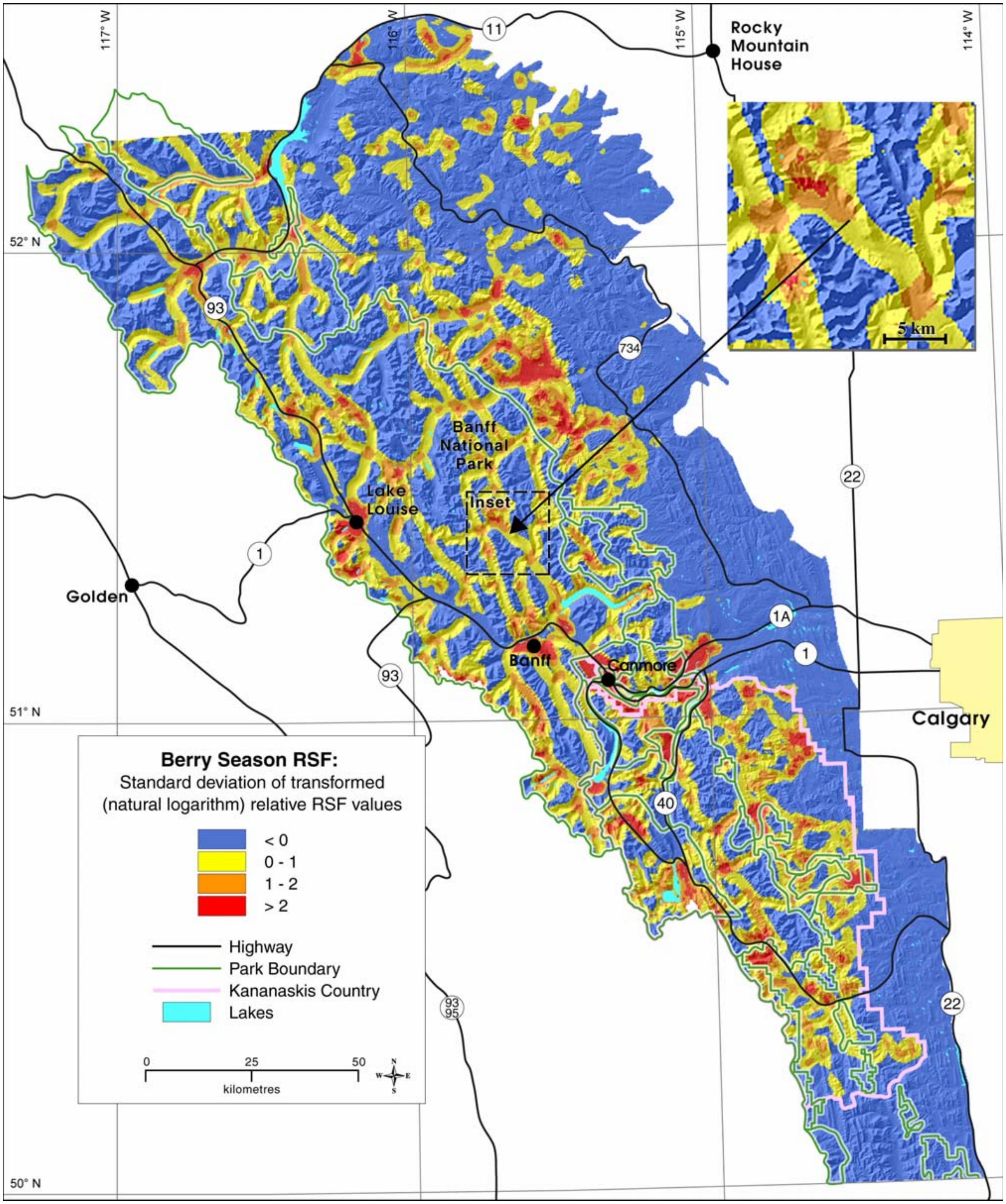

Figure 5. Relative probability of occurrence of adult female grizzly bears in the berry season during 1994 to 1999 in the eastern slopes of the Canadian Rocky Mountains. Based on resource selection functions from Theberge (2002).

DISCUSSION

We conclude that female grizzly bears used resource characteristics and heterogeneous landscape patterns differently than available within their home ranges when landscape pattern was measured at multiple scales. We showed that within individual home ranges there was selection by female grizzly bears for environmental characteristics beyond the immediate vicinity of 300 metres. Bears responded to, and often select for or against heterogeneous landscape patterns at different scales and simultaneously at several scales. These results are discussed below.

Selection by Bear Groups

The greatest likelihood of female grizzly bear occurrence, by season, was typified by the following characteristics.

1. Wary females in the preberry season: At the broad 3.0-km scale, females selected areas of low diversity of vegetation types, high ruggedness of terrain, low motorized access density, and moderately high non-motorized access density. At the 1.5-km scale selected was low density of non-motorized access. Within these broader landscapes, selected at the 300-m scale were high vegetation diversity, close proximity to edge, graminoid meadows, avalanche paths, and flat aspects. Rock was avoided.

2. Wary females in the berry season: At the broad 3.0-km scale, females selected high ruggedness, low density of motorized access, and moderately high density of non-motorized access. At the 1.5-km scale bears selected low density of non-motorized access, and high vegetation diversity. Within these broader landscapes, selected at the 300-m scale were graminoid meadows, close proximity to edge, and close proximity to water. Rock was avoided.

Characteristics of Responses to Human Access

In the multi-scale models, all female bears consistently selected pockets of low non-motorized human access density (1.5-km scale) within larger areas (3.0-km scale) of higher levels of non-motorized human access density. The apparent attraction at the 3.0-km scale can be explained because frequency of non-motorized human access, such as hiking trails, is common in the region and may be located in potentially productive areas that would be used by grizzly bears. In this study area, the high amounts of rock and ice, and associated highly rugged terrain, compresses usable habitat into valley sides and bottoms that are vegetated. Because hiking trails are also in these vegetated areas, it is possible that most bears cannot avoid being within 3.0 km of trails in vegetated areas. Donelon (2004) found that grizzly bears near Canmore, Alberta used areas closer to trails more than expected during the berry season.

Dense areas of *motorized* human access were never positively selected by female grizzly bears. Similarly, Gibeau (2000) documented different levels of access density, when motorized and non-motorized densities were combined, surrounding the locations of wary and habituated individuals in the eastern slopes region. Other research indicates that grizzly bear presence is negatively correlated with increasing density of high-use roads (Mace et al. 1996, Mace et al. 1999, Gibeau 2000).

Grizzly bears can persist in areas with roads and other human activities (McLellan and Shackleton 1988, Mace et al. 1996). However, Boone and Hunter (1996) illustrated, through computer simulation in a Montana-based model, that construction of permanent roads could cause great change to grizzly bear movements. Gibeau et al. (2002) found that adult female grizzly bears in the eastern slopes region of the Central Rockies Ecosystem may be choosing to avoid humans instead of seeking out high quality habitats. In accordance with Gibeau et al. (2002), our results indicate that human-specific variables were some of the most dominant variables in many models, illustrated by relatively small p-values. In support of the claim by Gibeau et al. (2002), our results indicate that the greatest likelihood of bear presence, particularly for wary bears, is in areas with a combination of selected ecological variables in 1.5-km diameter pockets of low densities of non-motorized access by humans.

Because the locations of the bears were restricted to daylight hours, our research does not address grizzly bear proximity to human activity or access density during the night. In the eastern slopes region, grizzly bears were closer to trails during periods when humans were inactive, between 17:00-08:00 hours (Gibeau et al. 2002). Due to aerial telemetry constraints the telemetry locations that we used in this study primarily represented daylight hours. Donelon (2004), using GPS telemetry collars on grizzly bears, showed that grizzly bears near Canmore and Lake Louise, Alberta, avoided areas of high human use during daylight hours but used the same areas more than expected at night when human use was low.

Characteristics of Vegetation Pattern

The mosaic of vegetation on the landscape in the eastern slopes region can be described by diversity, dominance, and distance to vegetation edges. To aid interpretation of the trends in the results, we discuss these variables together in this section.

Presence of female grizzly bears was frequently correlated with vegetation diversity at several scales. Wary female bears did not select areas of homogeneous vegetation, specifically they did not select low diversity with high dominance. Diversity might be important to grizzly bears due to increased variety in forage types, increased access to vegetation edges, and increased productivity of bear foods. Conversely, diversity of vegetation types might increase search time for forage, as a bear is required to search through a variable environment.

The models suggest 2 seasonal trends - selection for high vegetation diversity at the 300-m scale in the preberry season, and selection for high diversity at the 1.5-km scale in the berry season. Selection for high diversity at the fine scale during the spring might reflect the phenology of plants that are foods for grizzly bears. In the eastern slopes region, the succession of plant consumption by grizzly bears in the spring changes from hedysarum (*Hedysarum sulphurescens* and *H. alpinum*) roots, to horsetails (*Equisetum arvense*), grass species, and cow parsnip (*Heracleum lanatum*) (Hamer and Herrero 1987a). In a mountainous environment, such as the eastern slopes region, it is possible that the presence of microclimates from topographic change create local variability in plant maturity, thereby creating a shifting mosaic of useable habitats for grizzlies in the spring. This is consistent with phenologically driven feeding micro-habitat shifts previously observed in a portion of the study area (Hamer and Herrero 1987a).

That wary females in the preberry season select low diversity at 3.0-km and high diversity at 300-m suggests that these individuals can find fine-scale ecological attributes amongst broad areas of low diversity. This ability has also been suggested in other studies by observations in which grizzly bears have consistently foraged in small microsites dense with bear foods (Hamer and Herrero 1983, Waller and Mace 1997).

The second trend, during the berry season when wary bears selected areas with high diversity at the 1.5-km scale, potentially reflects selection for general proximity of a variety of vegetation types. Due to the broadspread presence of ripe buffaloberry (*Shepherdia canadensis*), bears might not have selected high levels of vegetation diversity at the local 300-m scale.

There is limited literature with which to compare the selection of heterogeneous vegetation patterns, specifically diversity and dominance, by individual species at different scales. A study of historical sightings of grizzly bears in the North Cascades ecosystem, in northern Washington, indicated selection of intermediate levels of diversity, or vegetation interspersion, in land-cover types (Agee et al. 1989). Black bears in Arkansas used low vegetation diversity less than expected and high diversity more than expected (Clark et al. 1993). Neither of these studies investigated multiple scales. Related to the selection of homogeneous vegetation types, Mace and Waller (1997) illustrated that selection of vegetation types by grizzly bears varied between scales ranging from 0.15 m^2 to 5 km^2. These studies indirectly support our findings.

Also related to vegetation pattern, close proximity to edge was frequently selected. Proximity to edge was strongly selected even after vegetation diversity had been accounted for in the models, indicating that bears might prefer environments with high variability of vegetation types within which individuals select to be closer or farther away from an edge.

There are many reasons why grizzly bears might select to be close to edges and diverse environments including hiding cover to escape from threats (McLellan and Shackleton 1989, Gunther 1990), temperature regulation, or increased forage productivity, increased foraging options, use of vegetation types that occur only in small patches, or avoidance of large blocks of homogeneous vegetation. Several of the major plant species consumed by grizzly bears are most productive in ecotone environments, such as buffaloberry under low canopy cover (Hamer 1996). Yellow hedysarum is dug and consumed by grizzly bears partly along forest edges (Hamer and Herrero 1983). Other research has suggested that locations adjacent to edge environments might be important for foraging (Schleyer 1983, Mattson 1997, Mace et al. 1999). In the early preberry season, bears might use environments closer to open edges where phenology is advanced, whereas in the late preberry season bears might use environments closer to shaded edges where the phenology is slightly delayed.

Characteristics of Terrain Pattern

The pattern of vegetation types across a landscape can be influenced by variation in terrain, and so can plant species richness and diversity (Burnett et al. 1998). In a mountainous environment, ruggedness might also affect plant phenology, potentially attracting bears to areas with terrain and vegetation variability. Female grizzly bears frequently selected relatively rugged terrain. We speculate that these bears avoided the highest classes of ruggedness due to the presence of steep rock and ice. Wary females selected high levels of ruggedness at the broadest scale during both seasons. Contrastingly, habituated individuals selected ruggedness at the local 300-m scale (Theberge 2002). Other research in the eastern slopes (Theberge 2002) found that selection of steep slopes was particularly strong for female grizzly bears with cubs-of-the-year during the berry season. Also in the eastern slopes region, Gibeau (2000) found that highway crossings by grizzly bears were correlated with areas (which were 3.0-km diameter) containing high ruggedness. Our research indicates that use of high levels of ruggedness is more frequent than just highway crossings, at least for wary female bears.

Other research has postulated that female grizzly bears, particularly those with cubs, might use rugged areas to increase their security, such as to decrease their rate of detection by other bears that could be threatening (Pearson 1975, Stelmock 1981, Darling 1987, Donelon 2004), or humans. If this security-seeking behaviour exists in female grizzly bears, then one might expect that use of rugged terrain would be apparent at some scale. The finest scale in our analysis, 300-m diameter, might have been too coarse to identify hiding or escape terrain immediately adjacent to individuals. However, selection of rugged terrain occurred at the broadest scale, during all seasons. We hypothesize that wary bears select large areas of relatively rugged terrain to minimize the frequency of encounters with threats, such as other bears or humans, travelling in the valley bottoms. Russell et al. (1979) found that female grizzly bears used valley bottoms less than males, and suggested that males displaced females from this habitat.

Influence of Heterogeneity-Variables on Immediate-Variables

Clearly, from the foregoing, bears respond to the environment at different scales. Other studies have demonstrated correlation with resource features at multiple scales for other species such as northern spotted owls (*Strix occidentalis caurina*), panthers (*Puma concolor coryi*), and woodland caribou (*Rangifer tarandus caribou*) (respectively Meyer et al. 1998, Kerkhoff et al. 2000, Apps et al. 2001), sometimes documenting that not all species respond to the same scales (Wallace et al. 1995, Etzenhouser et al. 1998). In many studies of grizzly bear ecology, the variables used to investigate habitat use describe the immediate environment, for example within a few hundred metres of bear locations, with little discussion regarding the possibility that bears may be aware of, and potentially responding to, more distant environmental features (as suggested in Mace and Waller 1997).

Of the immediate-variables, both in this chapter and in other results presented in Theberge (2002), wary grizzlies consistently selected avalanche in the preberry season, and close proximity to edge, and graminoid meadows in both seasons. Consistently not selected or avoided were deciduous, water, ice/ snow, conifer-SW-facing, and rock/ soil. That these variables maintain significance despite a multitude of contexts suggests the general overriding importance of these variables to the ecology of grizzly bears in the eastern slopes region. Presumably, consistently selected vegetation types are important to female grizzly bears because they contain significant amounts of seasonal bear foods (Hamer and Herrero 1987b, Mace et al. 1996, Waller and Mace 1997, McLellan and Hovey 2001, Theberge 2002).

The results of our research indicate that bear presence is correlated with various heterogeneous landscape patterns. This trend has been suggested elsewhere, although not all species, even those in the same taxonomic family, respond to heterogeneous landscape patterns in the same way (McGarigal and McComb 1995, Etzenhouser et al. 1998, Manson et al. 1999, Naugle et al. 1999). In other research, landscape patterns influenced not only the spatial distribution of movement for a species (Boone and Hunter 1996), but also the distance moved (Wegner and Merriam 1990, Taylor and Merriam 1995).

The identification of landscape pattern is dependent upon the scale of measurement (Turner et al. 1989). Consequently, identifying the relationship between wildlife movement and landscape pattern is contingent upon selecting the appropriate scale for investigation from a multitude of potentially applicable scales (Meyer et al. 1998). Most likely, grizzly bears within their home ranges respond to resource characteristics and landscape patterns at other scales beyond those investigated here.

Geographic Areas with High Probability of Female Grizzly Bear Occurrence

We identified 4 large areas that had a high probability of female grizzly bear occurrence. Each of these areas contained a substantial proportion of valley bottom. Three of the four areas were sites of major concentrated human development (Lake Louise, Banff and the Canmore/Bow corridor). The fourth area, the Red Deer River, Ya Ha Tinda area, south to and including the Burnt Timber drainage, has major extensive human use. Additional evidence regarding the attraction of the latter area for grizzly bears comes from the Province of Alberta's grizzly bear trapping here during spring, 2004. Nine female grizzly bears, 8 of these adult, were caught here (M.L. Gibeau, Warden Service, Parks Canada, Lake Louise, Alberta).

MANAGEMENT IMPLICATIONS

Our research indicates that grizzly bears select areas that have attributes beyond the immediate vicinity of an individual bear at any one time. This observation is important to the management of grizzly bears in the eastern slopes region, because persistence of the species will depend, in part, upon effective habitat management across a large region. General caution has been expressed regarding the use of a constant measuring scale, such as the immediate scale often investigated in resource selection modeling, which might distort an understanding of grizzly bear habitat use by aggregating or dividing resource units causing a species to appear indiscriminate in its habitat use (Milne 1991). Despite such concerns and other suggestions that individual grizzly bears might perceive broad landscapes (Mace et al. 1996), few studies have investigated scale-dependent habitat selection of grizzly bears within their home ranges (of notable exception Mace and Waller 1997).

In the eastern slopes region, adult females selected secure areas equal to or greater than 9.0 km^2 (slightly larger than 3.0-km diameter) that contained potentially useable land with very low human use (Gibeau et al. 2001). Such selection for these security areas suggests that grizzly bears might perceive landscapes at broad scales. The presence and maintenance of "secure" habitat, defined as areas where an adult female grizzly bear is able to meet its foraging needs on a daily basis with low likelihood of disturbance by humans, has been recommended by other studies (Mattson et al. 1992, Gibeau et al. 2001). Grizzly bears that have access to secure habitat have low probabilities of becoming habituated or food-conditioned, and had significantly less mortality than non-wary female grizzlies (Mattson et al. 1992).

Comparisons between the results of our resource selection function models and the apparent selection of secure areas found by Gibeau et al. (2001) is difficult because of differences in methodology, particularly because Gibeau et al. (2001) did not consider the effects of scale or other selected habitat attributes. Nonetheless their recommended protection within 9.0 km^2 security areas is similar to our multi-scale resource selection results. These multi-scale results demonstrated that female grizzlies used areas of low non-motorized access density at the 1.5-km scale in combination with a set of other selected resources, not necessarily at the 3.0-km scale that Gibeau et al. (2001) described. We presume that these bears would select somewhat larger areas of land that were not disturbed by non-motorized human access if the optimum combination of variables were present. Substantiating this presumption is the trend in our analysis indicating that bears avoided areas that contained high density of motorized access at the 3.0-km scale. Consequently, we encourage the establishment of management programs that protect *contiguous* areas of selected resource attributes, with low levels of human use at the 1.5-km scale. Such management programs would be congruent with general ecological recommendations that connectivity, or lack of fragmentation, between habitats is important (Noss et al. 1996).

Large blocks of undisturbed land, such as security areas, may be important to grizzlies, but only if they also contain resource characteristics typically selected by the species. The results in this chapter suggest that bears used heterogeneous landscape patterns more than available within their home ranges. Management in the eastern slopes region needs to consider not only the maintenance of specific landscape attributes, such as vegetation edge or avalanche chutes, but also landscape structure, such as high levels of vegetation community diversity.

That relatively high levels of diversity and presence of edge environments were consistently important in resource selection potentially signifies 1) a general attraction to environments in which a variety of foods, at various phenological stages, are available, and/ or 2) avoidance of large blocks of homogeneous vegetation. Increasing levels of homogeneity in the landscape could occur due to lack of periodic disturbance such as fire. The removal of fire, or near removal, from the eastern slopes ecosystem may have altered patterns of diversity and edge, allowing some vegetation types to succeed to more homogeneous states. Maintenance of natural fire regimes is recommended. Prescribed burns are an alternative, provided that the appropriate frequency, intensity, periodicity and seasonality are attained.

A set of resource characteristics was consistently selected by adult female grizzlies (Theberge 2002). To increase the likelihood of persistence of grizzly bears in the eastern slopes region, we recommend that management minimize human disturbance in areas that contain resource characteristics that are consistently selected by wary female bears. Specifically, management needs to focus upon areas that are within 60 metres of vegetation edges (Theberge 2002), that have high levels of diversity within 300-m and 1.5-km windows, and that consist of relatively rugged terrain within broad 3.0-km areas. Also of importance are graminoid meadows during all seasons, avalanche chutes during the spring, and riparian areas adjacent to water during summer and autumn. To respect the needs of grizzly bears, human activities in these areas should be carefully managed, particularly to ensure that areas containing these characteristics maintain low levels of human access within 1.5-km diameter windows. As well, management planning in the eastern slopes region should include the identification of security areas (Gibeau et al. 2001), within which management is aimed at minimizing human access in contiguous 1.5-km diameter areas or larger. Furthermore, habitat to connect areas with such attributes, even if of somewhat lesser attractiveness, is also essential if we are to avoid habitat loss and attendant grizzly bear population stress.

Our identification of geographic areas where there was a high probability of adult female grizzly bear occurrence can aid regional decision-making by highlighting locations where management action could make areas that are attractive to grizzly bears safer for their use. Because all of these areas are developed for intensive or extensive human use there is a relatively high mortality probability for adult female grizzly bears (Chapter 6.6, this report). Managing these landscapes for human use and providing for grizzly bear safety will challenge managers.

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10.4 COMPARISON OF RESULTS REGARDING RESOURCE SELECTION MODELS FOR FEMALE GRIZZLY BEARS IN THE EASTERN SLOPES BASED ON COARSE-FILTER AND FINE-FILTER APPROACHES

Jeannette Theberge and Saundi Stevens

INTRODUCTION

The research conducted by Theberge (2002) and Stevens (2002) addresses 2 approaches to understanding landscape selection by bears (Table 1). This results in somewhat different management implications regarding grizzly bear habitat conservation. Highlighted in this chapter are substantial differences in our results, and their respective management implications. As in our previous sections, these results pertain to female grizzly bears that exhibited wary-type behaviours towards humans.

Table 1. Similarities and differences in modeling approaches taken by Stevens (2002) and Theberge (2002) to determine habitat selection of female grizzly bears in the eastern slopes of the Canadian Rocky Mountains.

	Stevens 2002	***Theberge 2002***
Management Implications	**Coarse approach for management to monitor broad changes to greenness across landscape**	**Finer (multiscale) approach for management where intervention and habitat conservation can focus on specific variables**
Study Area	11,400 km^2 east of Continental Divide 5,000 km^2 west of Continental Divide	11,400 km^2 east of Continental Divide
Software to Delineate Home Range	Animal Movement extension in Arc View	KERNELHR
Collection of Bear Locations	Aerial telemetry	Aerial telemetry
Generation of Random Locations	Approximately 25,000 random locations distributed in and between home ranges	Approximately 40,000 random locations (3,000 per home range) distributed within home ranges
Order of Resource Selection (Johnson 1980)	2nd order - description of selected resources in study area where bears are known to occur and where they do not occur	3rd order - description of selected resources within the known home ranges of bears
Seasons Investigated	Berry Season (July 15 - October 31)	Preberry Season (May 1 - July 15) Berry Season (July 16 - October 31)
Approach to Research Question	Correlation of female bear presence with attributes and greenness parameters, largely based on Landsat reflectance	Correlation of female bears with attributes and landscape pattern at multiple scales, based largely on vegetation classification
Human access	Measured density of all human access in 1.5-km radius (equivalent to 3.0-km diameter) moving window	Measured both non-motorized and motorized access density in 1.5-km and 3.0-km diameter moving windows
Modeling Approach	RSF using logistic regression. Model selection using AIC	RSF using logistic regression. Backward elimination of variables based on p values.

Stevens (2002) adopted a coarse filter approach by investigating the correlation of the presence of bears with the variables related to greenness, a surrogate of grizzly bear habitat quality. This study area encompassed lands within and between known bear home ranges. The approach taken by Theberge (2002) permits finer scale management planning because it addresses the correlation of the presence of bears with a suite of variables related to vegetation types and landscape patterns at multiple scales. Theberge's study area included only lands within bear home ranges.

COARSE SCALE MANAGEMENT APPROACH

Stevens (2002) concluded that density of high greenness and distance to high greenness were the most important predictors of female grizzly bear occurrence, of variables investigated. Greenness has been found to correlate strongly with grizzly bear presence (Mace et al. 1999, Gibeau 2000), and has been used to identify grizzly bear habitat across large areas (Nielsen et al. 2002). High levels of greenness represent abundance and vigour of living vegetation, particularly herbaceous and deciduous. In the Central Rockies Ecosystem, high levels of greenness are correlated with avalanche paths and areas of herbaceous vegetation types (Wierzchowski 2000). Low levels of greenness are found where phytomass is low (i.e. rock and ice). This is a relative index. In other environments, high levels of greenness have been correlated with mature agricultural crops.

The links between greenness and habitat selection of grizzly bears are not completely understood. Consequently, it may be difficult to manage specifically to create increases or decreases of greenness habitat. For example, the resulting levels of greenness after ecological manipulations, such as forest harvest or prescribed fire of varying intensity and severity, may not be predictable due to variability in successional pathways. Nonetheless, greenness may be a useful tool in monitoring broad ecological changes across jurisdictions over time, thereby indicating potential changes in the presence of female grizzly bears.

FINE SCALE MANAGEMENT APPROACH

Theberge (2002) concluded that locations of female grizzly bears were correlated with environmental conditions and heterogeneous landscape patterns at different scales. The results provide some basis for management action or habitat enhancement, particularly related to areas with the following characteristics: within 60 metres of vegetation edges, high levels of vegetation diversity within 300-m and 1.5-km windows, rugged terrain within broad 3.0-km areas, graminoid meadows, avalanche paths, or riparian areas. To maintain grizzly bear habitat, some of these characteristics can be maintained, or human activities can be strategically directed away from them.

HUMAN-USE VARIABLES

Although Stevens found in some models that female bears were selecting higher levels of human access density at the 1.5-km radius scale (equivalent to Theberge's 3.0-km diameter scale), she also found that the confidence limits on this parameter estimate were broad, indicating large variance. Consequently, Stevens determined that the model with the best explanation of variance was a model that excluded human access density.

In contrast, Theberge concluded that access density was a significant factor influencing presence of female grizzly bears. During both seasons, female bears selected pockets of low non-motorized human access density (1.5-km scale) within larger areas (3.0-km scale) of higher levels of non-motorized human access density. Areas of high levels of motorized access density were never selected by wary female grizzly bears. Differences in the results between Theberge and Stevens are likely attributable to the different scales and variables used for modeling, the different approaches of 2^{nd} and 3^{rd} order selection analysis, and the lumping or splitting of categories of human access types.

Other research has suggested that the will of individual bears to access high quality habitat will prevail over their wariness towards humans (McLellan and Shackleton 1988, Mace et al. 1996, Gibeau 2000). In the eastern slopes, human presence is widespread throughout the region but concentrated in valley bottoms and side slopes. It is likely that bears are often relatively close to human-created features by default. They may be avoiding human contact through selecting pockets of low access density, hiding in vegetative cover, or being less active during times of peak human use. However, there are substantial costs for bears near human features, particularly related to the truncated longevity of individual bears (Mattson et al. 1996, McLellan et al. 1999, Benn and Herrero 2002), potentially impacting the persistence of the population.

MANAGEMENT IMPLICATIONS

Each study has different management applications. Models related to greenness (Stevens 2002), are useful as a coarse management tool. Land managers can monitor broad changes in greenness, and human activities in grizzly bear security areas that have high greenness values, across decades. This can be used as an early-warning signal to precipitate management action or habitat enhancement. Models based on vegetation pattern (Theberge 2002) provide ecological correlates with bear presence, thereby allowing land managers to actively manage specific ecological attributes, manage levels of human use in areas with concentrations of important attributes, or take other management actions. We feel that in the eastern slopes of the Central Rockies Ecosystem, it may be most appropriate to use both these coarse and fine approaches to ensure that habitat used by female grizzly bears is conserved.

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