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A Multi-Species Reserve Network for the Evan-Thomas Valley, Alberta

by

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ABSTRACT

The Evan-Thomas Valley is an area of importance for wildlife habitat and movement. Although highly developed, the area still retains ecological value, but continued pressure from commercial development has led to a desire to identify any remaining priority areas to aid management policy. To accomplish this goal, a reserve network of habitat patches and movement corridors was created for three focal species; the grizzly bear (*Ursus arctos*), wolf (*Canis lupus*) and lynx (*Lynx canadensis*). A resource selection function identified areas of higher resource value in order to delineate habitat patches. Least-cost corridor models were run between habitat patches and detected areas of more likely movement; these were zoned as movement corridors. The species-specific reserve networks of habitat patches and movement corridors were overlaid such that areas of importance to multiple species could receive more focused management efforts.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE: INTRODUCTION

1.1 Reserve Design

In order for wildlife populations to survive and reproduce, species-specific resources and conditions are required. Areas that provide these necessary resources and conditions are termed habitat (Morrison *et al.* 1992, Garshelis 2000). As habitat is a key element in species survival, human development and resource extraction activities can be problematic for wildlife management. These activities can cause direct loss of habitat and can also fragment remaining habitat, so that it becomes degraded or isolated. As a result, there is potential for a reduction in resource procurement and an increase in mortality rates. As such, habitat loss and fragmentation are recognised as being major threats to the conservation of wildlife. Consequently the process of reserve creation to safeguard habitat has become a major part of conservation biology (Morrison *et al.* 1992, Weaver *et al.* 1996, Primack 2002).

However, the implementation of reserves has only recently begun to be studied extensively, and shortcomings in existing reserves have been identified through recent findings regarding range requirements and population viability analysis. This problem of inadequate or inappropriate reserve design is particularly acute within the Central Canadian Rocky Mountains. Though large protected areas have been established in the area since 1885 with the founding of Banff National Park, it is now recognised that the areas protected consist mostly of rock and ice and hence provide relatively little useful habitat (Schindler 2002, Dearden and Dempsey 2004). In this environment the traditional method of reserve design, whereby large reserves are created and managed as discrete entities, is not appropriate, as truly vast areas of land would be required (Noss *et al.* 1996). For instance, it is now believed that the national parks system within the Central Canadian Rocky Mountains, which consists of not only Banff National Park, but also Yoho and Kootenay National Parks, an area of tens of thousands of square kilometres, cannot sustain a grizzly bear (*Ursus arctos*) population alone (Gibeau *et al.* 2001). Though the national parks would form a core reserve, the provincial lands bordering these large reserves are now recognised as being essential in providing the additional habitat required by the populations of far ranging species that are centred on the national parks (Schindler 2002, Dearden and Dempsey 2004).

Though the area of land protected at a provincial level has continued to increase within the last decade (Dearden and Dempsey 2004), the traditional method of creating new large reserves, which would be the ideal solution, is inappropriate. Much of the land has already been heavily developed and much of the remaining habitat exists in small isolated patches. Instead, within much of the provincial land bordering large reserves, another approach to reserve design is required. That approach would incorporate human use (Soulé and Simberloff 1986, Newmark 1995, Noss *et al.* 1996, Primack 2002, Schindler 2002).

Noss (1995) detailed a reserve design approach suitable for a developed landscape. Patches of habitat within a human dominated matrix are identified and connected by movement corridors. It should be immediately noted that within this study the term patch and corridor were used in a functional rather than a structural sense (Rosenberg *et al.* 1997). That is, rather than looking for distinct physical boundaries between forest and grassland, the objective was to identify areas, irrespective of structure, that are of importance for habitat or movement. Although the habitat patches may be relatively small, as long as movement along corridors is feasible the total area of all patches can significantly increase the amount of habitat protected, and this in turn, will increase effective population sizes (Noss 1995). In addition to increasing the total reserve area, a network such as this can also be highly useful in connecting larger reserves. The establishment of such connections will facilitate gene flow and dispersal and hence reduce extinction risks (Soulé and Simberloff 1986, Newmark 1995). A network also has an advantage in that multiple interconnecting patches and corridors are created. This multiplicity is useful as no landscape is in perpetual stasis. Environmental variation, and more significantly, catastrophic events such as wildfire could quickly alter the landscape such that the original design becomes irrelevant. A reserve network, with what might appear to be redundant and unnecessary features, increases the ability of the reserve to absorb future changes (Soulé and Simberloff 1986).

Once an appropriate working model for reserve design has been identified, three ecological factors are usually used as a basis for establishing areas for inclusion within a reserve. These are protection of specific species of interest, biodiversity hotspots and whole ecosystems (Soulé and Simberloff 1986, Primack 2002). Although the three factors are recognised as being generally complementary (Soulé and Simberloff 1986, Primack 2002), the location and scale of the proposed reserve will likely dictate the appropriate emphasis.

For instance, in the case of developed provincial lands within the Central Canadian Rocky Mountains, a more feasible approach would be to base reserve design around large carnivores. Any new reserves would likely be at too fine a scale for an ecosystem-based approach, and due to the area's relatively low species richness and endemism, areas extensive enough for large carnivores would probably protect most other species (Noss *et al.* 1996, Primack 2002).

There are, however, concerns with a single-species approach. Habitat use and movement are species-specific processes, but mapping patches and corridors out for all species is logistically impractical. A more prudent approach is to pick several species of interest (Beier and Loe 1992, Noss 1995). Lambeck (1997) suggested a multi-species approach that uses a set of carefully selected focal species whose habitat and movement requirements, when combined, meet the requirements of all other species. This approach would give results that are more ecologically meaningful, while maintaining feasible levels of data collection and analysis (Lambeck 1997). In regard to reserve network design, once the habitat patches and movement corridors are defined for each species, the species-specific reserve networks may be overlaid to produce a multi-species reserve network (Noss 1995).

1.2 The Evan-Thomas Valley

The Evan-Thomas Valley (ETV) located within the Canadian Rocky Mountains of Alberta (Figure 1) is a good example of the recent interest in provincial lands as part of a larger reserve network, to which the Noss (1995) reserve network model could be applied. The 454 km^2 study area is not large enough on its own to support populations, or even individuals. The area does however represent a broad spectrum of the environments found within the Canadian Rocky Mountains. It is recognised as being ecologically important both in providing habitat for a large diversity of species and in forming a connectivity hub that facilitates regional movement between surrounding valleys (ACDPPA 2004).

Within the study area, elevations range from 1300m to 3000m across which montane, subalpine and alpine ecoregions are present. Climate is typical for the latitude and continental location, with moderate precipitation as rain and snow occurring during both summer and winter. Temperatures range between +30^{o}C and -30^{o}C. Dominant overstory cover consists of lodgepole pine (*Pinus contorta*), trembling aspen (*Populus tremuloides*), subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*) and white spruce (*Picea glauca*). Though the valley was actively logged, most of this activity occurred previous to a large wildfire in 1936. Consequently, the forest age is fairly uniform (Johnson and Fryer 1987, ACDPPA 2004).

There have been some small scale resource extraction activities, including logging and mining, but the major human impact on the landscape results from recreational tourism. Located within an hour’s drive of Calgary and other urban centres, the study area has seen major government investment in the last three decades. It now contains two hotels, two ski hills, a thirty-six hole golf course, an RV park, a ranch and numerous trails. The area also provides access to parks to the south along Highway 40, which dissects the study area and is used by 800,000 vehicles a year (ACDPPA 2004).

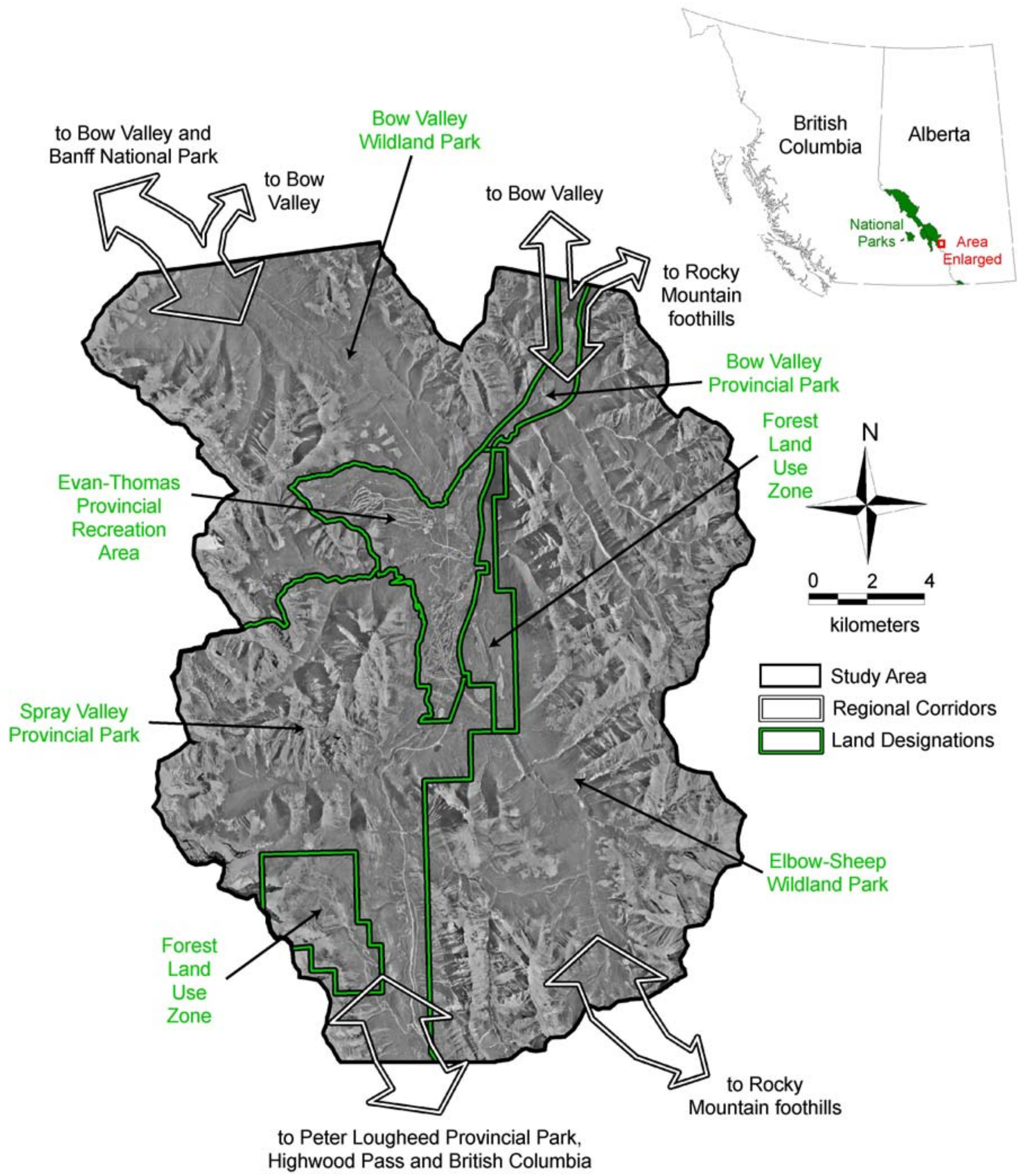


Figure 1. Location of the Evan-Thomas Valley, with land designations, regional corridors and study area.

While the valley is recognised as having local and regional ecological importance, it has never been the subject of a fine scale investigation. Thus, although the valley is known to be used in a broad sense, how it is used is less clear. This distinction is important because if the functionality of important connectivity hubs such as the ETV is lost, the regional corridor and habitat network may be compromised. As the valley is highly developed, there is concern as to how much more development the valley can absorb while still maintaining its function of providing habitat and allowing successful and energetically efficient movement of wildlife.

1.3 Research Objectives and Thesis Organisation

The broad objective of this thesis is to provide information regarding habitat and movement of large carnivores within the ETV. The findings can then form part of future reserve design decisions. This will fill a knowledge gap identified in the recently published management guidelines for the preservation of wildlife within the area (ACDPPA 2004). More specifically, the tasks involved in this procedure are as follows:

1. Choose appropriate focal species.
2. Identify habitat patches for each focal species.
3. Distinguish movement corridors to connect habitat patches, and form species-specific reserve network.
4. Combine species-specific reserve network to produce a multi-species reserve network.
5. Provide considerations for application of multi-species reserve network for management decisions.

Chapter Two details the choice of three focal species and provides a review of the analytical methods employed. These topics are detailed in Chapter Two in order to avoid unnecessary repetition of background information and justification in Chapters Three, Four and Five, which detail the application and results of these methods to three differing focal species. Chapter Six describes the process and results of combining the findings of all three focal species. The final chapter summarises the results of previous chapters, as well as providing some brief management recommendations and suggesting considerations for future work.

The appendices provide highly detailed information relating to wildlife survey methods and creation of landcover characteristics, the key elements of which are summarised within the document. The purpose of putting this information within the appendices is to speed the flow of discussion and also to avoid repetition of methods used in the analysis of data for each focal species.

CHAPTER TWO: METHODS

2.1 Focal Species Selection

The selection of focal species should be guided by the goals of a study; ideally all endemic fauna should be considered. However, datasets for multiple years, suitable for both delineation of habitat use and movement in the study area, only existed for two large carnivores – the grizzly bear (*Ursus arctos*) and the wolf (*Canis lupus*). Fortunately, there is support for the use these carnivores as a first step of reserve network design, which is the delineation of habitat patches. Paquet *et al.* (1996) investigated the umbrella function of the grizzly bear, wolf and lynx (*Lynx canadensis*) and found that they provided at least partial habitat coverage for 378 of 381 vertebrate species within the Central Canadian Rocky Mountains. Several studies have used these three carnivores as focal species in conservation planning in the Rocky Mountains (Alexander 2001, Carroll *et al.* 2001, Noss *et al.* 2002). These studies advocated the need for a multi-species approach, and confirmed the difference in requirements between species.

Unfortunately, these three carnivores may not be ideal for identifying movement corridors. Miller *et al.* (1998) warned against the sole use of large carnivores for planning connections as smaller species are likely to perceive the same habitat gaps as being much larger and hence less permeable. However, due to a lack of appropriate data, it was assumed that the combined movement corridors for the grizzly bear, wolf and lynx would represent corridors used by many other species. This allowed for the utilisation of extensive existing datasets, while minimising the amount of new data collection required.

2.2 Secure Habitat Patch Modelling

The first step in the process of reserve network design is identification of habitat patches between which animals may move (Beier and Loe 1992, Noss 1995). Resource selection function (RSF) models were used to identify areas with high resource value. An RSF describes the probability of an area being exploited by a certain species, on the basis of use of resources present in that area.

In construction of RSF models, a use versus availability logistic regression design was used, in which disproportionate use relative to availability indicated selection (Manly *et al.* 2002). In this approach, use is described by known presence locations of the species of interest (scored 1) and availability (scored 0). Availability can include either all available resource units or a sample of available units. Logistic regression was chosen as it is well suited to the binary use availability approach, does not require normal distribution, and can incorporate continuous and categorical variables (Tabachnik and Fidell 2001). Before analysis, all variables were entered into a correlation matrix to identify any bivariate correlations greater than 0.7. If present, correlated variables were not allowed within the same model. This procedure helped to address the assumption of absence of multicollinearity between resource characteristic variables.

Analysis can follow one of two possible paths, depending on the sampling technique employed. When all available resource units are known and can be included, resource selection can be defined as

$$\mathrm{w}^*(\mathrm{x}) = \frac{\exp\left(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n\right)}{1 + \exp\left(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n\right)} \qquad \text{Eq.(1)}$$

where w*(x) is the RSF value and β_0 to β_n are coefficients to be estimated from species data when compared to the resource characteristics x_1 to x_n (Manly *et al.* 2002).

When it is not possible to use all available resource units, only a relative measure of resource use can be estimated with the use of

$$\mathrm{w}(\mathrm{x}) = \exp\left(\beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n\right) \qquad \text{Eq.(2)}$$

where w(x) is the RSF and β_1 to β_n are coefficients to be estimated from species data when compared to the resource characteristics x_1 to x_n (Mace *et al.* 1999, Manly *et al.* 2002, Nielsen *et al.* 2002, Nielsen *et al.* 2003). The β coefficients in Eq.(2) can be estimated from logistic regression that omits the intercept (Erickson *et al.* 2001, Boyce *et al.* 2002):

$$\tau(\mathrm{x}) = \frac{\exp\,(\beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n)}{1 + \exp\,(\beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n)} \qquad \text{Eq.(3)}$$

As the multivariate importance of potential resource characteristics was not known, models of all combinations of resource characteristics were created and ranked using Akaike's Information Criterion (AIC). AIC is a model selection method based on the level of model fit in relation to the number of included variables – the principle of parsimony. AIC eliminates the use of arbitrarily significance values (Anderson *et al.* 2000, Burnham and Anderson 2002, Eberhardt 2003).

As sample sizes were relatively small, the second-order AIC ($\mathrm{AIC_c}$) was used:

$$\mathrm{AIC_c} = -2\mathrm{LL} + 2\mathrm{K} + \frac{2\mathrm{K}(\mathrm{K}+1)}{n - \mathrm{K} - 1} \qquad \text{Eq.(4)}$$

where -2LL is the minus two log-likelihood, a measure of model fit produced from the logistic regression model in question (Tabachnick and Fidell 2001); K is the number of estimable parameters in the model, and *n* is the sample size (Burnham and Anderson 2002).

When one is interpreting results from a suite of candidate models, it is not the absolute $\mathrm{AIC_c}$ that is important, but the value relative to the other models. Therefore, candidate models were ranked with the use of delta AIC (Δ_i), which is the difference between each model's $\mathrm{AIC_c}$ and the minimum $\mathrm{AIC_c}$ of all candidate models. Akaike weights (w_i) were computed to determine how much better the optimal model was relative to other candidate models.

$$\Delta_i = \mathrm{AIC}_{\mathrm{c}\,i} - \mathrm{AIC}_{\min} \qquad \text{Eq.(5)}$$

$$w_i = \frac{\exp(-0.5\Delta_i)}{\sum_{r=1}^{R} \exp(-0.5\Delta_r)} \qquad \text{Eq.(6)}$$

Evaluation of the best model chosen using AIC is an important step as the best model may only be the best of a poor set of models (Anderson *et al.* 2000, Burnham and Anderson 2002, Eberhardt 2003). Boyce *et al.* (2002) explained the complications of evaluating use versus availability based RSF models, and proposed a technique for their evaluation which will form the basis of the evaluation used here.

Here, the probability surface was broken into ten roughly equal-area bins of increasing probability, and the numbers of use locations were tallied within each bin. If the RSF were to predict well, then it would be expected that as the rank of the bin increased, so would the number of use locations. A Spearman's rank correlation between rank of bin and rank of use locations within that bin range will indicate model strength. This process was conducted with resubstituted data and with independent data with the use of

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n^3 - n} \qquad \text{Eq.(7)}$$

where r_s is the Spearman's Rank, d_i is the difference between the ranks for each bin and n is the number of bins (Zar 1999).

Once an RSF was selected, evaluated and accepted, it was then used to identify secure habitat areas. This identification was done through the initial exclusion of areas that were not secure. Gibeau *et al.* (2001) used a distance of 500m from areas of high human use.

Here, a 500m buffer was used for motorised access and a 200m buffer for non-motorised access. These distances fit well with the results of Benn *et al.* (1998) who found that most grizzly bear mortalities occur within that disturbance zone. The remaining secure area was then broken into habitat patches in which a high habitat value was evident. This was taken as the mean RSF cell value within the patch in relation to the mean RSF value of the study area. However, as patches that were too small or of a poor shape may not serve a purpose (Morrison *et al.* 1992), criteria for useful patches were needed in order to support the decision process. For this study, the Bow Corridor Ecosystem Advisory Group (BCEAG) guidelines (BCEAG 1999) were used as decision criteria, primarily to match existing reserve design that had been conducted in the surrounding area. For local habitat patches, which should provide short term resources to wildlife while they negotiate a reserve network, a minimum size of $4.5km^2$ was quoted. In addition, a minimum width of 1.2km and a surface area to perimeter ratio of 0.45 or greater was prescribed. Patches larger than $10km^2$ were considered regional habitat patches capable of supporting animals for longer periods of time. This measure was consistent with regional security areas defined by Gibeau *et al.* (2001).

This approach does not suggest that small patches or areas near high human activity are of no use, but directs attention towards areas that will likely provide the essential resources without exposure to an increased level of human induced mortality risks. These are the habitat areas deserving the most attention in reserve design.

2.3 Movement Corridor Modelling

Once the habitat patches were identified, movement corridors could be established to provide connectivity between the patches. The primary purpose of the corridors, as with Beier and Loe (1992) and Rosenberg *et al.* (1997), is to provide safe passage between the core reserve patches – conduit corridors as defined by Hess and Fischer (2001).

For modelling of movement corridors, a least-cost distance corridor approach was chosen (Walker and Craighead 1997). Least-cost distance corridors describe, between features of interest which in this case were habitat patches, the likelihood of an area being used by an animal as it moves between the two habitat patches. The area along which movement is most likely can then be described as a movement corridor.

Least-cost distance corridors, like least-cost pathways (Paquet *et al.* 1996, Adriaensen *et al.* 2003), are created through the use of a friction surface, which represents landscape permeability. Areas with a higher friction are less desirable for movement due to environmental factors in that area. However, as opposed to least-cost pathways which produce a single line, least-cost corridors provide the ability to create an area of most likely movement. The latter has far more biological relevance for defining movement corridors.

To create a friction surface, environmental variables with importance for movement must first be identified. Rosenberg *et al.* (1997) noted that animals were more likely to move through areas that contain preferred habitat. In addition, Paquet *et al.* (1996), Duke *et al.* (2001) and Mech and Boitani (2003) described the likelihood of corridor use by wolves was a function not only of habitat quality, but also of energetic efficiency and security. Travel was more likely in areas of higher quality habitat and across terrain that was easy to negotiate, provided cover and had minimal human activity. This approach seemed reasonable, and similar comments have been made in regard to both grizzly bears (Noss *et al.* 1996, Benn *et al.* 1998, Gibeau 2000, Gibeau *et al.* 2002) and lynx (Koehler and Aubry 1994, Apps 2000, Poole 2003). Therefore, the friction surfaces required were created on the basis of those variables.

Habitat potential was represented by the RSF that was created for each species. Energetic efficiency was dictated by slope, with higher slopes having a greater friction. Security was represented by two factors, forest density as cover, and road density as human disturbance. Before the creation of friction surfaces, all values were rescaled to range between 0 and 1, through the division of all values by the maximum value, so that all variables had the same impact. In order that higher levels of habitat potential and forest cover represented less friction these variables were inverted through the subtraction of all values from the maximum value of 1. The sum of these four variables resulted in a friction surface:

$$\text{Friction} = (1 - \text{habitat value}) + (\text{slope}) + (1 - \text{forest density}) + (\text{road density}) \qquad \text{Eq.(8)}$$

Adriaensen *et al.* (2003) advised friction surfaces be made species-specific. This means that although the same variables may be of importance in creating a friction surface, each variable may be more or less important, with the relative importance depending on the species. Singleton *et al.* (2002) and Walker and Craighead (1997) approached this problem by giving different weights to the variables comprising a friction surface. These weights were determined from a review of the literature relating to movement behaviour of the species concerned, and this was the approach taken here also. It was recognised that the use of general evidence from the literature to assign weightings in a qualitative manner could be considered arbitrary; therefore, the gradation of weighting was kept very simple. If on the basis of the literature, any of the four variables in Eq.(8) were highlighted as having some importance, that variable was given a double weighting. If any of the variables were discussed as perhaps being critical to movement, the variable was given a triple weighting. The grizzly bear, wolf and lynx weightings are discussed in the three following, species-specific chapters.

Once the friction surface was created, the ArcView spatial analyst cost-distance extension (ESRI 1996) was used to create cost-distance layers from each movement source area in the study area. These movement source areas were the previously identified habitat patches and known areas of regional importance for movement to the surrounding areas (Figure 1). The resulting cost-distance layer represented the minimum cost, calculated from a combination of both distance and friction, from the source area to every other location on the landscape.

Through the addition of the cost-distance surfaces for two source areas, a least-cost corridor layer was produced, where lower values indicated more probable movement between the source areas. After the creation of least-cost corridor layers between all source areas, each layer was rescaled to run from zero through the subtraction of the minimum least-cost corridor value; then, all layers were combined through the use of the minimum value from all least-cost corridor layers. The result was a least-cost corridor network layer that indicated areas of higher movement probability between all source areas.

Finally, a level of movement probability from the continuous surface was chosen to delineate corridors. As with defining the habitat patches, the categorisation of the continuous movement surface was problematic. Again, the BCEAG guidelines (BCEAG 1999) were used to identify a probability cut-off point that produced corridors meeting the minimum corridor criteria. High resolution aerial photography was used to make minor changes so that corridors were logical and consistent with the BCEAG guidelines.

The resulting movement corridors and habitat patches formed a reserve network for each species. The corridors were evaluated through the use of independent movement data as part of the species reserve network. Using movement data was important as this allowed the evaluation to go beyond that of most studies, which simply show animal presence within corridors and from that, assume use of the area for movement (Rosenberg 1997, Niemelä 2001). Examination of the distribution of movement paths across the landscape makes it possible to demonstrate continued and consistent animal movement through corridors as part of a reserve network (Niemelä 2001). To this end, the movement data was buffered by its associated error, and then the resulting area was divided amongst habitat patches, movement corridors and the intervening matrix. The reserve network was accepted if the majority of the independent movement data, taken as more than 80%, fell outside of the matrix and in the reserve network.

CHAPTER THREE: GRIZZLY BEAR RESERVE NETWORK DESIGN

3.1 Introduction

This chapter describes the application to the grizzly bear of the methods detailed in Chapter Two. Firstly, information relating to grizzly bear modelling is reviewed. Then the grizzly bear data available to build and evaluate the habitat patch and corridor models is reported. Reasoning is given for the choice of resource characteristics. The application of this data to the model building and evaluation methods from Chapter Two is then outlined with any species-specific features. Finally, the results of the grizzly bear habitat patch and reserve network design process are reported and discussed.

3.1.1 Grizzly Bear Modelling Review

It is important to understand some of the biological factors that have effects on grizzly bear modelling results. For instance, pooling data across important demographic or temporal boundaries can conceal resource selection patterns (Morrison *et al.* 1992, Schooley 1994). In the case of Canadian Rockies grizzly bears, differences have been found between sexes (Wielgus and Bunnell 1994), seasons (McLellan and Hovey 2001, Theberge 2002, Nielsen *et al.* 2003) and individuals (Nielsen *et al.* 2002). Ideally, a dataset should be split across these boundaries so that model results are not confounded. However, the degree of data splitting that can be accomplished is dependent upon the amount of data available; after partitioning, a large enough data must remain to have statistical power.

As grizzly bear resource selection is expected to be most variable between sexes and seasons (Gibeau pers. comm. 2004), these partitions were considered first. Female bears are the reproductive engine of the population, and managing the landscape for their needs likely will improve the chances of population persistence (Wielgus and Bunnell 1994, Benn *et al.* 1998, Theberge 2002). Consequently only female bear data were used.

Vegetation forms a major component of a grizzly bear's diet. Hence, plant phenology, in particular the emergence of berries, can be a driving factor in terms of seasonal resource selection (Benn *et al.* 1998, McLellan and Hovey 2001, Nielsen *et al.* 2003). Thus, female bear data were divided into two seasons; pre-berry (den emergence to the 15th of July) and berry (July 16th to denning). These dates were chosen to be consistent with existing regional analyses (Wielgus and Bunnell 1994, Gibeau 2000, Stevens 2002, Theberge 2002).

Further temporal or demographic data splitting was not possible due to the limited size of the dataset. The resulting reserve networks created for female grizzly bear seasons in the two seasons would be combined to make a single grizzly bear reserve network that would be representative of female grizzly bear requirements for both seasons.

3.2 Methods

3.2.1 Grizzly Bear Radio-Telemetry and GPS Collar Data

Two large grizzly bear datasets were used. In addition to preliminary data screening to remove values with missing, incorrect, duplicated or questionable information, locations within three weeks of collaring (Cattet *et al.* 2004) or one week of aversive conditioning involving a pain stimulus (Gibeau pers. comm. 2004) were also removed to try and avoid contamination of data from human induced behavioural changes.

Locations within an hour of another location were used to estimate movement paths. One hour was chosen as a threshold because all of the global positioning system (GPS) tracking data were collected at this frequency. Of the data points remaining, a further screening removed any points from the same animal that occurred within the following 24 hours. This was done on the assumption that after 24 hours, a bear could have chosen to move to any point within its home range, and hence would improve the independence of the remaining locations (Erickson *et al.* 2001).

Information for radio-collared grizzly bears was provided by the Eastern Slopes Grizzly Bear Project (ESGBP), the methods for which are detailed in Gibeau and Herrero (1995) and Gibeau and Stevens (2003). Bears were collared between 1994 and 2002 with conventional VHF collars. Between April and November each year, radio-locations were obtained by aerial telemetry approximately once a week, while ground locations were acquired opportunistically every one to three days. In addition, periodic tracking sessions were also conducted with locations at hourly intervals. Within the study area between August 1994 and July 2003, a total of 174 aerial and 229 ground locations were collected for 8 female bears. Tracking of 2 bears between August of 1996 and September of 1998 provided 26.51km of movement data from 24 different tracking sessions. Through testing with stationary collars in known locations, average locational error was calculated to be approximately 150m (Gibeau 2000).

Data collected from GPS collared grizzly bears, provided by Alberta Parks and Protected Areas and Alberta Sustainable Resource Development, is detailed in Donelon (2004). Capture of animals was done on an opportunistic basis or as part of management actions and hence does not represent a true random sample of the population. Televilt GPS-Simplex ™ collars were used; they were programmed to collect locations on an hourly basis. All data was downloaded directly from retrieved collars. Between June 2001 and October 2003, two female bears provided 903.84km of movement data from 724 separate tracking events and 90 independent resource use locations. Through testing with stationary collars under a variety of cover types, GPS collar locations were found to lie within 27.61m, 95% of the time (Donelon 2004).

Additional radio-tracking of previously collared grizzly bears was also collected specifically for this study. The methods are explained in detail in Appendix A. In summary, between April and November 2003, the study area was searched at least twice a day for presence of a collared animal. If an animal was located, locations were acquired at half-hour intervals. Only one female bear was tracked, and this tracking resulted in 50.31km of movement data from eleven separate tracking sessions. Through testing with a moving target, accuracy was found to be on average 328m.

Once pooled, the entire grizzly bear dataset for the study area, summarised in Table 1, consisted of eight individual bears, for which 319 ground telemetry and GPS locations, 174 aerial locations and 998.66km of movement data from 759 separate movement paths were obtained. This data was split roughly evenly between preberry and berry seasons.

Table 1. Summary of female grizzly bear resource use and movement data.

Bear	RSF Construction Data Ground Telemetry and GPS Collar Download Locations (Time Period)	RSF Evaluation Data Aerial Telemetry Locations (Time Period)	Movement Data Radio-Tracking and GPS Collar Download Movement Paths (Total Length, Time Period)
		Preberry Season	
#26	36 (6/7/94-8/7/99)	47 (30/6/94-9/7/99)	-
#35	24 (10/6/96-14/7/97)	14 (14/6/96-11/7/97)	3 (5.40km, 14/7/97-15/7/97)
#39	4 (26/6/95-17/5/96)	-	-
#47	2 (13/6/02-15/6/02)	1 (12/6/02)	-
#69	15 (10/6/01-29/6/01)	4 (9/5/01-29/6/01)	141 (143.80km, 23/4/01-8/7/01)
#70	40 (10/6/01-11/7/03)	14 (7/6/01-11/7/03)	265 (275.90km, 3/6/01-15/7/03)
#80	2 (26/6/02-25/5/03)	2 (21/5/03-31/5/03)	-
#88	8 (11/5/03-30/5/03)	3 (21/5/03-12/6/03)	8 (37.41km, 10/5/03-1/6/03)
Totals	131 (6/7/94-30/5/03)	85 (30/6/94-11/7/03)	417 (462.51km, 14/7/97-15/7/03)
		Berry Season	
#26	88 (7/8/94-18/9/99)	51 (25/7/94-16/9/99)	18 (20.19km, 29/7/95-6/9/98)
#35	30 (25/7/96-3/9/97)	16 (26/7/96-10/9/97)	3 (0.92km, 9/8/96)
#39	16 (18/7/95-26/7/96)	4 (18/8/95-26/7/96)	-
#47	-	1 (6/8/02)	-
#69	3 (9/10/00-14/10/00)	4 (6/10/00-13/11/00)	51 (78.04km, 6/10/00-29/10/00)
#70	48 (6/8/00-26/10/03)	8 (10/10/00-14/10/03)	267 (424.10km, 20/7/01-26/10/03)
#80	1 (23/9/02)	2 (17/7/02-19/10/02)	-
#88	2 (26/7/03-31/7/03)	3 (29/7/03-12/8/03)	3 (12.90km, 28/7/03-24/8/03)
Totals	188 (7/8/94-31/7/03)	89 (25/7/94-14/10/03)	342 (536.15km, 29/7/95-26/10/03)

3.2.2 Resource Availability

The data collected by aerial telemetry and GPS collars were largely immune to spatial sampling restrictions. However, ground based radio-telemetry within a mountainous environment can be complicated by complex topography (Kenward 2001, White and Garrott 1990). If large portions of the study area cannot be surveyed but are included when availability is measured, then ground based radio-telemetry may be biased towards those areas which could be surveyed. This problem was investigated by generating a Viewshed (ESRI 1998) from all surveyed roads. This Viewshed included all areas visible from three or more road nodes, and was assumed to reflect the areas where a signal might be picked up reliably from a radio collar. The output in Figure 2 shows a notable difference between the area of telemetry reception and the study area for both preberry and berry seasons. Therefore, to combat any survey bias, data analysis was restricted to an analytical frame consisting of the overlap between the telemetry reception area and a 1km buffer around a 100% minimum convex polygon around known locations. Only radio-telemetry and GPS collar locations and measures of resource availability within this analytical frame were used to try and ensure robust models. The model output from these analytical frames was then extrapolated to the entire study area, and the aerial telemetry data, as a spatially independent form of data, was reserved for model evaluation.

3.2.3 Grizzly Bear Resource Characteristics

Choice of resource characteristic variables was dictated by biological reasoning and previous significance in resource selection studies. The greenness tasselled cap transformation for Landsat imagery has been used widely and found to be consistently significant in grizzly bear resource selection studies, since it is linked to biomass and health of grizzly bear plant foods (Mace *et al.* 1999, Nielsen *et al.* 2002, Stevens 2002, Maraj and Gates 2004). Other previously significant variables include elevation (Wielgus and Bunnell 1994, Stevens 2002, Theberge 2002, Nielsen *et al.* 2003) which has a

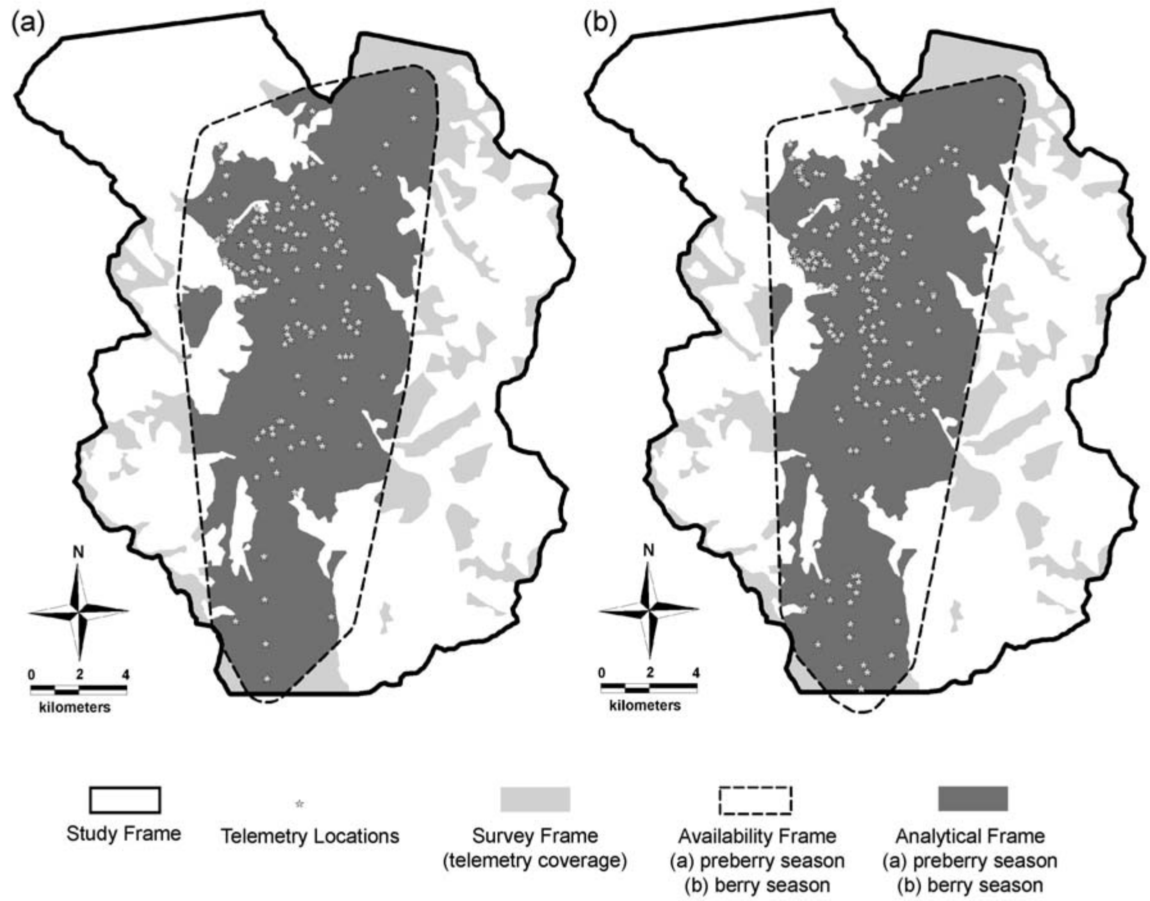


Figure 2. Analytical framing for ground based radio-telemetry data; showing study frame, survey frame and analytical frames for (a) preberry and (b) berry season.

microclimatic effect on vegetation and human activity patterns (Gibeau 2000, Gibeau *et al.* 2002, Nielsen *et al.* 2002, Stevens 2002). Landcover types such as avalanche chutes (McLellan and Hovey 2001, Theberge 2002), shrub fields (Wielgus and Bunnell 1994, Nielsen *et al.* 2002, Theberge 2002) and grass meadows (Theberge 2002) have been seen to have importance in grizzly bear habitat selection as they contain important bear foods such as hedysarum (*Hedysarum sp.*), horsetail (*Equisetum arvense*), buffaloberry (*Shepherdia canadensis*), cow parsnip (*Heracleum lanatum*) and glacier lily (*Erythronium grandiflorum*).

Therefore, the resource characteristics chosen for inclusion in resource selection models were elevation, road density, greenness, avalanche chute density, grass density and shrub density. Creation of each of all resource characteristic datasets is detailed in Appendix B.

3.2.4 Model Building and Evaluation

The grizzly bear data described above was then used in conjunction with the model building and evaluation methods in Chapter Two. Each step in the process was conducted twice, once for each of the two seasons.

For production of an RSF, not all of the available resource cells could not incorporated, due to their abundance. Therefore, the ground based radio-telemetry and GPS collar resource use locations were used in conjunction with a systematic sample of resource availability. This systematic sample consisted of a grid of points spaced at 480m across the analytical frames in Figure 2. Choice of this sampling level is described in Appendix B.

For the preberry season, this process resulted in the inclusion of a total of 690 resource availability points to compare against the 131 ground based telemetry and GPS resource use points. For the berry season, a total of 676 resource availability points were included to compare against the 188 ground based telemetry and GPS resource use points. When resource data were extracted for point locations, values were always taken as a mean from a circular buffer with a radius equal to that of the 150m estimated error. GPS collar data required no buffering as accuracy was consistent with the grain of the study. As only a sample of the available resources was used, logistic regression models were created with the use of Eq.(2) and Eq.(3) on page 9.

AIC was then used to rank the candidate models from all possible combinations of the chosen resource variables. The best model from the AIC rankings was evaluated through resubstitution of the original telemetry locations, and with independent aerial telemetry locations. The evaluation was conducted through the use of the method for a use-availability design of Boyce *et al.* (2002) described in Chapter Two.

Once evaluated and accepted, the best RSF model was used to define habitat patches. Firstly, the non-secure areas 500m from high use roads and 200m from high use trails were excluded. Separate preberry and berry season non-secure areas were created to reflect changes in the distribution and level of human use on the landscape. Then patches were delineated that followed the size and shape criteria for patches prescribed by the BCEAG guidelines (BCEAG 1999), while maintaining a high mean RSF value within each patch.

Least-cost distance corridors were used to identify the areas most likely to be used for movement between the identified habitat patches. The required friction surface for each grizzly bear season was based on Eq.(8) on page 14, but with weightings relating specifically to grizzly bears during each season such that the friction surface was species and season specific.

Female grizzly bears must gain enough fat reserves to sustain them through winter denning and birthing; their resulting preoccupation with food procurement peaks with the emergence of the seasonal berry crop (Weaver *et al.* 1996, Singleton *et al.* 2002). Therefore the habitat friction variable was given a double weighting in the berry season. The friction surfaces for preberry season and berry season were created through the use of Eq.(9) and Eq.(10) respectively.

$$\text{Friction} = (1 - \text{habitat value}) + (\text{slope}) + (1 - \text{forest density}) + (\text{road density}) \qquad \text{Eq.(9)}$$

$$\text{Friction} = (2 \times (1 - \text{habitat value})) + (\text{slope}) + (1 - \text{forest density}) + (\text{road density}) \qquad \text{Eq.(10)}$$

The least-cost distance corridors created between the various patches were then combined. The resulting probability surface was then used in conjunction with the criteria of the

BCEAG guidelines (BCEAG 1999) to identify movement corridors, with the movement corridors and habitat patches forming a reserve network. The corridors were evaluated as part of the reserve network, through the use of independent movement data. This was done through a buffering the movement data by its associated error, 328m for radio-tracking data and 30m for GPS tracking data, and through a splitting of the resulting area between patches, corridors and the intervening matrix. The proportions of the error accounted movement data within patches, corridors and matrix were calculated for an indication of model fit.

3.3 Results

3.3.1 Preberry Season

The results of the preberry season AIC model selection process are shown in Table 2. Here the models created from all combinations of resource characteristics are ranked from high to low on the basis of model fit in relation to the number variables included within the model. Models have been ranked by Δi, with the candidate models being those with $\Delta i<2$. The best model is listed at the top with the ωi showing the degree to which it is better than the other candidate models (Burnham and Anderson 2002).

The model coefficients for the candidate models are shown in Table 3. This information allows for an assessment of the logic and stability of the candidate models.

The best model for the preberry season chosen through AIC ranking, which contained elevation (E), avalanche chute density (Av), shrub density (SDe) and road density (RDe), is shown in Eq.(11).

$$w(x) = \exp\left((-0.001 \times E) + (1.380 \times Av) + (0.782 \times SDe) + (-2.045 \times RDe)\right) \qquad \text{Eq.(11)}$$

Table 2. Comparison of logistic regression models developed for preberry season grizzly bear resource selection, with the use of all combinations of resource variables and AIC. Values reported include the logistic regression -2log-liklihood (-2LL), number of model parameters (K), the AIC (AIC), the corrected AIC (AICc), the relative AICc (Δi) and the Akaike Weight (ωi). Resource variables included in each model are coded as follows: elevation (E), road density (RDe), greenness (G), grass density (GDe), shrub density (SDe) and avalanche chute density (Av).

Model	-2LL	K	AIC	AICc	Δi	ωi
SDe, RDe, Av, E	701.041	5	711.041	711.115	0.000	0.231
Av, E	705.341	3	711.341	711.370	0.256	0.203
RDe, Av, E	703.605	4	711.605	711.654	0.539	0.176
SDe, Av, E	704.102	4	712.102	712.151	1.036	0.137
RDe, Av, G, E	702.456	5	712.456	712.530	1.415	0.114
SDe, RDe, Av, G, E	700.436	6	712.436	712.539	1.425	0.113
SDe, GDe, RDe, Av, E	700.517	6	712.517	712.620	1.506	0.109
Av, G, E	704.578	4	712.578	712.627	1.512	0.108
GDe, Av, E	704.696	4	712.696	712.745	1.630	0.102
GDe, RDe, Av, E	702.824	5	712.824	712.898	1.783	0.095
SDe, GDe, RDe, Av, G, E	699.282	7	713.282	713.420	2.305	0.073
GDe, RDe, Av, G, E	701.378	6	713.378	713.481	2.367	0.071
SDe, GDe, Av, E	703.424	5	713.424	713.498	2.383	0.070
SDe, Av, G, E	703.504	5	713.504	713.578	2.463	0.067
GDe, Av, G, E	703.723	5	713.723	713.797	2.682	0.060
SDe, GDe, Av, G, E	702.643	6	714.643	714.746	3.632	0.038
RDe, E	709.743	3	715.743	715.772	4.658	0.022
SDe, RDe, E	707.916	4	715.916	715.965	4.850	0.020
GDe, RDe, E	708.889	4	716.889	716.938	5.823	0.013
RDe, G, E	708.956	4	716.956	717.005	5.890	0.012
SDe, GDe, RDe, E	706.983	5	716.983	717.057	5.942	0.012
SDe, RDe, G, E	707.285	5	717.285	717.359	6.244	0.010
GDe, RDe, G, E	707.858	5	717.858	717.932	6.817	0.008
SDe, E	711.928	3	717.928	717.957	6.843	0.008
GDe, E	712.007	3	718.007	718.036	6.922	0.007
SDe, GDe, RDe, G, E	706.137	6	718.137	718.240	7.126	0.007
G, E	712.312	3	718.312	718.341	7.227	0.006
SDe, GDe, E	711.252	4	719.252	719.301	8.186	0.004
GDe, G, E	711.512	4	719.512	719.561	8.446	0.003
SDe, G, E	711.669	4	719.669	719.718	8.603	0.003
SDe, GDe, G, E	710.880	5	720.880	720.954	9.839	0.002
E	725.9	2	729.900	729.915	18.800	0.000
SDe, GDe, RDe, G	886.066	5	896.066	896.140	185.025	0.000
SDe, GDe, RDe, Av, G	884.317	6	896.317	896.420	185.306	0.000

GDe, RDe, Av, G	894.109	5	904.109	904.183	193.068	0.000
GDe, RDe, G	896.376	4	904.376	904.425	193.310	0.000
SDe, GDe, RDe, Av	908.026	5	918.026	918.100	206.985	0.000
SDe, GDe, RDe	911.404	4	919.404	919.453	208.338	0.000
SDe, GDe, G	913.178	4	921.178	921.227	210.112	0.000
SDe, GDe, Av, G	912.253	5	922.253	922.327	211.212	0.000
GDe, RDe, Av	917.529	4	925.529	925.578	214.463	0.000
GDe, RDe	921.626	3	927.626	927.655	216.541	0.000
SDe, GDe, Av	931.206	4	939.206	939.255	228.140	0.000
SDe, GDe	933.334	3	939.334	939.363	228.249	0.000
GDe, G	939.425	3	945.425	945.454	234.340	0.000
GDe, Av, G	938.127	4	946.127	946.176	235.061	0.000
SDe, RDe, Av, G	937.711	5	947.711	947.785	236.670	0.000
SDe, RDe, G	948.147	4	956.147	956.196	245.081	0.000
GDe, Av	955.095	3	961.095	961.124	250.010	0.000
GDe	957.707	2	961.707	961.722	250.607	0.000
RDe, Av, G	963.6	4	971.600	971.649	260.534	0.000
RDe, G	979.008	3	985.008	985.037	273.923	0.000
SDe, Av, G	986.475	4	994.475	994.524	283.409	0.000
SDe, RDe, Av	989.179	4	997.179	997.228	286.113	0.000
SDe, G	995.760	3	1001.760	1001.789	290.675	0.000
SDe, RDe	1010.911	3	1016.911	1016.940	305.826	0.000
RDe, Av	1016.599	3	1022.599	1022.628	311.514	0.000
SDe, Av	1034.345	3	1040.345	1040.374	329.260	0.000
RDe	1045.921	2	1049.921	1049.936	338.821	0.000
SDe	1054.028	2	1058.028	1058.043	346.928	0.000
Av, G	1059.996	3	1065.996	1066.025	354.911	0.000
G	1077.188	2	1081.188	1081.203	370.088	0.000
Av	1107.44	2	1111.440	1111.455	400.340	0.000

Table 3. Preberry season grizzly bear candidate model coefficients.

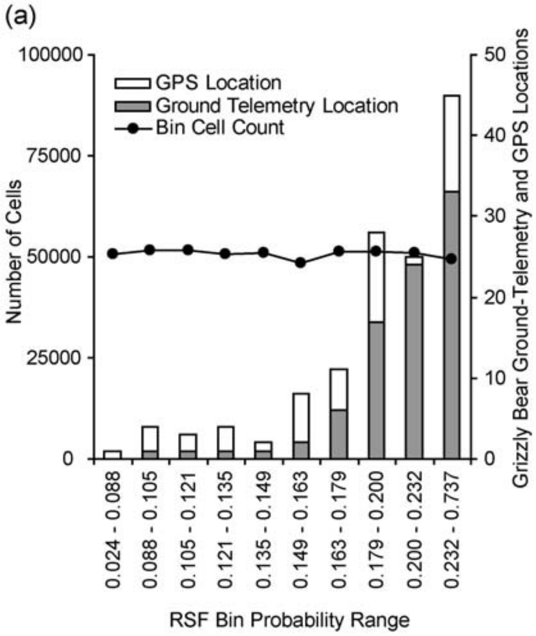
Model	Elevation (E)	Avalanche Chute Density (Av)	Road Density (RDe)	Shrub Density (SDe)	Greenness (G)	Grass Density (GDe)
SDe, RDe, Av, E	-0.001	1.389	-2.045	0.782	-	-
Av, E	-0.001	1.445	-	-	-	-
RDe, Av, E	-0.001	1.342	-1.580	-	-	-
SDe, Av, E	-0.001	1.514	-	0.570	-	-
RDe, Av, G, E	-0.001	1.392	-1.774	-	1.377	-
SDe, RDe, Av, G, E	-0.001	1.435	-2.205	0.756	1.268	-
SDe, GDe, RDe, Av, E	-0.001	1.395	-2.123	0.804	-	0.337
Av, G, E	-0.001	1.509	-	-	1.124	-
GDe, Av, E	-0.001	1.462	-	-	-	0.286
GDe, RDe, Av, E	-0.001	1.343	-1.639	-	-	0.313

Figure 3 graphically illustrates the number of grizzly bear locations within each of the equal area RSF probability ranges, which formed the basis for the Spearman's Rank correlations used to evaluate the models. Two evaluations were conducted: (a) for resubstituted model ground telemetry data and (b) for independent aerial telemetry locations. The Spearman's Rank correlation for the resubstituted data was 0.89, while the independent data rank was 0.64.

Once they had been identified as reliable, the RSFs were then used as the basis for delineation of habitat patches. The preberry RSF shown in Figure 4 indicates the areas of higher probability of use by grizzly bears, as well as illustrating the extent of the non-secure area that had been masked out. Figure 4 also shows the results of the habitat patch delineation, with the area, shape ratio and mean RSF value criteria used in the design of each patch also noted.

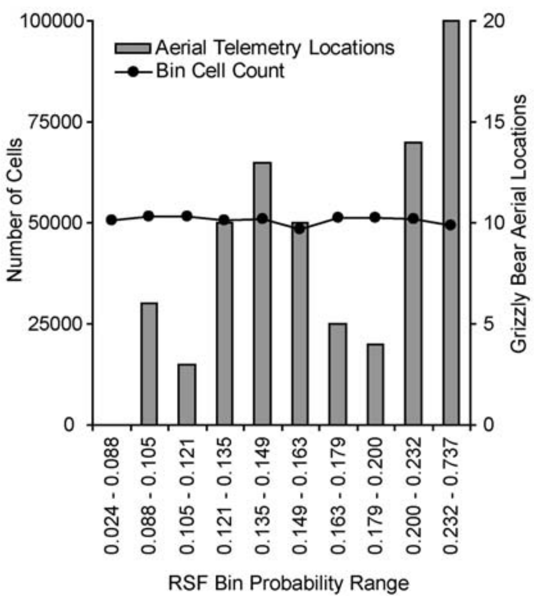
Figure 5 shows the result of the preberry season least-cost distance corridor modelling. The likelihood of use for movement is given, along with the defined movement corridors and the independent grizzly bear movement data used to evaluate the reserve network. Of the total 32.48 km^2 of error buffered movement data, 13.95 km^2 or 43% of the area fell within habitat patches, 16.18 km^2 or 50% fell within movement corridors and 2.35 km^2 or 7% fell within the matrix. A total of 93% of the error accounted movement data fell within the reserve network.

(a)



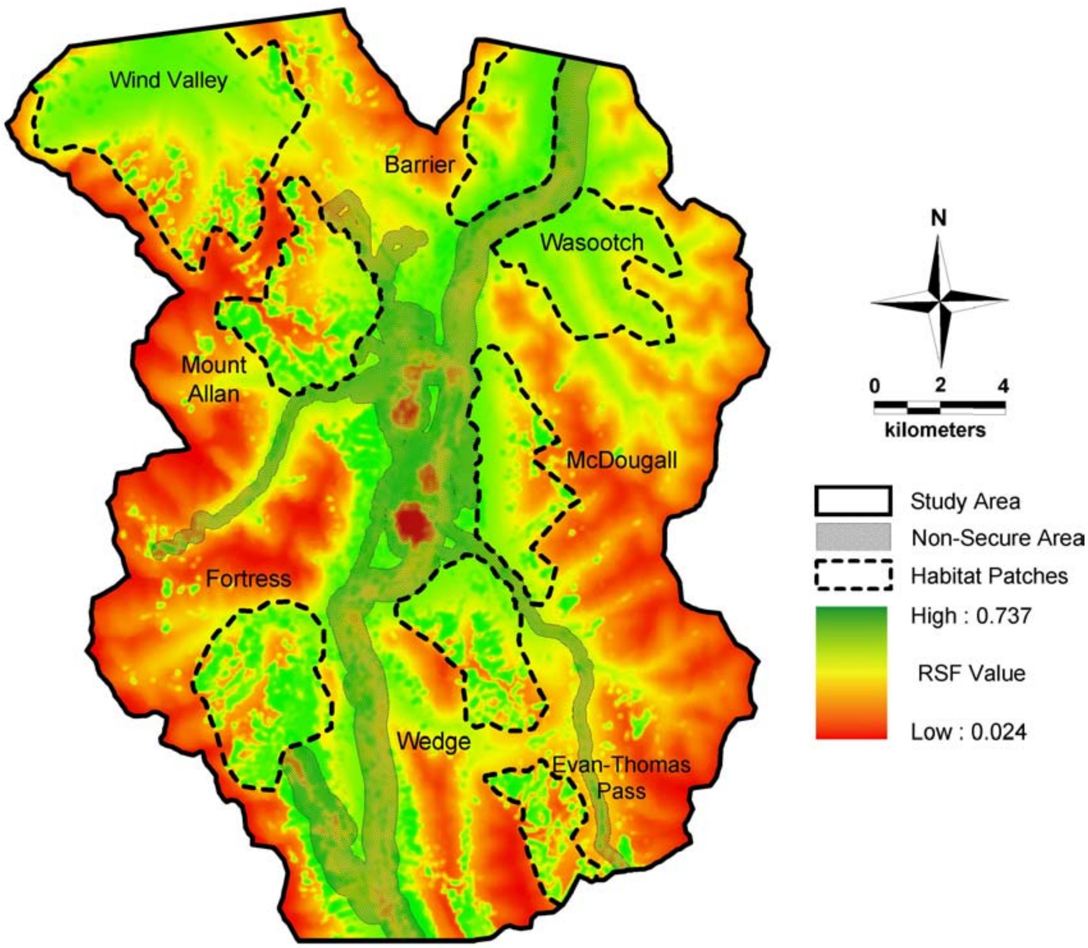
		Resubstituted Data		
RSF Bin Range	Bin Rank (x)	Ground Telemetry and GPS Location	Location Rank (y)	$(x-y)^2$
0.024-0.088	1	1	1	0.00
0.088-0.105	2	4	4.5	6.25
0.105-0.121	3	3	3	0.00
0.121-0.135	4	4	4.5	0.25
0.135-0.149	5	2	2	9.00
0.149-0.163	6	8	6	0.00
0.163-0.179	7	11	7	0.00
0.179-0.200	8	28	9	1.00
0.200-0.232	9	25	8	1.00
0.232-0.737	10	45	10	0.00
			$(x-y)^2 =$	17.5
			$r_s =$	0.89
			$P =$	<0.002

(b)



		Independent Data		
RSF Bin Range	Bin Rank (x)	Aerial Telemetry Locations	Location Rank (y)	$(x-y)^2$
0.024-0.088	1	0	1	0.00
0.088-0.105	2	6	5	9.00
0.105-0.121	3	3	2	1.00
0.121-0.135	4	10	6.5	6.25
0.135-0.149	5	13	8	9.00
0.149-0.163	6	10	6.5	0.25
0.163-0.179	7	5	4	9.00
0.179-0.200	8	4	3	25.00
0.200-0.232	9	14	9	0.00
0.232-0.737	10	20	10	0.00
			$(x-y)^2 =$	59.5
			$r_s =$	0.64
			$P =$	<0.1

Figure 3. Evaluation of grizzly bear preberry season RSF with the use of Spearman's Rank correlations for (a) resubstituted model training data and (b) independent data.



	Size (km^2)	Perimeter (km)	Surface Area/Perimeter Ratio	RSF Values	
				Mean	SD
Study Area	454.30			0.158	0.065
Regional					
Wind Valley	27.07	27.36	0.99	0.158	0.065
Fortress	16.41	16.25	1.01	0.208	0.078
Barrier	11.67	15.07	0.77	0.207	0.053
Wasootch	15.15	20.09	0.75	0.190	0.022
McDougal	13.87	20.48	0.68	0.181	0.046
Mount Allan	16.89	20.42	0.83	0.187	0.076
Wedge	13.16	16.04	0.82	0.196	0.068
Local					
Evan-Thomas Pass	7.02	13.41	0.52	0.176	0.068

Figure 4. Preberry season grizzly bear RSF probability surface and secure habitat patches.

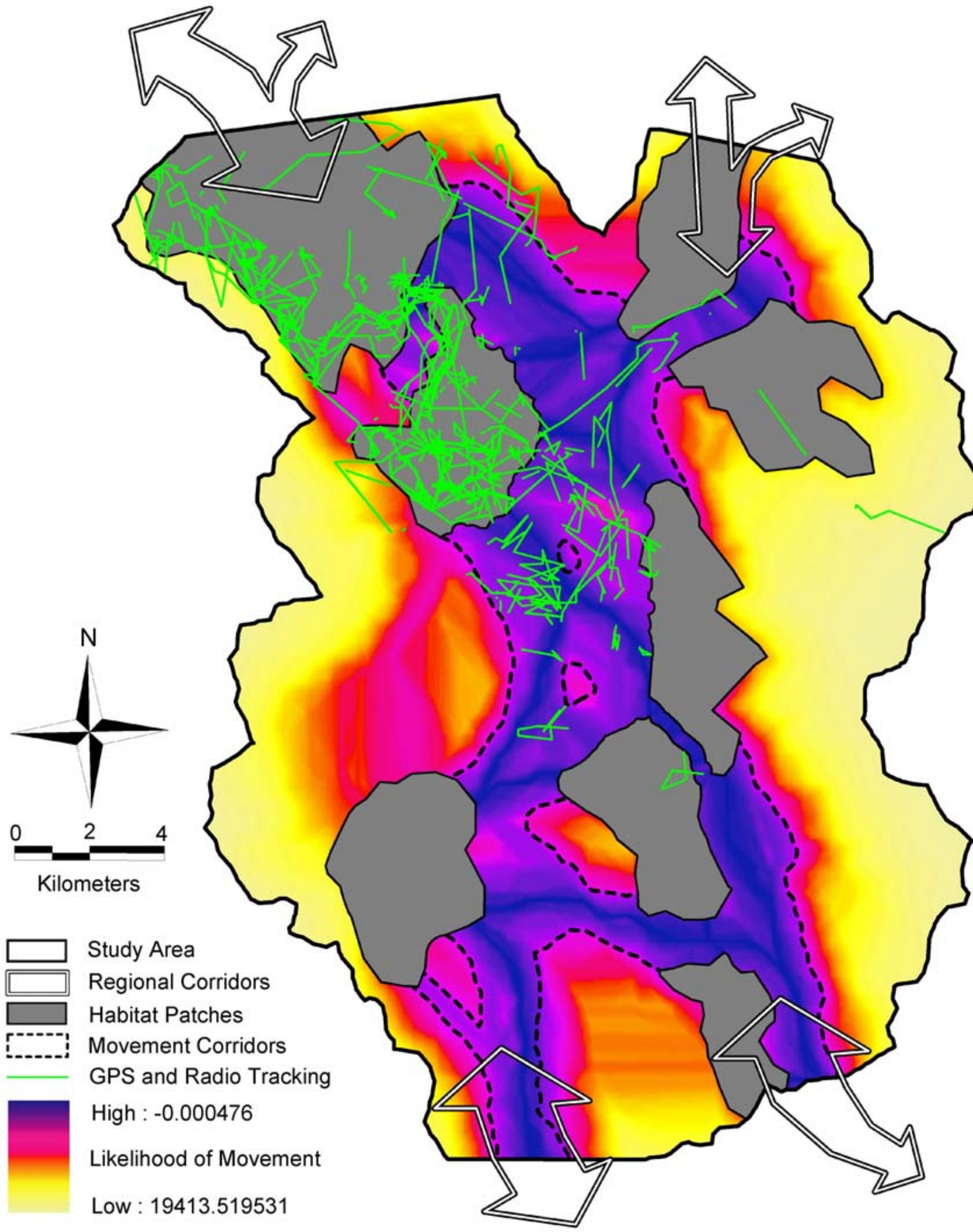


Figure 5. Preberry season likelihood of grizzly bear movement between habitat patches and resulting movement corridors.

3.3.2 Berry Season

The results of the berry season AIC model selection process are shown in Table 4. Here the models created from all combinations of resource characteristics are ranked from high to low on the basis of model fit in relation to the number variables included within the model. Models have been ranked by Δi with the candidate models being those with $\Delta i<2$. The best model is listed at the top with the ωi showing the degree to which it is better than the other candidate models (Burnham and Anderson 2002).

The model coefficients for the candidate models are shown in Table 5. This information allows for an assessment of the logic and stability of the candidate models.

The best model for the berry season chosen through AIC ranking, which contained the elevation (E), greenness (G) and grass density (GDe) resource variables, is shown in Eq.(12).

$$w(x) = \exp\left((-0.001 \times E) + (7.484 \times G) + (0.609 \times GDe)\right) \qquad \text{Eq.(12)}$$

The results of the preberry season model evaluation are shown in Figure 6. Figure 6 graphically illustrates the number of grizzly bear locations within each of the equal area RSF probability ranges, which formed the basis for the Spearman's Rank correlations used to evaluate the model. Two evaluations were conducted for (a) resubstituted ground telemetry data and (b) independent aerial telemetry locations. The Spearman's Rank correlation for the resubstituted data was 0.98, while the independent data rank was 0.88.

Once they had been identified as being reliable, the RSFs were then used as the basis for delineating habitat patches. The berry season RSF shown in Figure 7 indicates the areas of higher probability of use by grizzly bears, as well as illustrating the extent of the non-secure area that had been masked out. Figure 7 also shows the results of the habitat

Table 4. Comparison of logistic regression models developed for berry season grizzly bear resource selection, with the use of all combinations of resource variables and AIC. Values reported include the logistic regression -2log-liklihood (-2LL), number of model parameters (K), the AIC (AIC), the corrected AIC (AICc), the relative AICc (Δi) and the Akaike Weight (ωi). Resource variables included in each model are coded as follows: elevation (E), road density (RDe), greenness (G), grass density (GDe), shrub density (SDe) and avalanche chute density (Av).

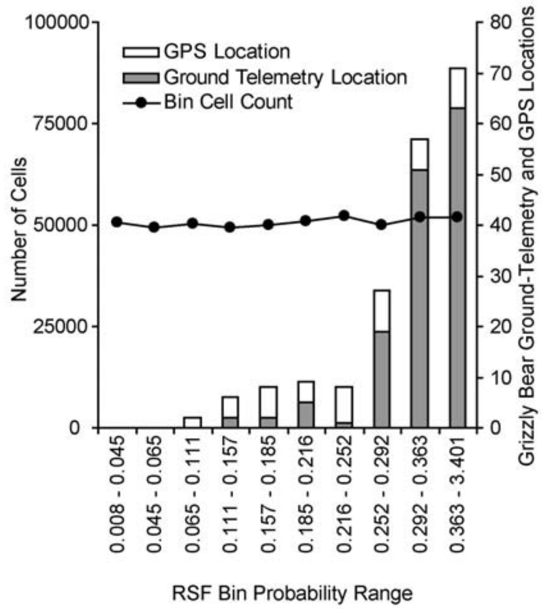
Model	-2LL	K	AIC	AICc	Δi	ωi
GDe, G, E	869.764	4	877.764	877.811	0.000	0.362
GDe, Av, G, E	869.503	5	879.503	879.573	1.762	0.150
SDe, GDe, G, E	869.571	5	879.571	879.641	1.830	0.145
G, E	873.619	3	879.619	879.647	1.836	0.145
GDe, RDe, G, E	869.651	5	879.651	879.721	1.910	0.139
SDe, GDe, Av, G, E	869.155	6	881.155	881.253	3.442	0.065
Av, G, E	873.321	4	881.321	881.368	3.557	0.061
GDe, RDe, Av, G, E	869.308	6	881.308	881.406	3.595	0.060
RDe, G, E	873.461	4	881.461	881.508	3.697	0.057
SDe, G, E	873.542	4	881.542	881.589	3.778	0.055
SDe, GDe, RDe, G, E	869.510	6	881.510	881.608	3.797	0.054
RDe, Av, G, E	873.065	5	883.065	883.135	5.324	0.025
SDe, GDe, RDe, Av, G, E	869.038	7	883.038	883.169	5.358	0.025
SDe, Av, G, E	873.140	5	883.140	883.210	5.399	0.024
SDe, RDe, G, E	873.422	5	883.422	883.492	5.681	0.021
SDe, RDe, Av, G, E	872.945	6	884.945	885.043	7.232	0.010
SDe, GDe, Av, E	880.777	5	890.777	890.847	13.036	0.001
SDe, GDe, E	883.720	4	891.720	891.767	13.956	0.000
SDe, GDe, RDe, Av, E	880.543	6	892.543	892.641	14.830	0.000
SDe, GDe, RDe, E	883.653	5	893.653	893.723	15.912	0.000
SDe, Av, E	885.734	4	893.734	893.781	15.970	0.000
SDe, E	888.811	3	894.811	894.839	17.028	0.000
SDe, RDe, Av, E	885.344	5	895.344	895.414	17.603	0.000
GDe, Av, E	887.471	4	895.471	895.518	17.707	0.000
GDe, E	889.493	3	895.493	895.521	17.710	0.000
GDe, RDe, Av, E	886.354	5	896.354	896.424	18.613	0.000
SDe, RDe, E	888.653	4	896.653	896.700	18.889	0.000
GDe, RDe, E	888.805	4	896.805	896.852	19.041	0.000
Av, E	891.947	3	897.947	897.975	20.164	0.000
RDe, Av, E	890.598	4	898.598	898.645	20.834	0.000
RDe, E	893.289	3	899.289	899.317	21.506	0.000
E	898.712	2	902.712	902.726	24.915	0.000
SDe, GDe, RDe, Av	1072.177	5	1082.177	1082.247	204.436	0.000
SDe, GDe, RDe, Av, G	1070.607	6	1082.607	1082.705	204.894	0.000
SDe, GDe, Av	1076.821	4	1084.821	1084.868	207.057	0.000

SDe, GDe, Av, G	1075.890	5	1085.890	1085.960	208.149	0.000
SDe, GDe, RDe	1078.225	4	1086.225	1086.272	208.461	0.000
GDe, RDe, Av	1078.718	4	1086.718	1086.765	208.954	0.000
SDe, GDe	1082.078	3	1088.078	1088.106	210.295	0.000
SDe, GDe, RDe, G	1078.105	5	1088.105	1088.175	210.364	0.000
GDe, RDe, Av, G	1078.692	5	1088.692	1088.762	210.951	0.000
SDe, GDe, G	1082.052	4	1090.052	1090.099	212.288	0.000
GDe, RDe	1085.252	3	1091.252	1091.280	213.469	0.000
GDe, RDe, G	1084.352	4	1092.352	1092.399	214.588	0.000
GDe, Av	1088.616	3	1094.616	1094.644	216.833	0.000
GDe, Av, G	1087.566	4	1095.566	1095.613	217.802	0.000
GDe, G	1091.355	3	1097.355	1097.383	219.572	0.000
GDe	1094.031	2	1098.031	1098.045	220.234	0.000
SDe, RDe, Av	1120.653	4	1128.653	1128.700	250.889	0.000
SDe, RDe, Av, G	1120.638	5	1130.638	1130.708	252.897	0.000
SDe, Av	1133.991	3	1139.991	1140.019	262.208	0.000
RDe, Av, G	1133.336	4	1141.336	1141.383	263.572	0.000
SDe, Av, G	1133.791	4	1141.791	1141.838	264.027	0.000
RDe, Av	1137.07	3	1143.070	1143.098	265.287	0.000
SDe, RDe, G	1140.307	4	1148.307	1148.354	270.543	0.000
SDe, RDe	1143.411	3	1149.411	1149.439	271.628	0.000
RDe, G	1149.876	3	1155.876	1155.904	278.093	0.000
SDe, G	1150.958	3	1156.958	1156.986	279.175	0.000
SDe	1155.83	2	1159.830	1159.844	282.033	0.000
Av, G	1155.412	3	1161.412	1161.440	283.629	0.000
RDe	1164.345	2	1168.345	1168.359	290.548	0.000
G	1167.994	2	1171.994	1172.008	294.197	0.000
Av	1169.717	2	1173.717	1173.731	295.920	0.000

Table 5. Berry season grizzly bear candidate model coefficients.

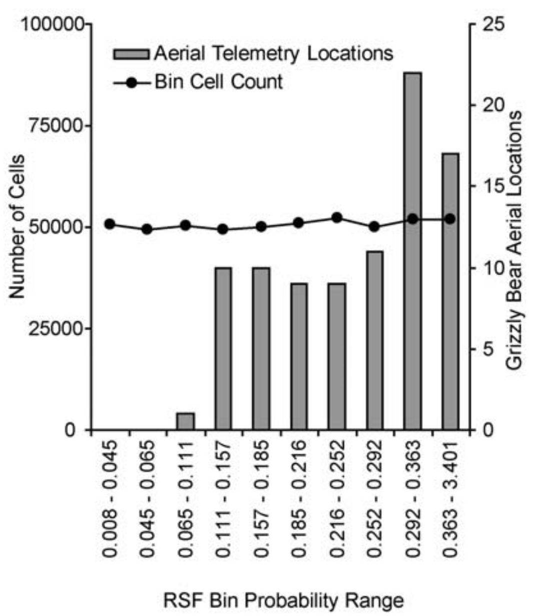
Model	Elevation (E)	Greenness (G)	Grass Density (GDe)	Avalanche Chute Density (Av)	Shrub Density (SDe)	Road Density (RDe)
GDe, G, E	-0.001	7.484	0.609	-	-	-
GDe, Av, G, E	-0.001	7.306	0.607	0.267	-	-
SDe, GDe, G, E	-0.001	7.098	0.621	-	0.212	-
G, E	-0.001	7.572	-	-	-	-
GDe, RDe, G, E	-0.001	7.436	0.607	-	-	0.250

(a)



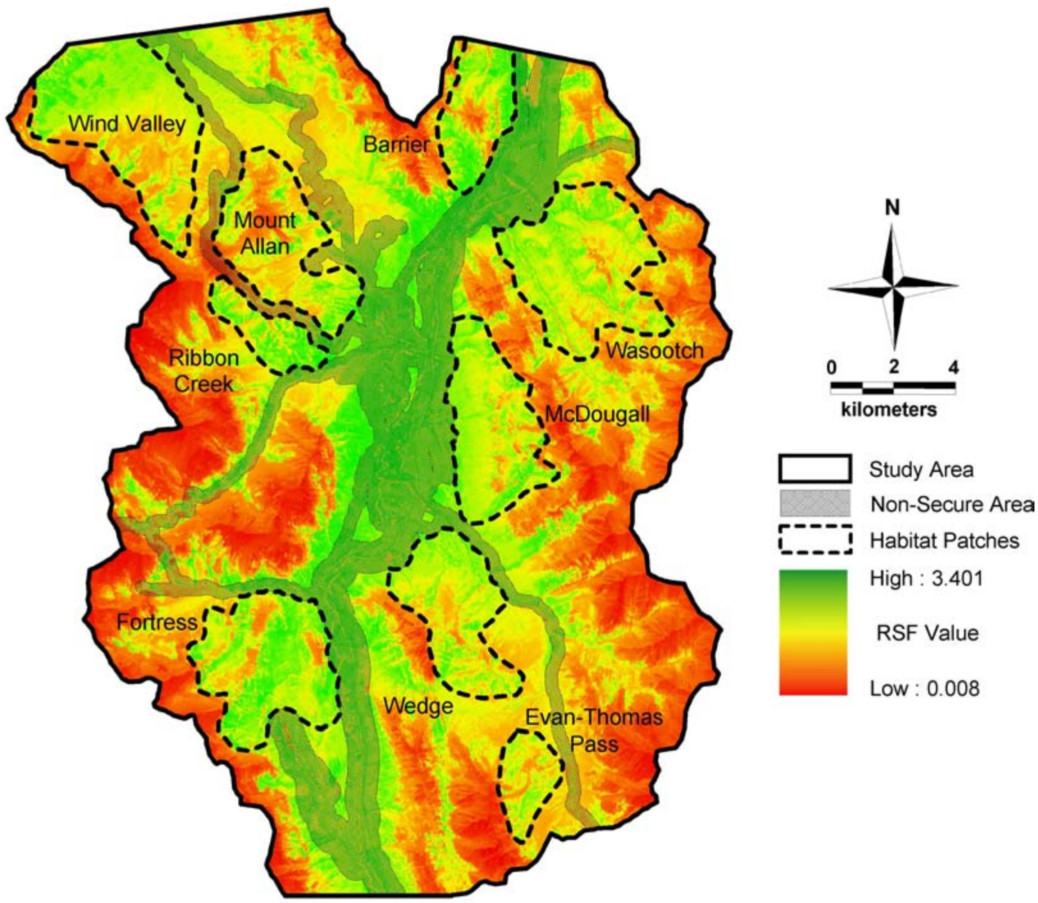
RSF Bin Range	Bin Rank (x)	Resubstituted Data: Ground Telemetry and GPS Locations	Resubstituted Data: Location Rank (y)	$(x\text{-}y)^2$
0.008-0.045	1	0	1.5	0.25
0.045-0.065	2	0	1.5	0.25
0.065-0.111	3	2	3	0.00
0.111-0.157	4	6	4	0.00
0.157-0.185	5	8	6.5	2.25
0.185-0.216	6	9	7	1.00
0.216-0.252	7	8	6.5	0.25
0.252-0.292	8	27	8	0.00
0.292-0.363	9	57	9	0.00
0.363-3.401	10	71	10	0.00
			$(x\text{-}y)^2$ =	4
			r_s =	0.98
			P =	<0.001

(b)



RSF Bin Range	Bin Rank (x)	Independent Data: Aerial Telemetry Locations	Independent Data: Location Rank (y)	$(x\text{-}y)^2$
0.008-0.045	1	0	1.5	0.25
0.045-0.065	2	0	1.5	0.25
0.065-0.111	3	1	3	0.00
0.111-0.157	4	10	6.5	6.25
0.157-0.185	5	10	6.5	2.25
0.185-0.216	6	9	4.5	2.25
0.216-0.252	7	9	4.5	6.25
0.252-0.292	8	11	8	0.00
0.292-0.363	9	22	10	1.00
0.363-3.401	10	17	9	1.00
			$(x\text{-}y)^2$ =	19.5
			r_s =	0.88
			P =	<0.002

Figure 6. Evaluation of grizzly bear berry season RSF with use of Spearman's Rank correlations for (a) resubstituted model training data and (b) independent data.



	Size (km^2)	Perimeter (km)	Surface Area/Perimeter Ratio	RSF Values	
				Mean	SD
Study Area	454.30			0.201	0.140
Regional					
Wind Valley	21.37	20.45	1.04	0.233	0.093
Fortress	16.78	18.56	0.90	0.273	0.116
Wasootch	19.24	21.22	0.91	0.232	0.065
McDougal	14.41	17.85	0.81	0.245	0.071
Wedge	12.81	16.73	0.77	0.228	0.065
Mount Allan	14.47	19.12	0.76	0.190	0.090
Local					
Ribbon Creek	4.94	10.95	0.45	0.302	0.126
Barrier	8.37	12.42	0.67	0.283	0.138
Evan-Thomas Pass	4.73	8.86	0.53	0.197	0.059

Figure 7. Berry season grizzly bear RSF probability surface and secure habitat patches.

patch delineation, with the area, shape ratio and mean RSF value criteria used in the design of each patch also noted.

Figure 8 shows the result of the preberry season least-cost distance corridor modelling. The likelihood of use for movement between the features of interest is given, along with the defined movement corridors and the independent grizzly bear movement data used to evaluate the reserve network. Of the total 34.82 km^2 of error buffered movement data, 12.76 km^2 or 37% of the area fell within habitat patches, 16.17 km^2 or 46% fell within movement corridors and 5.89 km^2 or 17% fell within the matrix. Thus, 83% of the error accounted movement data fell within the reserve network.

3.4 Discussion

During preberry season, the best model was formed by elevation, avalanche chute density, shrub density and road density. Elevation and avalanche chute density appeared to be the most important variables as these two variables were present in all candidate models, and formed the second ranked model on their own. Associations of preberry grizzly bear data to the resource characteristics were as expected. As shown in Table 3, positive associations were seen with the avalanche chute density, shrub density, grass density and greenness variables which represent food sources. Negative associations were seen with elevation and road density, which represent increasing levels of unproductive habitat and human disturbance respectively.

During the berry season, the best model was formed by grass density, greenness and elevation. Greenness and elevation appeared to be the most important variables in this season as they were present in all candidate models, and formed one of the five candidate models on their own. Associations of grizzly bear data to the resource characteristics were largely as expected. As shown in Table 5, positive associations were seen with the avalanche chute density, shrub density, grass density and greenness variables which again

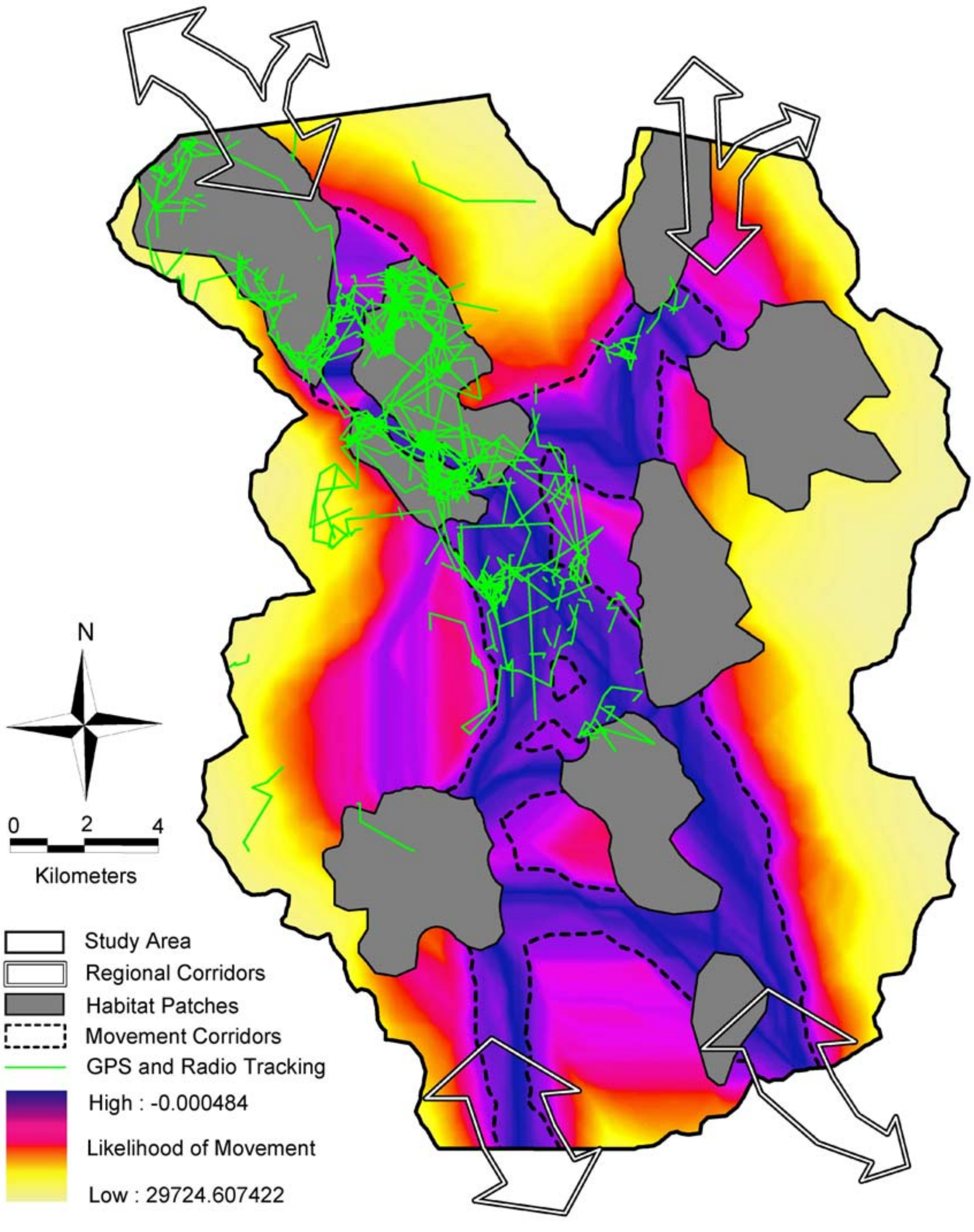


Figure 8. Berry season likelihood of grizzly bear movement between habitat patches and resulting movement corridors.

represent food sources. A negative association was seen with elevation which represents increasing levels of unproductive habitat. However, the positive association to road density during berry season did not seem logical, as this indicates areas with high levels of human disturbance. It is speculated that during berry season, as grizzly bears enter hyperphagia, they may become less affected by human disturbance as they focus on foraging (Gibeau 2000). In addition, due to the lack of wildfire within the study area, forest cover is of a fairly uniform age and structure. This has led to the critical buffaloberry food source often being found in areas of high road density where the forest canopy has been opened up artificially.

As seen in Figure 3 and Figure 6, grizzly bear locations for both seasons were found largely in the bins with higher probabilities of occurrence for both (a) the resubstituted model training data and (b) the independent data from aerial radio-telemetry. This pattern suggested that the models were relatively accurate. This supposition was substantiated by the Spearman's rank correlations. In the preberry season the correlations were 0.89 for the resubstituted ground-telemetry and GPS collar data, and 0.64 for the independent aerial telemetry data. During the berry season, the correlations were 0.98 for the resubstituted ground-telemetry and GPS collar data, and 0.88 for the independent aerial telemetry data. As such, these models were accepted for use in the reserve design process.

High quality grizzly bear habitat can be found across much of the study area, with concentrations both in valley bottoms and alpine areas. It is also evident from Figure 4 and Figure 7 that grizzly bear secure habitat patches occur generally in the same locations for both seasons. An increased level of human use during the berry season has created more numerous, smaller habitat patches.

As can be seen in Figure 5 and Figure 8, for both seasons grizzly bear movement probability was fairly diffuse across the landscape, resulting in wide corridors. There appear to be few occasions where grizzly bear movement is being restricted and funnelled through tight corridors. Though the results do not conform to a classic impression of corridors, this should not necessarily cast doubt on the corridor model. It might just mean that grizzly bears are less affected by the variables used to create the friction surfaces. Regarding the habitat component, due to grizzly bears' high dietary plasticity, they can be expected to be found almost anywhere on the landscape. In addition, grizzly bears may be less averse to travelling away from forested cover, as some of their prime habitat occurs in open areas. Aversion to travelling in steep areas should still follow, but from GPS tracking data there was evidence of some movements across fairly extreme terrain. Therefore, grizzly bears may be expected to utilise a greater variety of areas for movement.

During evaluation of these grizzly bear models with movement data, a discrepancy became evident. There appeared to be small pockets of high quality habitat that were being heavily utilised, but because of the BCEAG size and shape guidelines (BCEAG 1999), they were not identified as habitat patches. This could be an indication that even quite small habitat patches have value, if only as stepping-stones to aid movement within a landscape. That possibility has been proposed by several authors (Simberloff *et al.* 1992, Rosenberg *et al.* 1997, Niemelä 2001, Primack 2002), and perhaps should not be ignored during reserve design.

As 93% and 83% of the error accounted movement data fell within the preberry and berry season reserve networks respectively, both models were accepted and used for the multi-species reserve network created in Chapter Six.

CHAPTER FOUR: WOLF RESERVE NETWORK DESIGN

4.1 Introduction

This chapter applies to the wolf the methods detailed in Chapter Two. Firstly, information relating to wolf modelling is reviewed. Then, the wolf data available to build and evaluate the habitat patch and corridor models is reported. Reasoning is given for the choice of resource characteristics. The application of this data to the model building and evaluation methods from Chapter Two are then outlined with any species-specific features. Finally, the results of the wolf habitat patch and reserve network design process are reported and discussed.

4.1.1 Wolf Modelling Review

It is important to understand some of the basic ecology of wolves in order to avoid problems of pooling data across important demographic, temporal and spatial boundaries. Such pooling can conceal or confound resource selection patterns (Morrison *et al.* 1992, Schooley 1994). For instance, wolves are known to show disparate behaviour between seasons (Paquet *et al.* 1996, Mech and Boitani 2003). In general, wolves can be expected to be found at lower elevations during winter and higher elevations in summer, as the movement of their prey move between seasonal pastures is dictated by snowpack. In addition, during pup-rearing, movements become restricted and more focused around den and rendezvous sites. Therefore, as all movement data on wolves within the study area came from winter snow tracking, this must only be used in conjunction with radio-telemetry data from a winter season (November 15^{th} to April 15^{th}). This time restriction leads to a slight problem, in that conclusions from the winter models, although likely to be broadly true, cannot be an absolute representation of annual activity patterns. Therefore, the reserve design may not adequately provide for non-winter wolf requirements.

As wolves are gregarious and individuals in a pack exhibit similar behaviour, it is important to sample at the pack level to prevent pseudo-replication of data (Erickson *et al.* 2001, Callaghan 2002). In relation to the methods used, if two radio-collared wolves were moving as part of a pack, only data points from one animal (the one with the greater social dominance if known) were used. Similarly, when tracking was done, only a single movement path was recorded as long as the pack appeared to be moving as a unit.

4.2 Methods

4.2.1 Wolf Snow Tracking Data

Wolf snow tracking had been conducted from 1994 to 2003 by the Central Rockies Wolf Project (Callaghan 2002). Locations of radio-collared wolves were used to help find tracks, though opportunistic sightings were also investigated. Backtracking was conducted on foot, with movement paths recorded through the use of a hand-held GPS unit. In addition to the recording of movement paths, bedsites and killsites were also noted. Within the study area, 88 tracking events for at least two different packs were conducted with the result that 130.9km of tracking data and 17 killsites and bedsites were found. The accuracy of the tracking data is expected to be roughly 100m (Callaghan pers. comm. 2004).

4.2.2 Radio-Telemetry Data

Wolf radio-telemetry data had also been collected for numerous individuals and years within the study area by the Central Rockies Wolf Project. Preliminary data screening was done to remove values with missing, incorrect, duplicated or questionable information; locations within three weeks of collaring were also removed to try and avoid contamination of data from human induced behavioural changes (Kenward 2001, Withey *et al.* 2001). Of the data points remaining, a further screening removed any points from the same animal that occurred within the following 24 hours. This was done on the assumption that after 24 hours, a wolf could have chosen to move to any point within its home range, and hence would improve the independence of the remaining locations (Erickson *et al.* 2001).

The exact radio-telemetry methods are detailed in Callaghan (2002) and summarised here. Between December 1991 and March 2003, wolves were radio-collared, and relocations of animals were attempted daily by either ground or air. During this time four different radio-collared wolves had been recorded in the study area, so that 71 ground locations and 5 aerial locations were produced. Through testing with stationary collars, the wolf radio-telemetry data were known have an average accuracy of 225m (Callaghan 2002).

4.2.3 Resource Availability

Data collected by aerial telemetry are largely immune to spatial sampling restrictions. However, ground based radio-telemetry within a mountainous environment can be complicated by complex topography (Kenward 2001, White and Garrott 1990). If large portions of the study area cannot be surveyed but are included when availability is measured, then ground based radio-telemetry may be biased towards those areas which could be surveyed. This problem was investigated through generation of a Viewshed (ESRI 1998) from all surveyed roads. This Viewshed included all areas visible from three or more road nodes, and was assumed to reflect the areas where a signal might be picked up reliably from a radio collar. The output in Figure 9 shows a notable difference between the area of telemetry reception and the study area. Therefore, to combat any survey bias, data analysis was restricted to an analytical frame. It consisted of the overlap between the telemetry reception area and a 1km buffer around a 100% minimum convex polygon surrounding known locations. Only radio-telemetry locations and measures of resource availability within this analytical frame would be used to try and ensure robust models. The model output from these analytical frames was then extrapolated to the entire study area. The aerial telemetry data, as a spatially independent form of data, was reserved for model evaluation.

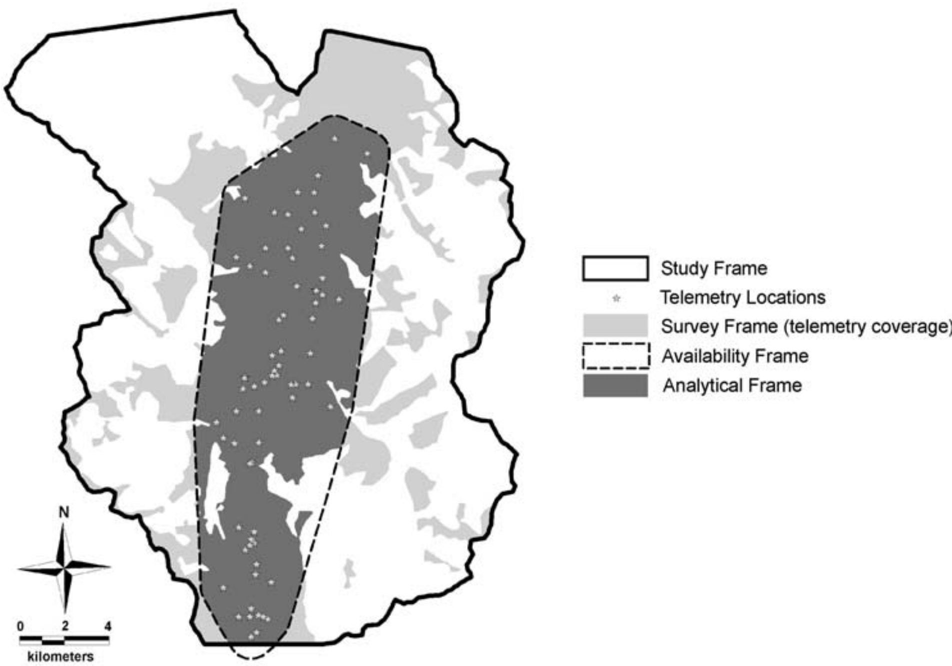


Figure 9. Analytical framing for wolf ground based radio-telemetry data showing study frame, survey frame and analytical frames.

4.2.4 Wolf Resource Characteristics

Choice of resource characteristic variables was dictated by biological reasoning and previous significance in resource selection studies. Prey has been a constant predictor in wolf resource selection (Paquet *et al.* 1996, Callaghan 2002, Mech and Boitani 2003). The main prey species of wolves within this area were ungulates, such as white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*) and moose (*Alces alces*). Prey is more likely to be found within grassy and shrubby areas, which have been directly linked with wolf resource selection (Paquet *et al.* 1996). Higher elevations generally are more energetically expensive to access due to higher snow depths, and tend to have fewer ungulates. Likewise, northern and eastern aspects tend to be avoided (Paquet *et al.* 1996, Callaghan 2002), as are areas of rugged terrain (Callaghan

2002). Road density, a measure of human disturbance, has also shown to be significant for predicting wolf occurrence (Mladenoff *et al.* 1995, Paquet *et al.* 1996, Weaver *et al.* 1996, Callaghan 2002).

Therefore, the resource characteristics chosen were elevation, terrain ruggedness, road density, grass and shrub density and aspect. Aspect was represented by transformations to northness and eastness to assess the level of association with north to south and east to west facing slopes respectively. Creation of these resource characteristic datasets is detailed in Appendix B.

4.2.5 Model Building and Evaluation

The wolf data described above was then used in conjunction with the model building and evaluation methods in Chapter Two.

For production of an RSF, not all of the available resource cells could be incorporated due to their abundance. Therefore, the ground based radio-telemetry resource use locations were used in conjunction with a systematic sample of resource availability. This systematic sample consisted of a grid of points spaced at 480m across the analytical frames represented in Figure 9. Choice of this sampling level is described in Appendix B. This resulted in a total of 545 resource availability points within the analytical frame being included to compare against the 71 ground based telemetry resource use points. When resource data were extracted for point locations, values were always taken as a mean from a circular buffer with a radius equal to that of the estimated error of 225m. As only a sample of the available resources was used logistic regression models were created with the use of Eq.(2) and Eq.(3) on page 9.

AIC was then used to rank the candidate models from all the possible combinations of the chosen resource variables. The best model from the AIC rankings was evaluated through resubstitution of the original ground telemetry locations, and with independent data consisting of aerial telemetry locations and locations of killsites and bedsites from snow tracking. The evaluation was conducted with the use of the method for a use-availability design of Boyce *et al.* (2002) described in Chapter Two.

Once evaluated and accepted, the best RSF model was used to define habitat patches. Firstly the non-secure areas 500m from high use roads and 200m from high use trails during winter were excluded. Then habitat patches were delineated; they followed the size and shape criteria for useful patches prescribed by the BCEAG guidelines (BCEAG 1999), while a high mean RSF value was maintained within the patch.

Least-cost distance corridors were used to identify the areas most likely to be used for movement between the identified habitat patches. The required friction surface for wolves was based on Eq.(8) on page 14, but with weightings relating specifically to wolves. Due to the large distances wolves travel in their search for prey, energetic efficiency has been noted as factor of importance for wolf movement, with wolves more likely to utilise flatter areas (Paquet *et al.* 1996, Duke *et al.* 2001, Singleton *et al.* 2002, Mech and Boitani 2003). As the terrain appeared to be of particular importance, slope was given a double weighting:

$$\text{Friction} = (1 - \text{habitat value}) + (2 \times \text{slope}) + (1 - \text{forest density}) + (\text{road density}) \qquad \text{Eq.(13)}$$

The least-cost distance corridors between the various patches were combined. The resulting probability surface was then used in conjunction with the criteria of the BCEAG guidelines (BCEAG 1999) to identify movement corridors; the movement corridors and habitat patches formed a reserve network. The corridors were evaluated as part of the reserve network, with the use of the independent snow tracking movement data. This evaluation was done through the buffering of the tracking data by its associated error of 100m; the resulting area between patches, corridors and the intervening matrix were then split. The proportions of the error accounted movement data within patches, corridors and matrix were calculated for an indication of model fit.

4.3 Results

The results of the AIC model selection process are shown in Table 6. Here the models created from all combinations of resource characteristics are ranked from high to low on the basis of model fit in relation to the number of variables included within the model. Models have been ranked by Δi, with the candidate models being those with $\Delta i<2$. The best model is listed at the top, with the ωi showing the degree to which it is better than the other candidate models (Burnham and Anderson 2002).

The model coefficients for the candidate models are shown in Table 7. This information allows for an assessment of the logic and stability of the candidate models.

The best model containing elevation (E) and terrain ruggedness (TR) is shown in Eq.(14),

$$w(x) = \exp\left((-0.048 \times \mathrm{TR}) + (-0.001 \times \mathrm{E})\right) \qquad \text{Eq.(14)}$$

The results of the best model evaluation are shown in Figure 10. It illustrates graphically the number of wolf locations falling within each of the equal area RSF probability ranges, which formed the basis for the Spearman's Rank correlations used to evaluate the models. Two evaluations were conducted for (a) resubstituted ground telemetry wolf locations and (b) independent aerial telemetry locations and wolf killsites and bedsites locations from snow tracking. The Spearman's Rank correlation for the resubstituted data was 0.95, while the independent data rank was 0.78.

Table 6. Comparison of logistic regression models developed for wolf resource selection, with the use of all combinations of resource variables and AIC. Values reported include the logistic regression -2log-liklihood (-2LL), number of model parameters (K), the AIC (AIC), the corrected AIC (AICc), the relative AICc (Δi) and the Akaike Weight (ωi). Resource variables included in each model are coded as follows: elevation (E), eastness (Ea), northness (Na), road density (RDe), terrain ruggedness (TR) and grass and shrub density (GSDe).

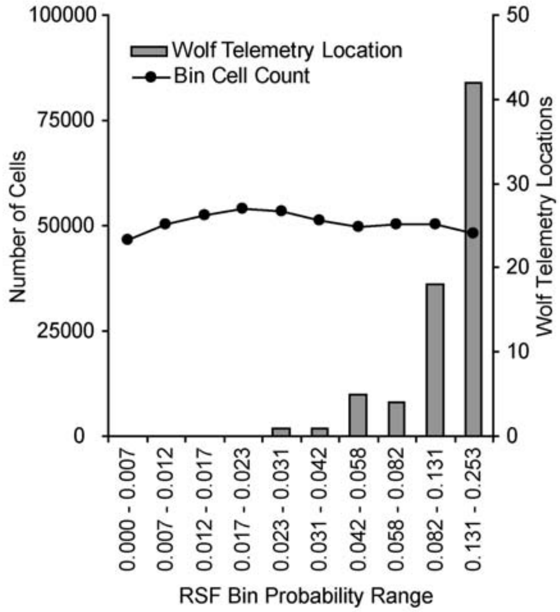
Model	-2LL	K	AIC	AICc	Δi	ωi
TR, E	395.696	3	401.696	401.735	0.000	0.226
TR, Ea, E	394.91	4	402.910	402.975	1.240	0.121
TR, RDe, E	395.379	4	403.379	403.444	1.709	0.096
GSDe, TR, E	395.57	4	403.570	403.635	1.900	0.087
TR, Na, E	395.666	4	403.666	403.731	1.996	0.083
E	400.439	2	404.439	404.459	2.723	0.058
TR, RDe, Ea, E	394.576	5	404.576	404.674	2.939	0.052
GSDe, TR, Ea, E	394.662	5	404.662	404.760	3.025	0.050
TR, Na, Ea, E	394.899	5	404.899	404.997	3.262	0.044
GSDe, TR, RDe, E	395.308	5	405.308	405.406	3.671	0.036
TR, RDe, Na, E	395.345	5	405.345	405.443	3.708	0.035
GSDe, TR, Na, E	395.513	5	405.513	405.611	3.876	0.032
GSDe, TR, RDe, Ea, E	394.408	6	406.408	406.546	4.811	0.020
TR, RDe, Na, Ea, E	394.565	6	406.565	406.703	4.968	0.019
GSDe, TR, Na, Ea, E	394.628	6	406.628	406.766	5.031	0.018
GSDe, TR, RDe, Na, E	395.256	6	407.256	407.394	5.659	0.013
GSDe, TR, RDe, Na, Ea, E	394.378	7	408.378	408.562	6.827	0.007
GSDe, TR, RDe	407.535	4	415.535	415.600	13.865	0.000
GSDe, TR, RDe, Ea	405.809	5	415.809	415.907	14.172	0.000
GSDe, TR, RDe, Na	406.584	5	416.584	416.682	14.947	0.000
GSDe, TR, RDe, Na, Ea	405.07	6	417.070	417.208	15.473	0.000
GSDe, TR, Ea	410.456	4	418.456	418.521	16.786	0.000
GSDe, TR	412.636	3	418.636	418.675	16.940	0.000
GSDe, TR, Na	411.092	4	419.092	419.157	17.422	0.000
GSDe, TR, Na, Ea	409.23	5	419.230	419.328	17.593	0.000
TR, RDe	413.391	3	419.391	419.430	17.695	0.000
TR, RDe, Ea	412.393	4	420.393	420.458	18.723	0.000
TR, RDe, Na	412.582	4	420.582	420.647	18.912	0.000
RDe, E	415.164	3	421.164	421.203	19.468	0.000
TR, RDe, Na, Ea	411.753	5	421.753	421.851	20.116	0.000
Ea, E	416.538	3	422.538	422.577	20.842	0.000
GSDe, E	416.576	3	422.576	422.615	20.880	0.000
Na, E	416.684	3	422.684	422.723	20.988	0.000
RDe, Ea, E	414.796	4	422.796	422.861	21.126	0.000
RDe, Na, E	414.978	4	422.978	423.043	21.308	0.000

GSDe, RDe, E	415.074	4	423.074	423.139	21.404	0.000
GSDe, Na, E	416.186	4	424.186	424.251	22.516	0.000
Na, Ea, E	416.269	4	424.269	424.334	22.599	0.000
GSDe, Ea, E	416.302	4	424.302	424.367	22.632	0.000
RDe, Na, Ea, E	414.582	5	424.582	424.680	22.945	0.000
GSDe, RDe, Ea, E	414.757	5	424.757	424.855	23.120	0.000
GSDe, RDe, Na, E	414.816	5	424.816	424.914	23.179	0.000
GSDe, Na, Ea, E	415.9	5	425.900	425.998	24.263	0.000
GSDe, RDe, Na, Ea, E	414.488	6	426.488	426.626	24.891	0.000
TR	429.529	2	433.529	433.549	31.813	0.000
TR, Na	427.58	3	433.580	433.619	31.884	0.000
TR, Ea	428.049	3	434.049	434.088	32.353	0.000
TR, Na, Ea	426.438	4	434.438	434.503	32.768	0.000
GSDe, RDe, Na, Ea	613.483	5	623.483	623.581	221.846	0.000
GSDe, Na, Ea	618.704	4	626.704	626.769	225.034	0.000
GSDe, RDe, Na	618.938	4	626.938	627.003	225.268	0.000
GSDe, RDe, Ea	621.301	4	629.301	629.366	227.631	0.000
GSDe, Na	624.887	3	630.887	630.926	229.191	0.000
GSDe, RDe	626.506	3	632.506	632.545	230.810	0.000
GSDe, Ea	628.296	3	634.296	634.335	232.600	0.000
GSDe	634.36	2	638.360	638.380	236.644	0.000
RDe	767.383	2	771.383	771.403	369.667	0.000
RDe, Na	766.594	3	772.594	772.633	370.898	0.000
RDe, Ea	767.346	3	773.346	773.385	371.650	0.000
RDe, Na, Ea	766.55	4	774.550	774.615	372.880	0.000
Na	851.116	2	855.116	855.136	453.400	0.000
Na, Ea	851.1	3	857.100	857.139	455.404	0.000
Ea	853.93	2	857.930	857.950	456.214	0.000

Table 7. Wolf candidate model coefficients.

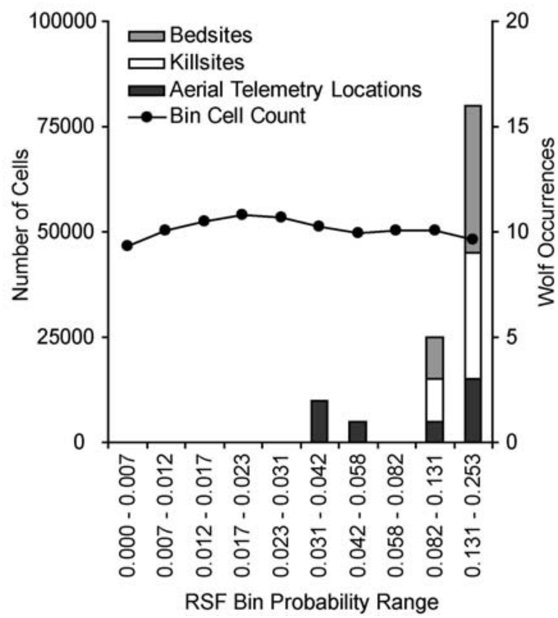
Model	Elevation (E)	Terrain Ruggedness (TR)	Eastness (Ea)	Road Density (RDe)	Grass and Shrub Density (GSDe)	Northness (Na)
TR, E	-0.001	-0.048	-	-	-	-
TR, Ea, E	-0.001	-0.048	0.152	-	-	-
TR, RDe, E	-0.001	-0.050	-	-0.749	-	-
GSDe, TR, E	-0.001	-0.049	-	-	-0.148	-
TR, Na, E	-0.001	-0.048	-	-	-	-0.041

(a)



RSF Bin Range	Bin Rank (x)	Resubstituted Data: Ground Telemetry Location	Location Rank (y)	$(x-y)^2$
0.000-0.007	1	0	2.5	2.25
0.007-0.012	2	0	2.5	0.25
0.012-0.017	3	0	2.5	0.25
0.017-0.023	4	0	2.5	2.25
0.023-0.031	5	1	5.5	0.225
0.031-0.042	6	1	5.5	0.225
0.042-0.058	7	5	8	1
0.058-0.082	8	4	7	1
0.082-0.131	9	18	9	0
0.131-0.253	10	42	10	0
			$(x-y)^2$ =	7.5
			r_s =	0.95
			P =	<0.001

(b)



RSF Bin Range	Bin Rank (x)	Independent Data: Aerial Telemetry, Kills and Bedsites	Location Rank (y)	$(x-y)^2$
0.000-0.007	1	0	3.33	5.43
0.007-0.012	2	0	3.33	1.77
0.012-0.017	3	0	3.33	0.11
0.017-0.023	4	0	3.33	0.45
0.023-0.031	5	0	3.33	2.79
0.031-0.042	6	2	8	4
0.042-0.058	7	1	7	0
0.058-0.082	8	0	3.33	21.81
0.082-0.131	9	5	9	0
0.131-0.253	10	16	10	0
			$(x-y)^2$ =	36.35
			r_s =	0.78
			P =	<0.02

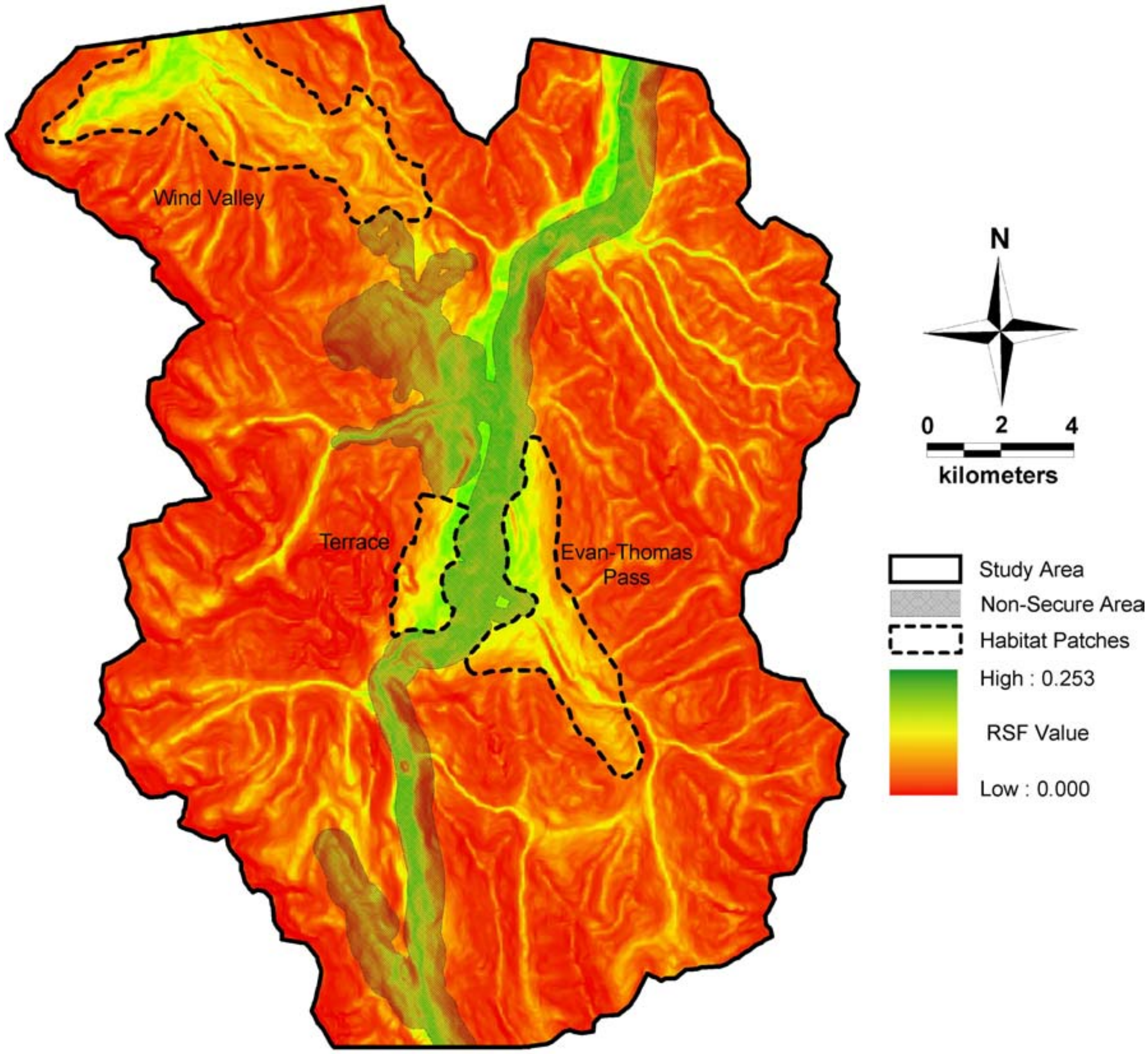
Figure 10. Evaluation of wolf RSF with the use of Spearman's Rank correlations for (a) resubstituted model training data and (b) independent data.

Once identified as being reliable, the RSF was then used as the basis for delineating habitat patches. The RSF shown in Figure 11 indicates the areas of higher probability of use by wolves, as well as illustrating the extent of the non-secure area that had been masked out. Figure 11 also shows the results of the habitat patch delineation. The area, shape ratio and mean RSF value criteria used in the design of each patch are also noted.

Figure 12 shows the result of least-cost distance corridor modelling. The likelihood of use for movement between the features of interest is given, along with the defined movement corridors and the independent wolf tracking data used to evaluate the reserve network. Of the total 20.59 km^2 of error buffered movement data, 4.52 km^2 or 22% of the area fell within habitat patches, 13.16 km^2 or 64% fell within movement corridors and 2.91 km^2 or 14% fell within the matrix. Thus, 86% of the error accounted movement data fell within the reserve network.

4.4 Discussion

Of the candidate models, elevation and terrain ruggedness were the most important variables. They formed the best model on their own and formed part of all candidate models. The associations shown in Table 7 were largely as expected. Negative associations were seen with increasing levels of elevation, terrain ruggedness, northness and road density. However, the positive association for eastness and the negative association to grass and shrub density were not as expected. Grass and shrub density was a variable included to represent prey. In fact, grass and shrub density might better describe non-cover, with wolves selecting for locations within cover. In theory, eastern slopes should be cooler with deeper snow and hence be avoided by wolves. It is possible that the local topography affected this relationship through shadows cast by surrounding mountains, or that the subtle difference between east and west slopes is not well represented by the eastness variable.



	Size (km^2)	Perimeter (km)	Surface Area/Perimeter Ratio	RSF Values	
				Mean	SD
Study Area	454.30			0.050	0.051
Regional					
Wind Valley	24.31	28.95	0.84	0.088	0.040
Evan-Thomas Pass	14.44	24.55	0.59	0.099	0.041
Local					
Terrace	4.86	10.87	0.45	0.128	0.056

Figure 11. Wolf RSF probability surface and secure habitat patches.

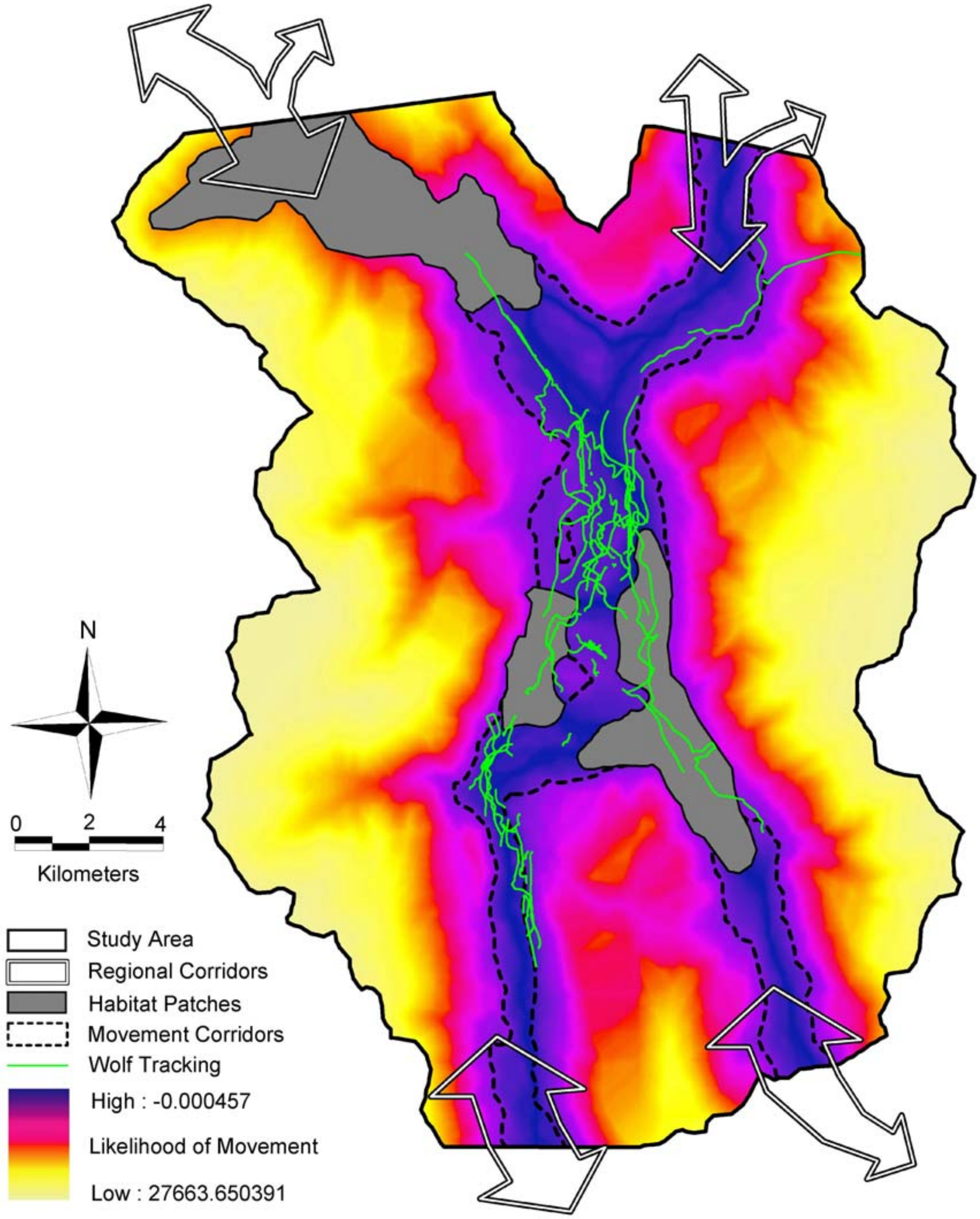


Figure 12. Winter likelihood of wolf movement between habitat patches and resulting movement corridors.

If models containing the potentially unreliable eastness and grass and shrub density variables are ignored, the best model containing elevation and terrain ruggedness was over twice as good as the other candidate models.

From the model evaluation results in Figure 10, it is clear that wolf locations were found largely in the bins with higher probabilities of occurrence. This effect was observed for both the resubstituted ground telemetry locations and the independent data from aerial radio-telemetry and snow tracking. This observation suggests that the models were relatively accurate, and that conclusion was supported by the Spearman's rank correlations. On a scale of 0 to 1, correlations were 0.95 for the resubstituted telemetry data, and 0.78 for the independent tracking and aerial telemetry data. Consequently, this model was accepted for use in the reserve design process.

Figure 11 shows clearly that the areas of high resource value occur largely in the valley bottoms; the vast majority of the study area is of little value for wolves. This finding indicates protection of high quality habitat for wolves in this environment should be a high priority. Unfortunately the valley bottoms are also the area in which most of the human development is also found, so that much of the prime habitat areas have been classified as non-secure. These circumstances have resulted in either very small habitat patches, or patches which contain larger amounts of less important habitat. Consequently, wolves would likely have to either be willing to expose themselves to human induced mortality risks associated with non-secure habitat in order to utilise the better habitat and movement corridors, or eke a living in less productive areas. The tracking data shown in Figure 12 seems to suggest that when wolves do use the study area, they have little choice but to use non-secure areas, and hence may be prone to high mortality rates.

As a total of 86% of the error accounted movement data fell within the reserve network, the design was accepted and used for the multi-species reserve network created in Chapter Six.

CHAPTER FIVE: LYNX RESERVE NETWORK DESIGN

5.1 Introduction

This chapter describes the application to the lynx of the methods detailed in Chapter Two. Firstly, information relating to lynx modelling is reviewed. Then the lynx data available to build and evaluate the habitat patch and corridor models is reported. Reasoning is given for the choice of resource characteristics. The applications of this data to the model building and evaluation methods from Chapter Two are then outlined with any species-specific features. Finally, the results of the lynx habitat patch and reserve network design process are reported and discussed.

5.1.1 Lynx Modelling Review

To avoid problems of pooling data across important demographic or temporal boundaries (Morrison *et al.* 1992, Schooley 1994) it is important to understand some of the biological factors that affect lynx. For instance, in the northern boreal forests of Canada, the snowshoe hare (*Lepus americanus*) is a critical prey species of the lynx and its population is known to cycle dramatically over time (Koehler and Aubry 1994, Poole 2003). This cycling may have dramatic effects on resource selection and produce confounding results when data is pooled across years. However, in the studies that have compared resource selection through years of fluctuating hare numbers, few differences were found (O'Donoghue *et al.* 1998). In general, resource selection was consistent among years (Murray *et al.* 1994, Poole *et al.* 1996, Mowat and Slough 2003). In addition, within the mountainous regions in the south of lynx distribution, such as the study area, snowshoe hare and lynx populations are thought to remain relatively low and stable over time (Koehler and Aubry 1994, Apps 2000). As such, this biological phenomenon was not considered, and data were pooled across years.

All lynx data were collected via snow tracking and have no associated demographic information. Previous lynx resource selection studies that incorporated demographic variance have found no difference in selection between sexes (Poole *et al.* 1996, Mowat and Slough 2003). In addition, negligible difference between age groups has been observed (Mowat and Slough 2003). Hence, the lack of demographic information of the snow tracking data used here was not considered critical, and data were pooled.

Snow tracking, being restricted to winter, is temporally biased. Ideally, separate analyses should be conducted for summer and winter lynx activity. Presence of snow during the winter and denning by female lynx during the summer create disparate environments and behavioural activities. However, of the few studies that have investigated the effects of season on habitat selection, little or no difference was found (Koehler 1990, Apps 2000, Mowat and Slough 2003). Differences that were evident indicated that during the summer, larger areas of the landscape became available, but that areas that were selected by lynx during winter are also important during summer. Winter could be considered to represent the period at which key resources are critical to lynx survival, and protecting for these areas would provide for core areas for summer activity as well, although it is likely that habitat use during the summer would become more widespread and diffuse. Although separate summer models would be desirable, in the absence of summer data, the winter models were assumed to have some year-round relevance.

5.2 Methods

5.2.1 Lynx Resource Use Transect Data

The only lynx resource use data available for the study area was from nine transects surveyed during three winters, 1997-2000 (Alexander 2001). Transects were surveyed between 24 and 120 hours after fresh snowfall and all lynx occurrences were recorded. Numbers of lynx were tallied to the start of 50m long sub-transects which were located to sub-meter accuracy through the use of differentially corrected GPS (Alexander 2001). Unfortunately, as can be seen in Figure 13, the sampling area is small in relation to the study area. To avoid sampling bias, data analysis was limited to an analytical frame consisting of just the area encompassed by transects. There is, however, an increased potential for erroneous results when the resulting model is extrapolated to the whole study area (Morrison *et al.* 1992).

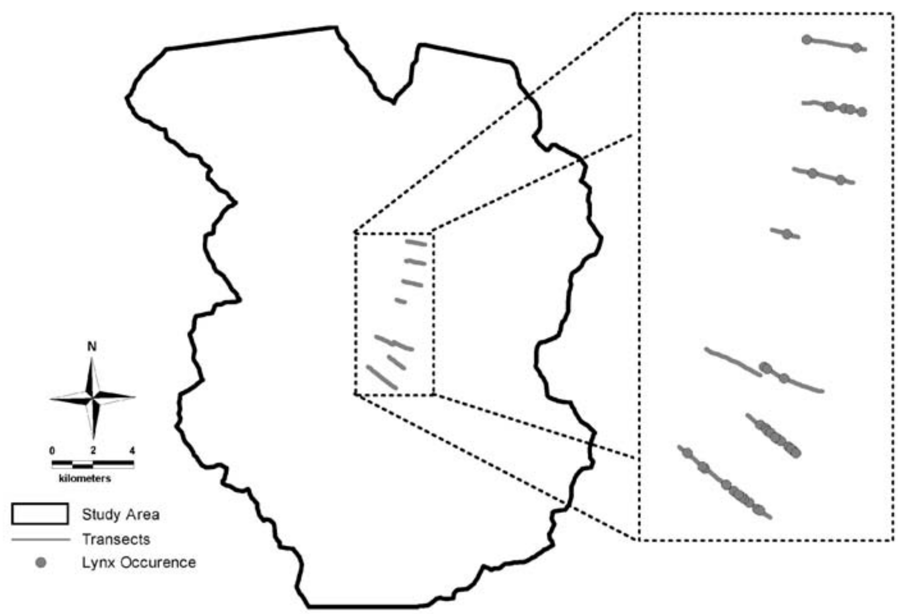


Figure 13. Sampling area of transects used for collection of lynx resource use data; plus inset showing distribution and abundance of lynx occurrence.

5.2.2 Lynx Snow Tracking Data

The first set of movement data for lynx in the study area was acquired through lynx tracking during the winter of 2003-2004 when snowfall and animal presence allowed. The exact methodology employed is detailed in Appendix C. In summary, transects were established and surveyed on foot for presence of lynx from 24 hours after snowfall events until tracking conditions became too poor. Backtracking was initiated from the point at which lynx tracks intersected a transect. Between November and April, a total of 27 lynx tracking sessions were conducted, resulting in 30.27km of movement data. In addition, 10 killsites and bedsites were recorded. The tracking data were recorded using a hand-held GPS unit, the accuracy of which was calculated to be 30m.

5.2.3 Lynx Resource Characteristics

Choice of resource characteristics was dictated by biological reasoning and determination of previous significance in resource selection studies. Lynx have been found within forested areas, as this is where snowshoe hare reside. Indeed, resource selection studies of landcover types have found selection for forest landcover to be very strong (Koehler 1990, Koehler and Aubry 1994, Poole *et al.* 1996, Mowat and Slough 2003), with apparent aversion to open or fragmented areas (Koehler 1990, Murray *et al.* 1994, Poole *et al.* 1996, Mowat and Slough 2003). Higher elevation areas (Apps 2000) and areas affected by human disturbance (Koehler and Aubry 1994, Poole 2003) were avoided. In addition, it has been noted that during winter lynx may be found in areas of deeper snow where their adaptations allow them to partition themselves successfully from other competitive carnivores such as coyotes (*Canis latrans*) and bobcats (*Lynx rufus*) (Koehler and Aubry 1994, Apps 2000). Snow accumulation was highly variable; nevertheless within the Rocky Mountains, north and east aspects can be expected to be cooler and hence to retain more snow.

Consequently, the resource characteristics chosen were forest density, elevation, road density and aspect. Aspect was represented by transformations to northness and eastness to assess the level of association with north to south and east to west facing slopes respectively. Creation of these resource characteristic datasets is detailed in Appendix B.

5.2.4 Model Building and Evaluation

The lynx data was used in conjunction with the model building and evaluation methods reviewed in Chapter Two.

For production of an RSF, all of the available resources, represented by the transects surveyed, could be incorporated. This represented a sample of 167 availability points used in conjunction with the 46 lynx transect use locations. Because all available points surveyed could be incorporated, the RSF model was created with the use of the logistic regression model shown in Eq.(1) on page 9.

AIC was then used to rank the candidate models from all possible combinations of the chosen resource variables. The best model from the AIC rankings was evaluated by resubstituting the original transect data, and by using presence of killsites and bedsites from independent tracking data. The evaluation for a use-availability design outlined in Boyce *et al.* (2002) was used.

Once evaluated and accepted, the best RSF model was used to define habitat patches. Firstly, the non-secure areas 500m from high use roads and 200m from high use trails during winter were excluded. Then, habitat patches were delineated in accordance with the size and shape criteria for useful patches prescribed by the BCEAG guidelines (BCEAG 1999), while a high mean RSF value was maintained within the patch.

Least-cost distance corridor models were used to identify the areas most likely to be used for movement between the identified habitat patches. The required friction surface for lynx was created using Eq.(8) on page 14, but with weightings relating specifically to lynx. Lynx are known to show a preference for travel in unbroken forested cover (Koehler and Aubry 1994, Singleton *et al.* 2002, Poole 2003). Koehler and Aubry (1994) noted that unforested areas greater than 100m wide may actually create virtual barriers to movement.

Since forest cover would appear to be a critical factor in lynx movement, forest density was given a triple weighting:

$$\text{Friction} = (1 - \text{habitat value}) + (\text{slope}) + (3 \times (1 - \text{forest density})) + (\text{road density}) \qquad \text{Eq.(15)}$$

The least-cost distance corridors between the various patches were combined. The resulting probability surface was then used in conjunction with the criteria of the BCEAG guidelines (BCEAG 1999) to identify movement corridors, with the movement corridors and habitat patches forming a reserve network. The corridors were evaluated as part of this reserve network with the use of the independent snow tracking data. To accomplish this end, the tracking data was buffered by its associated error of 30m, and the resulting area was then split between patches, corridors and the intervening matrix. The proportions of the error accounted movement data within patches, corridors and matrix were calculated for an indication of model fit.

5.3 Results

The results of the AIC model selection process are shown in Table 8. Here the models created from all combinations of resource characteristics are ranked from high to low on the basis of model fit in relation to the number of variables included within the model. Models have been ranked by Δi, with the candidate models being those with $\Delta i<2$. The best model is listed at the top, with the ωi showing the degree to which it is better than the other candidate models (Burnham and Anderson 2002).

The model coefficients for the candidate models are shown in Table 9. This information allows for an assessment of the logic and stability of the candidate models.

Table 8. Comparison of logistic regression models developed for lynx resource selection, with the use of all combinations of resource variables and AIC. Values reported include the logistic regression -2log-liklihood (-2LL), number of model parameters (K), the AIC (AIC), the corrected AIC (AICc), the relative AICc (Δi) and the Akaike Weight (ωi). Resource variables included in each model are coded as follows: elevation (E), eastness (Ea), northness (Na), road density (RDe) and Forest Density (FDe).

Model	-2LL	K	AIC	AICc	Δi	ωi
FDe, Na	199.349	4	207.349	207.541	0.000	0.219
FDe, Na, Ea	197.301	5	207.301	207.591	0.050	0.214
FDe, Na, E	198.357	5	208.357	208.647	1.106	0.126
RDe, FDe, Na	198.644	5	208.644	208.934	1.393	0.109
FDe, Na, Ea, E	196.789	6	208.789	209.197	1.655	0.096
RDe, FDe, Na, Ea	197.176	6	209.176	209.584	2.042	0.079
RDe, FDe, Na, E	198.212	6	210.212	210.620	3.078	0.047
RDe, FDe, Na, Ea, E	196.789	7	210.789	211.335	3.794	0.033
FDe, E	204.331	4	212.331	212.523	4.982	0.018
FDe	206.762	3	212.762	212.877	5.336	0.015
FDe, Ea, E	204.004	5	214.004	214.294	6.753	0.007
FDe, Ea	206.333	4	214.333	214.525	6.984	0.007
RDe, FDe	206.338	4	214.338	214.530	6.989	0.007
RDe, FDe, E	204.32	5	214.320	214.610	7.069	0.006
RDe, FDe, Ea	205.53	5	215.530	215.820	8.279	0.003
RDe, Na	208.147	4	216.147	216.339	8.798	0.003
RDe, FDe, Ea, E	203.989	6	215.989	216.397	8.855	0.003
Na, E	208.937	4	216.937	217.129	9.588	0.002
RDe, Na, E	206.974	5	216.974	217.264	9.723	0.002
RDe, Na, Ea	207.398	5	217.398	217.688	10.147	0.001
Na, Ea, E	207.663	5	217.663	217.953	10.412	0.001
RDe, Na, Ea, E	206.301	6	218.301	218.709	11.167	0.001
Na, Ea	211.97	4	219.970	220.162	12.621	0.000
Na	214.415	3	220.415	220.530	12.989	0.000
E	214.5	3	220.500	220.615	13.074	0.000
RDe, E	213.533	4	221.533	221.725	14.184	0.000
Ea, E	214.211	4	222.211	222.403	14.862	0.000
RDe	216.779	3	222.779	222.894	15.353	0.000
RDe, Ea, E	212.735	5	222.735	223.025	15.484	0.000
RDe, Ea	215.217	4	223.217	223.409	15.868	0.000
Ea	221.922	3	227.922	228.037	20.496	0.000

Table 9. Lynx candidate model coefficients.

Model	Constant	Forest Density (FDe)	Northness (Na)	Eastness (Ea)	Elevation (E)	Road Density (RDe)
FDe, Na	-4.029	2.731	1.018	-	-	-
FDe, Na, Ea	-4.790	2.691	1.560	-0.866	-	-
FDe, Na, E	-11.220	2.475	0.934	-	0.005	-
RDe, FDe, Na	-3.613	2.418	1.044	-	-	-1.921
FDe, Na, Ea, E	-10.097	2,502	1.410	-0.751	0.004	-

The best model identified by AIC contained the forest density (FDe) and northness (Na) variables, and is shown in Eq.(16).

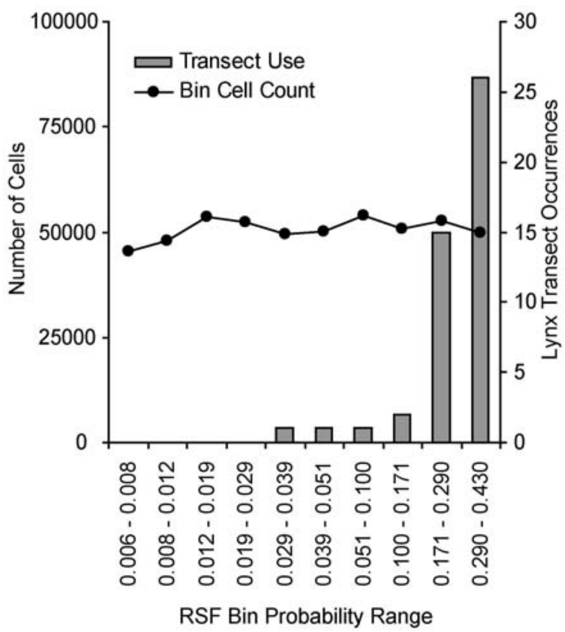
$$w*(x) = \frac{\exp(-4.029 + (2.731 \times \mathrm{FDe}) + (1.018 \times \mathrm{Na}))}{1 + \exp(-4.029 + (2.731 \times \mathrm{FDe}) + (1.018 \times \mathrm{Na}))} \qquad \text{Eq.(16)}$$

Figure 14 graphically illustrates, the Spearman's Rank correlations used to evaluate the best RSF model. This evaluation was based on the number of lynx locations that lie within each of the equal area RSF probability ranges. Two evaluations were conducted for (a) resubstituted lynx transect locations model building data, and (b) independent lynx killsites and bedsites locations. The Spearman's Rank correlation for the resubstituted data was 0.96, while the independent data rank was 0.83.

Once identified as being reliable, the RSF was then used as the basis for delineating habitat patches. The RSF shown in Figure 15 indicates the areas of higher probability of use by lynx, as well as illustrating the extent of the non-secure area that has been masked out. Figure 15 also shows the results of habitat patch delineation, with the area, shape ratio and mean RSF value criteria used in the design of each patch also noted.

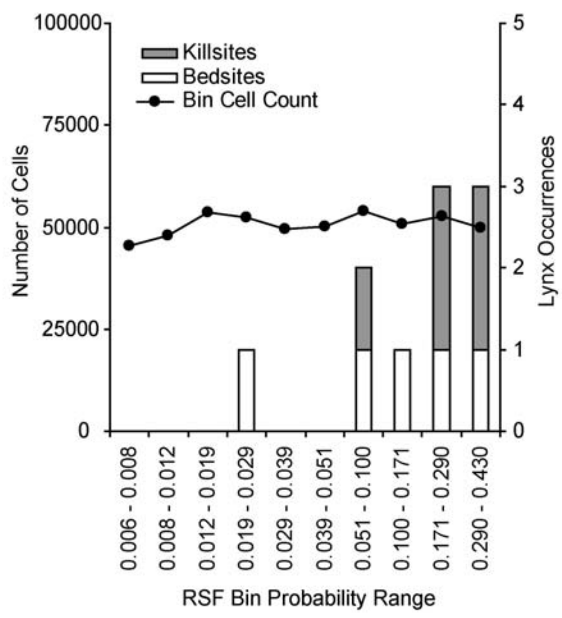
Figure 16 shows the result of least-cost distance corridor modelling. The likelihood of use for movement between the features of interest is given, along with the defined movement corridors and the independent lynx tracking data used to evaluate the reserve network. Of

(a)



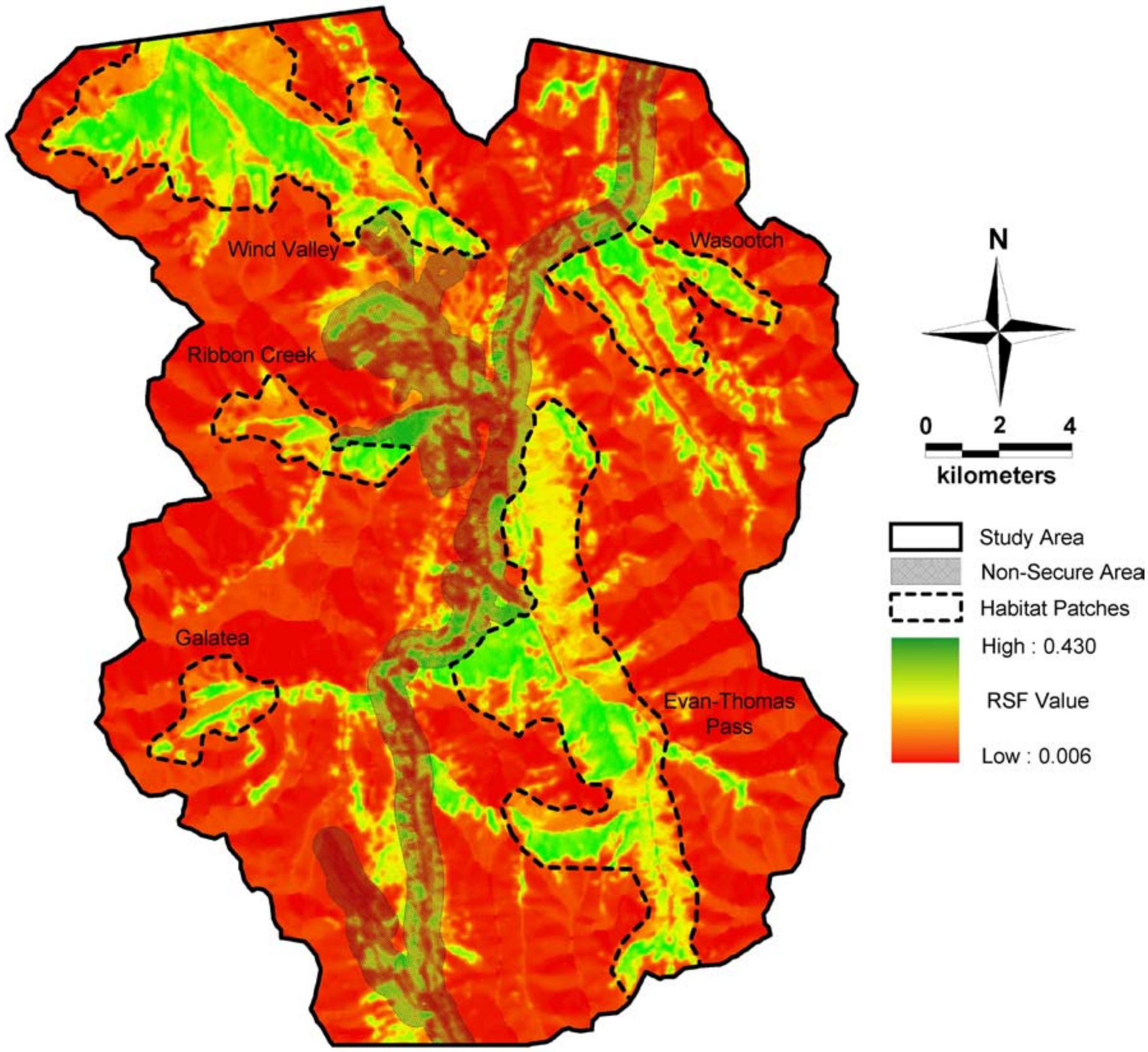
RSF Bin Range	Bin Rank (x)	Resubstituted Data: Transect Use	Use Rank (y)	$(x-y)^2$
0.006-0.008	1	0	2.5	2.25
0.008-0.012	2	0	2.5	0.25
0.012-0.019	3	0	2.5	0.25
0.019-0.029	4	0	2.5	2.25
0.029-0.039	5	1	6	1
0.039-0.051	6	1	6	0
0.051-0.100	7	1	6	1
0.100-0.171	8	2	8	0
0.171-0.290	9	15	9	0
0.290-0.430	10	26	10	0
			$(x-y)^2$ =	7
			r_s =	0.96
			P =	<0.001

(b)



RSF Bin Range	Bin Rank (x)	Independent Data: Kills and Bedsites	Use Rank (y)	$(x-y)^2$
0.006-0.008	1	0	3	4
0.008-0.012	2	0	3	1
0.012-0.019	3	0	3	0
0.019-0.029	4	1	6.5	6.25
0.029-0.039	5	0	3	4
0.039-0.051	6	0	3	9
0.051-0.100	7	2	8	1
0.100-0.171	8	1	6.5	2.25
0.171-0.290	9	3	9.5	0.25
0.290-0.430	10	3	9.5	0.25
			$(x-y)^2$ =	28
			r_s =	0.83
			P =	<0.005

Figure 14. Evaluation of lynx RSF with the use of Spearman's Rank correlations for (a) resubstituted model training data and (b) independent data.



	Size (km^2)	Perimeter (km)	Surface Area/Perimeter Ratio	RSF Values	
				Mean	SD
Study Area	454.30			0.094	0.114
Regional					
Wind Valley	36.43	37.22	0.98	0.240	0.133
Evan-Thomas Pass	40.63	48.43	0.84	0.213	0.119
Wasootch	12.47	19.93	0.62	0.199	0.130
Local					
Galatea	5.33	10.89	0.49	0.150	0.123
Ribbon Creek	6.52	14.58	0.45	0.174	0.122

Figure 15. Lynx RSF probability surface, non-secure area and habitat patches.

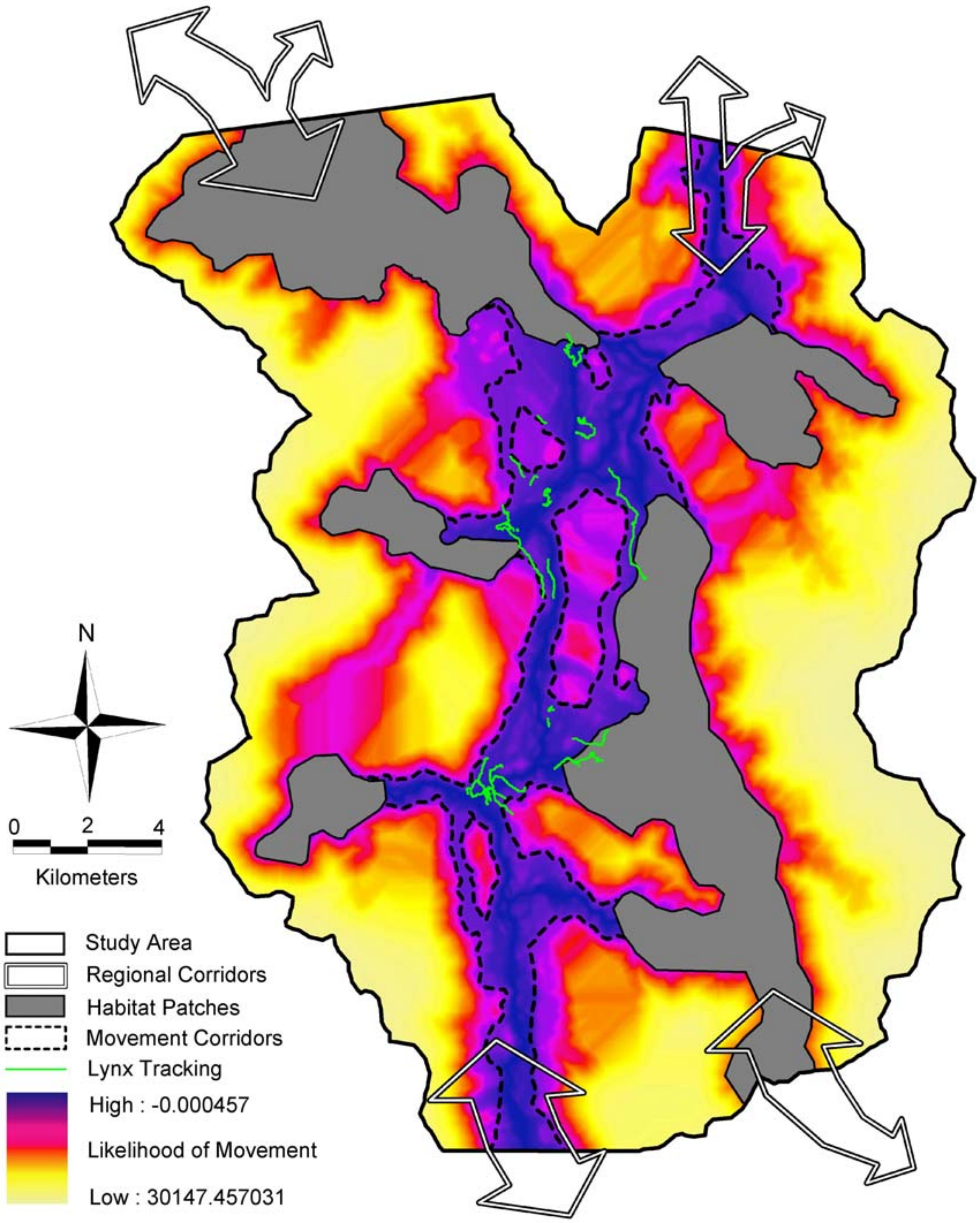


Figure 16. Winter likelihood of lynx movement between habitat patches and resulting movement corridors.

the total 1.66 km^2 of error buffered movement data, 0.20 km^2 or 12% fell within habitat patches; 1.40 km^2 or 84% fell within movement corridors; and 0.06 km^2 or 4% fell within the matrix. Thus, 96% of tracking data fell within the reserve network.

5.4 Discussion

Of the candidate models in Table 9, forest density and northness were the most important variables. As was expected, lynx were positively associated with these two previous variables, and negatively associated with road density. Elevation and eastness did not behave as expected. Regarding elevation, the observed positive association may relate to the sampling frame, which did not include high elevation areas. Hence, the selection for high elevation areas within the sampling area may actually represent selection for mid-elevation areas within the study area. Apps (2000) reported such selection for mid-elevations. The negative association to eastness, which would, in theory, mean selection for warmer areas with less snow is also unexpected. This may be because the potential effect on temperature and snowpack of eastern versus western slopes is a great deal more subtle than that of north versus south, and that eastness may not a reliable description of this variable. Because elevation and eastness were not behaving as expected, models containing these variables should probably be considered unreliable. Of the remaining candidate models, the best model, which contained forest density and northness, was more than twice as good as the next reliable model, which also added road density.

Figure 14 shows that lynx locations were found largely in the bins with higher probabilities of occurrence for both the resubstituted transect model training data and the independent data from snow tracking. This result suggests that the models were relatively accurate. That conclusion is backed by the Spearman's rank correlations. On a scale of 0 to 1, models scored 0.96 for the resubstituted transect data, and 0.83 for the independent tracking data. This model was accepted for use in the reserve design.

As can be seen in Figure 15, in general, most of the prime lynx habitat is unaffected by human disturbance. Much of the non-secure area is found in the montane valley bottom, which would naturally have minimal forest cover anyway. This is not to say that lynx are less affected by human disturbance; in fact, the opposite is probably true. Human disturbance would appear not to make habitat areas non-secure; instead, it removes the habitat entirely.

As can be seen in Figure 16, of the three focal species, lynx had the most limited areas of movement probability, producing lots of narrow corridors. Clearly, as would be expected from the friction surface model weightings, forest cover is dictating areas of movement for lynx. The corridors are occurring at lower and mid-elevation ranges which contain continuous belts of forested cover. This has created a situation in which lynx may be the species most susceptible to fragmentation. Removal of forest for development in some areas could reduce corridor widths to a point at which they are no longer functional, or essentially remove corridors altogether. As 96% of tracking data fell within the reserve network, the design was accepted for use in the multi-species reserve network created in Chapter Six.

CHAPTER SIX: MULTI-SPECIES RESERVE NETWORK

6.1 Introduction

Numerous authors have identified the potential for single focal species investigations to produce conservation guidelines irrelevant to many other species (Beier and Loe 1992, Noss 1995, Lambeck 1997). The research objective was, therefore, to identify areas of importance for habitat and movement for multiple focal species in order to broaden the umbrella coverage. To achieve this end, the three species-specific reserve networks created thus far needed to be compared. This comparison would allow for the identification of areas used by multiple focal species.

6.2 Method

The reserve network of secure resource patches and movement corridors for the three carnivores were overlaid, as in Noss (1995), to produce final delineations. In order that the grizzly bear would receive equal significance as other species, the preberry and berry season reserves were combined; they formed a single grizzly bear reserve network which would represent grizzly bear habitat patches and movement corridors for both seasons. The overlay was done as in Alexander (2001), with the use of Boolean images with species coded as follows; grizzly bear = 1, wolf = 2 and lynx = 4. In this way, after overlaying was done, the combination of species occurring in a single location could be determined.

6.3 Results

The result of the species overlay is shown in
Figure 17. It should be noted that increasing numbers do not necessarily indicate areas of greater importance; they represent differing combinations of species.

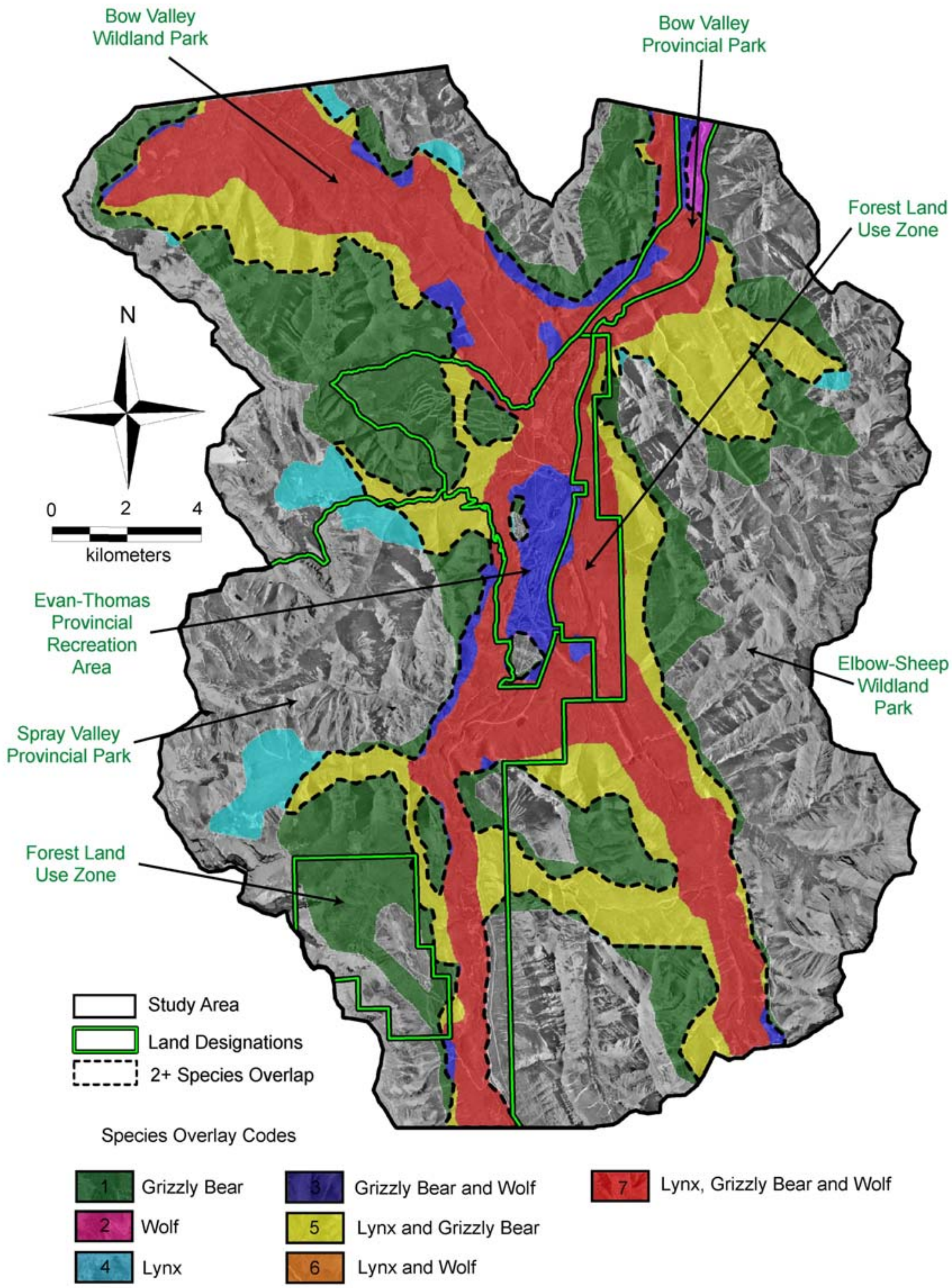


Figure 17. Multi-species reserve network overlay in relation to land designations.

6.4 Discussion

When all areas that are part of the multi-species overlay were considered, except for the rocky mountainous terrain, virtually all the study area was seen to be of use to at least one species. This was not surprising, as the focal species were specifically chosen to provide diverse umbrella coverage. In addition, the results provide strong evidence for the use of multiple species in reserve network planning. Even though the grizzly bear reserve network encompassed 98.9% of the wolf and 93.1% of the lynx networks, a great deal of information would be lost if the grizzly bear were chosen as the only focal species. Due to their dietary plasticity and movements, grizzly bears could be expected to found almost anywhere on the landscape, so that the reserve network would be very broad. One could, therefore, argue that use of grizzly bear alone may be the most appealing option from a conservation perspective, as it would support protection of a large area of land. However, in light of competition for land use rights, a focus on specific areas of greater importance for habitat and movement for more than one species may be more valuable. Such prioritisation could not be achieved through a consideration of grizzly bear requirements alone. Though the inclusion of lynx and wolf reserve models with the grizzly bear reserve model did not expand the total reserve area very much, it did allow for a gradation of areas of importance for two of or all of the focal species to be recognised (
Figure 17).

This approach would work fine for wolf and lynx as a large portion of their single reserve falls within this area. In contrast, a large proportion of the grizzly bear reserve, in particular the secure habitat patches, falls outside these areas. If these parts of the reserve remain unprotected, grizzly bears and the species it represents as an umbrella could be placed at risk. However, within the study area in question, this is unlikely to be the case. The vast majority of these areas are already included within land designated as parks and as such are protected. They are also largely alpine areas that are unattractive for further commercial development.

CHAPTER SEVEN: CONCLUSION

7.1 Summary of Model Findings

Models were built to try and identify areas of importance for habitat and movement for three focal species: the grizzly bear, the wolf and the lynx.

High quality grizzly bear habitat for both preberry and berry seasons was fairly consistent and was distributed across the study area. The high quality habitat was generally found in lower elevation areas, but was also associated with higher elevation features such as avalanche chutes and alpine meadows. However, because human disturbance was extensive at lower elevations, the vast majority of the secure habitat patches for both seasons occurred in higher elevation areas. A higher level of human activity in the study area during the berry season resulted in a more fragmented reserve network. Movement was also consistent between seasons, and in general was quite broad across the landscape.

Wolf models were restricted to winter. During this time, habitat preference appeared to be clearly linked to low elevation areas with low terrain ruggedness. Of the limited areas which provided these conditions, very little was considered secure from human disturbance. Movement models indicated that low elevation areas also were the most likely to be used by wolves.

Lynx models were also restricted to winter. During this time, areas with a higher proportion of forest density and northern aspects were considered most valuable to lynx. Movement was also dictated largely by forest cover, so that movement was restricted to the forested slopes; the core of this area was a combination of natural grasslands and human-created open areas.

Once the reserve networks from each species were overlaid, it became possible to identify areas of likely use to numerous species. The area of most importance, which was likely to be used by all three focal species, largely conformed to lower elevation forested areas.

7.2 Management Potential of Model

If conservation efforts within the ETV must be focused, then areas recognised in Figure 17 as being important to multiple species within areas of land without designated protection from development (such as the Evan-Thomas Provincial Recreation Area and the adjoining forest land use zone) should probably receive a higher priority – at least from the perspective of large carnivores.

In addition, models such as those presented here could incorporate forecasted land use change and quantify the potential impacts on the ecological functionality of the area. Findings from such an endeavour could then be weighed against the potential economic benefit in order that an appropriate course of action could be devised.

Although the multi-species reserve model produced here would be a good tool for helping to make management decisions, there are some areas of the process that deserve attention if this approach is to be further developed or applied elsewhere:

1. Choice of focal species might be better. Due to logistical constraints this investigation was required to make use of existing datasets. Although there was evidence to support their use, a different set of focal species would possibly be more appropriate, especially for movement modelling.

2. Factors other than habitat use and movement should be considered. For instance, providing for den sites would be a vital component of reserve design for species persistence.

3. Seasonal variability should be better accounted for. For grizzly bears models were created for the two major seasons of importance; for wolves and lynx, however, no summer information was available. Hence, there is the potential for some important seasonal variation to be absent from the findings of this study.

4. Weightings for species-specific friction surfaces should be based on analysis of actual movement data, rather than on general trends highlighted within the literature.

5. Quantitative methods for habitat patch delineation would be desirable. Although delineation was based on current guidelines, subjective opinion formed a large portion of identifying habitat patches and movement corridors. For more consistent and defendable reserve design, a more quantitative approach, perhaps with species-specific considerations, might give research findings more weight.

6. The BCEAG guidelines used as a basis for patch identification within this study may not be entirely appropriate as they preclude the inclusion of small patches within a reserve network. Small patches may still be of value, at least as stepping-stones to facilitate movement; therefore, after regional and local patches, a third order of patch might be included as a stepping-stone or movement patch.

7. Measurements of Human Activity. All decisions relating to classification of high and low levels of use for trails and roads within the study area were done entirely from opinion. Actual counts would help in classifying human use more accurately.

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APPENDIX A: RADIO-TRACKING DATA COLLECTION

To supplement the existing datasets additional grizzly bear radio-tracking was conducted during April to November 2003. Bear presence or absence within the study area was confirmed by driving available roads while scanning all frequencies with a roof mounted dipole antenna twice a day. For estimating locations a TRX-1000 receiver with a handheld three-element Yagi antenna was used in conjunction with the strongest signal and nulls method (Kenward 2001) to identify three agreeable bearings which were recorded using a hand-held compass with adjustable declination from known receiving locations. As bearings were taken sequentially, time between bearings was kept to a minimum in order to minimise error associated with animal movement, while at the same time trying to minimise distance to the animal and optimise bearing intersection angles – though all receiving locations were restricted to accessible roads. Bearings were entered directly into the GTM telemetry program (Sartwell 2000), which used the maximum likelihood estimator (MLE) technique (Lenth 1981) to calculate a point estimate of animal location. The MLE was chosen ahead of the Huber or Andrews estimator as outliers were identified and discarded immediately in the field, and is the most robust method (White and Garrott 1990).

As radio-telemetry can only produce estimates of animal locations, validation of the technique is required in order to determine the level of accuracy (White and Garrott 1990) which must be reported for data to be used appropriately (Saltz 1994). This evaluation is of particular importance for this study as it is based in a mountainous and forested area, both of which are noted as being inherently disadvantageous for radio-tracking (Kenward 2001, White and Garrott 1990), and uses radio-tracking data which rather than trying to record a single location aims to record movement which is something that inherently introduces further error when using sequential bearings (White and Garrott 1990, Schmutz and White 1990).

Kauhala and Tiilikainen (2002) compared the movement path recorded by a subject carrying a GPS unit and radio-collar and that of a radio-tracking session to assess bias and error. Such field tests (*n*=3) were conducted in areas from which most of the actual grizzly bear tracking data were concentrated, and with movement rates that attempted to be comparable to that of a grizzly bear. Through matching the times of bearing and location estimates to the actual location of the target subject, it was possible to calculate the actual bearings and locations. These could then be compared to estimates in order to assess bias and error. Each set of three bearings intersected across a mean angle of 80^o (SD = 29^o, range = 32 to 140^o, *n* = 36), and with all three bearings acquired over a mean time of 8.4 minutes (SD = 1.6mins, range = 4 to 12.5mins, *n* = 36). From comparisons with actual locations mean distance between the target and observer was 1742m (SD = 805m, range = 174 to 3855m, *n* = 105) mean bearing error was 8^o (SD = 8^o, range = 0^o to 52^o, *n* = 105) and mean location error was 328m (SD = 249m, range = 29 to 1125m, *n* = 35). In addition, bearing error and locational error were distributed normally around zero so no obvious bias is apparent within the data (Figure 18a and b).

In addition to quantifying error it is also important to consider the potential for over generalisation of a movement path through an inadequate survey frequency (Turchin 1998). Even perfect locations acquired too far apart in time may not appropriately represent a movement path (Pace 2001). Figure 18 illustrates how extreme this generalisation is for (c) the maximum frequency of half-hour locations and (d) the cut off level of one hour locations. Both resampled paths lose a great deal of detail, with the half-hour locations showing slightly more of the tortuous movements. However, they do both give a reasonable description of the actual path. Errors will further distort the picture, but at the scale that the data will be used the areas used for movement can be captured fairly well. In conclusion, it would appear that the radio-tracking accuracy and frequency used does give a good representation of actual animal movement for analysis at this scale.

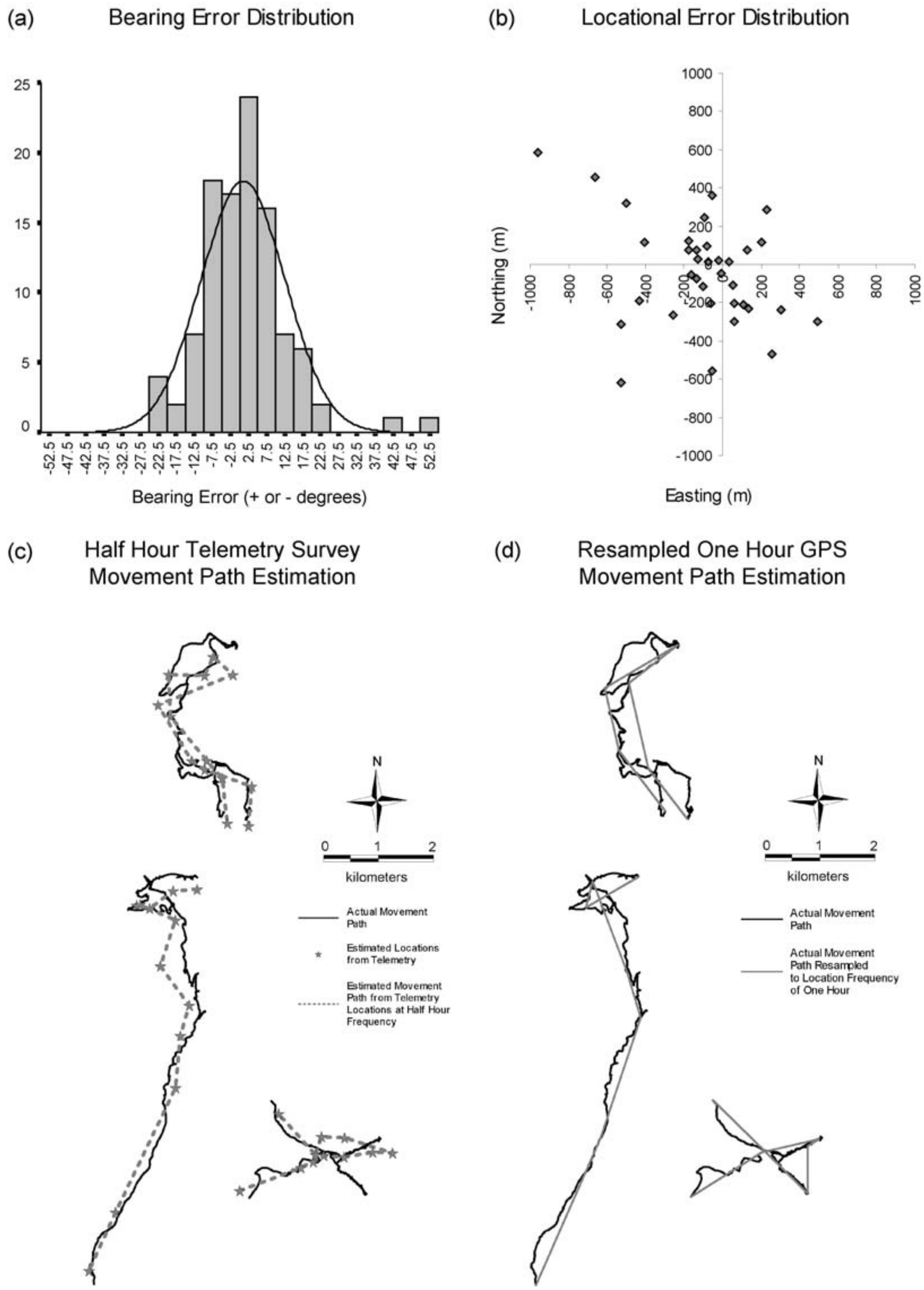

Figure 18. Radio-tracking accuracy assessment for (a) bearing error and (b) locational error, as well as the generalisation of movement to (c) half-hour and (d) on hour frequencies.

APPENDIX B: RESOURCE CHARACTERISTIC CREATION

B.1 Topographic Variables

A digital elevation model (DEM) with 30m resolution produced by Wierzchowski (2000) was used to produce topographic variables and to help in processing of other data. For resource selection elevation, aspect and terrain ruggedness layers were created. The raw DEM values were used a measure of elevation, while aspect was derived from the DEM using ArcView Spatial Analyst (ESRI 1998). To avoid classifying aspect and issues of circularity, the resulting aspect was then transformed to measures of eastness and northness as in Logan (2003). Terrain ruggedness was created as in Riley *et al.* (1999). For use in movement modelling a slope layer was created from the DEM using ArcView Spatial Analyst (ESRI 1998).

B.2 Vegetation Variables

Basic landcover categories (conifer forest, shrub, deciduous forest, grassland, avalanche chutes, water, ice/snow, rock/bare soil and cropland) were provided by a vegetation classification from Landsat imagery (Wierzchowski 2000) with a 30m cell resolution. To minimise the problems of discrete category boundaries (Garshelis 2000) presence density measures were created for forest, grass, shrub, avalanche chute categories and a combined grass and shrub category. In each case the category of interest was classified as being present (1), with the rest of the landscape classified as non-present (0), and a 90m radius circular moving window was run to calculate the mean presence level for each cell.

The greenness tasselled cap transformation of Landsat imagery is a seasonally variable resource, so two greenness layers were developed from May and August 2000 Landsat 7 images to match the preberry and berry seasons. The coefficients from Huang *et al.* (2002) were used as these were specifically created for Landsat 7 imagery, and required transformation of digital number to at-satellite reflectance which was beneficial as it would compensate for atmospheric and illumination changes and allow for direct comparison between the two seasonal images. One scene (24th of May 2000, path 42 row 25) was a Level 1G format (NASA 2004) while the second scene (28th of August 2000, path 42 row 25) was part of NASA's global orthorectified Landsat data set (Tucker *et al.* 2004). Both images were acquired from the University of Maryland's Global Land Cover Facility (http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp).

After the raw images were imported they were subset to a 42 by 42 km area of overlap, and simultaneously orthorectified using Geomatica Orthoengine (PCI Geomatics 2003a) in order to achieve good between image spatial agreements. As full Landsat images were not being used and the terrain in the area was rugged, software recommendations were that a rational functions math model with ten coefficients should be used. A total of 56 ground control points were collected following good practice (Lillesand and Kiefer 2000, PCI Geomatics 2003a, Jensen 2005) using existing reliable orthorectified one metre resolution panchromatic 1:20,000 aerial photography flown in July 1999 from Alberta Parka and Protected Areas and a DEM (Wierzchowski 2000), which when applied to each image producing an acceptable precision (root-mean-square errors = 24.02m and 25.87m). Concurrent with orthorectification, the images were also reprojected and resampled to 30m resolution using a nearest-neighbour approach which allowed for the retention of original pixel vales (Lillesand and Kiefer 2000).

Conversion of digital number values to at-satellite reflectance was conducted using Geomatica Focus (PCI Geomatics 2003b) and the procedure outlined in NASA (2004). The tasselled cap transformation of Huang *et al.* (2002) using at-satellite reflectance is robust against the effects of atmospheric interference, but topography can have a significant effect on the spectral response of optical images such as Landsat 7 (Lillesand and Kiefer 2000, Jensen 2005). However, Franklin (1991) noted that the correction techniques can be unreliable in highly variable terrain and with low sun angle imagery, both of which were apparent. Following Franklin (1991) the first stage normalisation algorithm of Civco (1989) was applied to the image in order to assess the potential to correct for topographic illumination. However, as the effect was either negligible or counter productive it was decided to keep the original unmodified image values. This was likely not to be too problematic as greenness is known to be tolerant to topographically induced illumination differences due to the first transformation, brightness, removing most of this information (Cohen and Spies 1992, Fiorella and Ripple 1993, Cohen *et al.* 1995).

Within each image cloud and associated shadow, shadows cast by mountains, and high elevation strongly illuminated ice and snow, produced unreliable measures of greenness. These areas were identified through manual digitising, supervised classification and with sun illumination models created using the study DEM and the Hillshade function of ArcView Spatial Analyst (ESRI 1998). Giles (2001) cautioned the use of sun illumination models due to accuracy being dependent upon the DEM, but inspection of the results was acceptable within the study area. After identification these areas were masked from analysis with species data, but for production of probability surfaces these areas needed some appropriate value. Therefore, for production of probability surfaces the masked areas filled with the average greenness value for the landcover classes in question. This process was deemed feasible as the masked area was minimal to begin with, and largely occurred in unimportant areas such as mountain peaks.

B.3 Human Disturbance Variables

Roads and trails within the study area were digitised using map data (accuracy ±10m) and orthorectified one metre resolution panchromatic 1:20,000 aerial photography flown in July 1999 from Alberta Parks and Protected Areas. Each feature was classified as being high or low use during winter, preberry and berry seasons, in order to allow for the creation of season specific measures of human disturbance accounting for changes in use levels and management practices. Low use trails were coded 1 and high use 2, and for roads low use 1 and high use 3.

Three seasonal road density layers were created by rasterising the vector roads to the same grain and extent as the other resource layers and calculating density by running a circular moving window over the raster surface calculating mean value with a radius of 500m around roads.

B.4 Measuring Resource Availability

All available resource units within the analytical frames produced for wolf and grizzly bear resource selection could not be used for data analysis as they were too numerous. Therefore, a systematic sample of the available resource units was taken, with differing levels of sampling compared to ensure that the sampling level chosen reduced the potential for sampling error (Manly *et al.* 2002). Table 10, Table 11 and Table 12 detail the representations of available resources from differing sample sizes for wolf, preberry season grizzly bear and berry season grizzly bear resource selection analytical frames respectively.

A systematic grid sample with points spaced at 480m was chosen as it was found that at this level the availability of resources was well represented but the number of sample points remained intuitively large enough for data analysis.

Table 10. Representations of available resources from differing sample sizes for wolf resource selection analytical frame.

		Analytical Frame (30m)	240m	480m	960m
Sample size		139705	2193	545	135
Elevation	Min	1391	1393	1398	1403
	Max	2864	2852	2808	2811
	Range	1473	1459	1410	1408
	Mean	1741.52	1742.49	1742.86	1739.70
	SD	258.99	259.53	260.52	264.74
Eastness	Min	-1	-1	-1	-1
	Max	1	1	1	1
	Range	2	2	2	2
	Mean	0.03	0.04	0.00	0.01
	SD	0.80	0.80	0.79	0.83
Northness	Min	-1	-1	-1	-1
	Max	1	1	1	1
	Range	2	2	2	2
	Mean	0.07	0.07	0.06	0.06
	SD	0.58	0.58	0.59	0.55
Terrain Ruggedness	Min	0	0	0	1.41
	Max	234.87	199.314	153.519	122.88
	Range	234.87	199.314	153.519	121.46
	Mean	25.61	25.66	25.65	24.48
	SD	20.57	20.92	20.87	20.97
Road Density	Min	0	0	0	0
	Max	0.72	0.69	0.67	0.54
	Range	0.72	0.69	0.67	0.54
	Mean	0.05	0.05	0.05	0.05
	SD	0.09	0.09	0.10	0.10
Grass and Shrub Density	Min	0	0	0	0
	Max	1	1	1	1
	Range	1	1	1	1
	Mean	0.32	0.32	0.32	0.30
	SD	0.32	0.33	0.32	0.30

Table 11. Representations of available resources from differing sample sizes for preberry season grizzly bear resource selection analytical frame.

		Analytical Frame (30m)	240m	480m	960m
Sample size		177759	2785	690	169
Elevation	Min	1374	1374	1379	1376
	Max	2864	2852	2808	2811
	Range	1490	1478	1429	1435
	Mean	1804.94	1805.42	1803.94	1789.95
	SD	304.16	305.09	302.76	292.44
Road Density	Min	0	0	0	0
	Max	1.12	1.11	0.97	0.46
	Range	1.12	1.11	0.97	0.46
	Mean	0.04	0.04	0.04	0.04
	SD	0.09	0.09	0.09	0.08
Greenness	Min	-0.39	-0.37	-0.33	-0.35
	Max	0.32	0.22	0.15	0.18
	Range	0.72	0.59	0.49	0.54
	Mean	-0.03	-0.03	-0.03	-0.03
	SD	0.09	0.09	0.09	0.09
Grass Density	Min	0	0	0	0
	Max	1	1	1	1
	Range	1	1	1	1
	Mean	0.24	0.25	0.24	0.26
	SD	0.29	0.29	0.28	0.28
Shrub Density	Min	0	0	0	0
	Max	1	1	1	0.83
	Range	1	1	1	0.83
	Mean	0.09	0.09	0.09	0.08
	SD	0.17	0.17	0.18	0.15
Avalanche Chute Density	Min	0	0	0	0
	Max	1	1	1	1
	Range	1	1	1	1
	Mean	0.05	0.05	0.05	0.05
	SD	0.15	0.15	0.16	0.17

Table 12. Representations of available resources from differing sample sizes for berry season grizzly bear resource selection analytical frame.

		Analytical Frame (30m)	240m	480m	960m
Sample size		173337	2713	676	166
Elevation	Min	1374	1374	1379	1380
	Max	2864	2852	2808	2811
	Range	1490	1478	1429	1431
	Mean	1787.85	1787.02	1788.65	1779.03
	SD	293.56	292.20	293.99	285.46
Road Density	Min	0	0	0	0
	Max	1.12	1.11	0.97	0.46
	Range	1.12	1.11	0.97	0.46
	Mean	0.04	0.04	0.04	0.04
	SD	0.10	0.10	0.09	0.09
Greenness	Min	-0.23	-0.18	-0.17	-0.17
	Max	0.32	0.29	0.21	0.22
	Range	0.54	0.46	0.38	0.39
	Mean	0.03	0.03	0.03	0.03
	SD	0.06	0.06	0.06	0.06
Grass Density	Min	0	0	0	0
	Max	1	1	1	1
	Range	1	1	1	1
	Mean	0.24	0.24	0.23	0.25
	SD	0.29	0.29	0.28	0.28
Shrub Density	Min	0	0	0	0
	Max	1	1	1	0.83
	Range	1	1	1	0.83
	Mean	0.09	0.09	0.09	0.08
	SD	0.17	0.17	0.18	0.16
Avalanche Chute Density	Min	0	0	0	0
	Max	1	1	1	1
	Range	1	1	1	1
	Mean	0.05	0.06	0.06	0.06
	SD	0.16	0.16	0.16	0.17

APPENDIX C: SNOW TRACKING DATA COLLECTION

In order to collect the first lynx movement data within the study area, a series of transects shown in Figure 19a were established and surveyed after fresh snowfall in order to locate lynx tracks. Halfpenny *et al.* (1995) advocated the use of linear features such as roads and trails for searching for tracks, as they allow for easier travel and so increase the survey coverage area. There should be no issue of correlating tracking data with these linear features as backtracking will give ample opportunity for habitat associations to become evident. Transect locations will also take into account topography and habitat (Halfpenny *et al.* 1995). For instance, in this environment movement in certain areas is constrained by mountains, creating pinch points through which movement is funnelled. Similarly the existing datasets give an idea as to areas of higher habitat use and movement, therefore transects located in these areas would have a better chance of detecting movement.

Transects also were positioned so that the smallest home range of the species being observed, taken as $8km^2$ for a female lynx (Koehler and Aubry 1994), cannot be present within the core of the study area without being intersected by at least one transect. This should reduce the chance of non-detection of resident animals. In addition, transects were positioned outside areas of avalanche danger, and backtracking was conducted with avalanche safety in mind.

Transects were surveyed on foot after fresh snowfall, until tracking conditions deteriorated so that track identification becomes unreliable or lynx movement was found. To reduce sampling bias consideration was given to the number of times a transect was surveyed and the total amount of time after snowfall, and though impeded by logistical problems transect survey levels were reasonably comparable (Figure 19b). Backtracking was initiated where an animal's tracks intersected a transect with locations recorded along the path at intervals of ten metres using a Garmin eTrex Legend hand held GPS unit with a specified accuracy of ±15m 95% of the time (Garmin Inc 2002). However, within a mountainous and forested environment such as the study area this accuracy could be lower. To gauge actual accuracy of locations taken from this GPS unit a test was run within a similar environment and during similar times to those encountered during field data collection. Locations (n=142) were taken evenly across one day (08:44:08 to 19:54:40) from a stationary unit, with the 'true' location dictated as the mean of all locations. Accuracy was assessed by comparing all locations to this mean location to generate measures of error. Though error ranged from as little as 0.7m to as high as 50.07m in general the distance from the true location was minimal (mean=9.31m, SD=9.03m), with >95% of locations within 30m. Thus, backtracking accuracy was set at 30m, which was supported by general observations when plotted against georeferenced datasets.

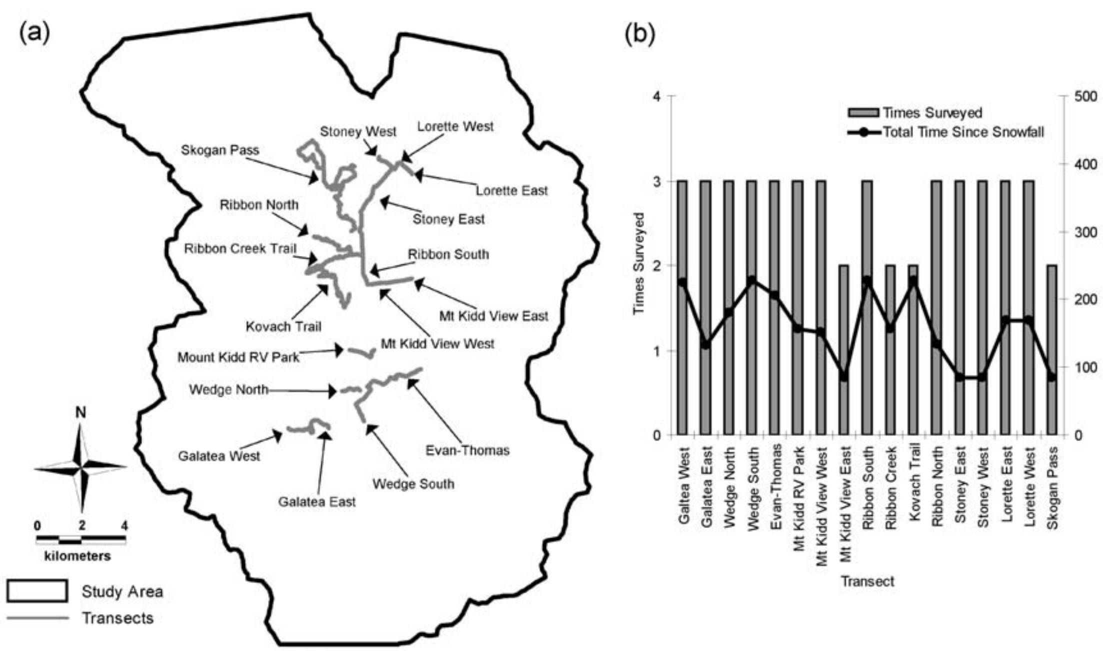

Figure 19. Snow tracking transects showing (a) positioning and coverage and (b) survey frequencies and total time since snowfall.