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Habitat structure and fragmentation of grizzly bear management units and home ranges in the Alberta Yellowhead ecosystem

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Habitat Structure and Fragmentation of Grizzly Bear Management Units and Home Ranges in the Alberta Yellowhead Ecosystem

by

Charlene Popplewell

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF GEOGRAPHY

CALGARY, ALBERTA
JULY, 2001

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Abstract

Landscapes that have high ecological, social, and economic values are needed to support both wildlife and humans. Grizzly Bear Management Units (BMUs), which are watersheds that approximate the size of female grizzly bear home ranges within the Foothills Model Forest in the Yellowhead Ecosystem, Alberta, Canada, are such areas. Humans rely on these same spaces for natural resources, particularly forestry, oil and gas, recreation, and coal mining. The activities and associated infrastructure impact wildlife habitat structure by modifying connectivity of the landscape’s food and cover. Grizzly bears (*Ursus arctos horribilis*) are a wildlife species of international management concern; therefore, there is great interest in ensuring adequate habitat to support the long-term persistence of grizzly bears within their large home ranges. The development and testing of integrative technological approaches to modelling landscape-level human disturbance on bear habitat offers land and wildlife managers an effective tool for maintaining the coexistence of critical grizzly bear habitat and sustainable natural resource development.

As one component of the 5-year Foothills Model Forest Grizzly Bear Research Program, the landscape-level human effects on habitat structure were quantified using remote sensing, geographic information systems (GIS), and landscape metrics. Grizzly bear habitat class patches were mapped from the land cover classification of a 1999 LANDSAT TM-5 image of the 5352-km$^2$ study area. The BMUs for comparison were selected based on similar natural environments before human use. Landscape structure
metrics indicative of fragmentation, connectivity, and edge density were calculated to quantify the effects of human activities on the habitat among BMUs and within individual home ranges, which were estimated using the minimum convex polygon method on 1999 radio telemetry data from collared grizzly bears.

Habitat structure within each BMU was compared to other BMUs and to home range habitat structure. BMUs having comparable habitat characteristics differed in landscape structure according to amount and type of disturbance (roads, forest harvesting). By relating the landscape metrics to grizzly bear density estimates, BMUs that may have resources developed further without adverse impact on bear habitat structure can be identified. In this way, remote sensing and GIS can assist large-scale land management planning regarding human impacts on grizzly bear habitat, and will be useful in determining "landscape threshold targets." However, continual population monitoring of grizzly bears in these areas is important to ensure that management actions are achieving the desired objective of long-term grizzly bear conservation.
Acknowledgements

I wish to extend my biggest thanks to Medina Hansen, Robin Munro, Julie Dugas, Monika Moskal, and Scott Nielsen. Without their expertise, data acquisition, image processing and classification, field support, and moral support, I would still be tramping aimlessly around the study area and fumbling about in the computer lab. Also, thank you to the capture crew (especially Marty and Bemie), veterinarians, and other project team members for their many hours of hard work in acquiring our grizzly bears and bear-related data.

The partners of the Foothills Model Forest Grizzly Bear Research Project are greatly appreciated for their financial and data contributions toward managing the Alberta Yellowhead Ecosystem for both grizzly bears and humans. Our sponsors include:

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- Alberta Newsprint
- Anderson Resources Ltd
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- BC Oil and Gas Commission Environmental Fund
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- BP Canada Energy Company
- Burlington Resources
- Canada Centre for Remote Sensing
- Canadian Resources Ltd
- Canadian Forest Products
- Canadian Hunter
- Canadian Wildlife Service
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<thead>
<tr>
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</tr>
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<tbody>
<tr>
<td>%LAND</td>
<td>Percent of Landscape (measure of class area)</td>
</tr>
<tr>
<td>AWMSI</td>
<td>Area Weighted Mean Shape Index</td>
</tr>
<tr>
<td>BMU</td>
<td>Bear Management Unit</td>
</tr>
<tr>
<td>CA</td>
<td>Class Area</td>
</tr>
<tr>
<td>CT</td>
<td>Cover Type</td>
</tr>
<tr>
<td>DEM</td>
<td>Digital Elevation Model</td>
</tr>
<tr>
<td>ED</td>
<td>Edge Density</td>
</tr>
<tr>
<td>FH</td>
<td>Foothills (BMUs)</td>
</tr>
<tr>
<td>FMF</td>
<td>Foothills Model Forest</td>
</tr>
<tr>
<td>GBRP</td>
<td>Grizzly Bear Research Project</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographical Information Systems</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>IDTA</td>
<td>Integrated Decision Tree Approach</td>
</tr>
<tr>
<td>IU</td>
<td>Interspersion-Juxtaposition Index</td>
</tr>
<tr>
<td>LD</td>
<td>Life forms and Disturbance</td>
</tr>
<tr>
<td>MCP</td>
<td>Minimum Convex Polygon (home range)</td>
</tr>
<tr>
<td>MNN</td>
<td>Mean Nearest Neighbour</td>
</tr>
<tr>
<td>MPS</td>
<td>Mean Patch Size</td>
</tr>
<tr>
<td>MT</td>
<td>Mountain (BMUs)</td>
</tr>
<tr>
<td>NAD83</td>
<td>North American Datum 1983</td>
</tr>
<tr>
<td>NFC</td>
<td>No Food or Cover</td>
</tr>
<tr>
<td>NUMP</td>
<td>Number of Patches</td>
</tr>
<tr>
<td>PSCOV</td>
<td>Patch Size Coefficient Of Variance</td>
</tr>
<tr>
<td>RS</td>
<td>Remote Sensing</td>
</tr>
<tr>
<td>TLA</td>
<td>Total Landscape Area</td>
</tr>
<tr>
<td>TM</td>
<td>Thematic Mapper</td>
</tr>
<tr>
<td>UTM</td>
<td>Universal Transverse Mercator</td>
</tr>
<tr>
<td>VN</td>
<td>Vegetated and Nonvegetated</td>
</tr>
</tbody>
</table>
1.0 Introduction

1.1 Overview of the Baseline Landscape Structure Research for the Foothills Model Forest Grizzly Bear Research Project

The grizzly bear (*Ursus arctos horribilis*) is a species of international management concern and is thought of as an important indicator species. Grizzly-containing ecosystems, such as the Alberta Yellowhead Ecosystem of West-Central Alberta, Canada, may be assessed by the presence, abundance, and health of grizzly bears to provide insight on the ecological integrity of the environmental conditions and processes that generate and maintain biodiversity and allow natural evolutionary change of the ecosystems. Ecosystem fragmentation occurs when human activities or natural processes divide the landscape. Therefore, having baseline habitat structure data for the landscape-level fragmentation effects of the human activities on the presence of grizzly bears will aid both private and public sectors in planning resource activities in the Alberta Yellowhead Ecosystem. Based on landscape structure and fragmentation results, the most appropriate sustainable development can be adequately determined in order to best manage and protect the habitat vital to wildlife and ensure the continuity of the landscape of economic and aesthetic value to humans.

Grizzly bears in Canada are dispersed over large areas of Western Canada (Servheen *et al.* 1999). Where there are limited human communities, such as in rugged mountains...
and northern latitudes, the bears are relatively large in number. In Alberta, the estimated population size is 800-850 bears (Alberta Environmental Protection, unpublished data; Servheen et al. 1999), but where they have not been extirpated due to the encroachment of human settlement, grizzly bears are listed as vulnerable in habitat that is also productive for forestry, mining, oil and gas development, and big game hunting. Specific conservation recommendations require that the rate of human-caused mortalities be managed, along with the provision of ample nonfragmented habitat of suitable quality and disturbance levels (Servheen et al. 1999). Viable populations of grizzly bears need large areas; therefore, research and management planning at the large regional scale is important in identifying potential fracture zones between sub-populations and maintaining sufficient connected habitat.

A greater understanding of the relationship between grizzly bear population characteristics, such as bear density, and habitat fragmentation, quantified by landscape metrics, will provide an effective management tool useful for land managers to balance the desire for critical grizzly bear habitat with sustainable resource extraction and associated infrastructure. The results are expected to quantify the amount of human impact that will influence bear density where there is a high level of disturbance and fragmentation on the landscape. Extrapolating to untested areas in the future will aid in predicting where resource extraction and other land use activities can continue, provided appropriate thresholds to the amount of human activity are not reached or exceeded.

This thesis looks at the degree of grizzly bear habitat fragmentation present in 1999 in the Foothills Model Forest (FMF) Grizzly Bear Research Project (GBRP) study area in
the Alberta Yellowhead Ecosystem. This establishes a baseline of landscape structure that will be useful for evaluating change and making future land management decisions. Differences among areas of analysis – Bear Management Units (BMUs) and home ranges – and BMU structure with respect to bear density is assessed by addressing the following fundamental questions:

- What is the grizzly bear habitat and how can it be measured?
- What landscape metrics are ecologically meaningful to grizzly bear habitat?
- How does scale affect the interpretation of habitat structure?
- What are the structural differences among BMUs and are they significant?
- What are the structural differences among home ranges and are they significant?
- How does the landscape structure of BMUs compare to that of home ranges?

Methods are needed to answer these questions in order to substantiate using landscape metrics in quantifying bear habitat fragmentation.

First and foremost, an appropriate and spatially accurate grizzly bear habitat-related map is required for any analysis to be meaningful. Satellite remote sensing classification products are widely recognized for their capability to perform regional mapping of the earth’s surface. In particular, the Landsat series of satellite images has been extensively used for applications in mapping wildlife habitat-related land cover types (Butterfield and Key, 1985; Craighead et al., 1985; Deuling, 1999; Franklin et al., 2001; Franklin et al., in press; Frohn, 1998; Mladenoff et al., 1995; Sachs et al., 1998; Tinker et al., 1998).

Using a Landsat classification, ecological analyses and modelling can be performed over entire landscapes using quantitative methods in landscape ecology within the context of
a geographical information system (GIS) (Bissonnette, 1997; Craighead et al., 1985; Forman, 1995; Turner and Gardner, 1991).

A common spatial analysis is to use landscape metrics for quantifying the composition, structure, and configuration of the satellite-based map (Forman, 1995; Haines-Young and Chopping, 1996; Turner, 1989). The spatial metrics, which describe and quantify the various landscape cover types, are useful in assessing wildlife habitat potential, human impacts on regional ecosystems, and overall landscape inventories. The composition and geographical distribution of the habitat class patches are quantified using various landscape structure metrics, which must then be assessed for determining landscape-habitat relationships. For example, two BMUs may have very similar values for a particular structural metric, but the bear density significantly differs suggesting that an alternate metric should be selected. Moreover, grizzly bear density may be different in management units having a greater amount of human impact than in units having a lower amount of human impact as quantified by a particular metric.

1.2 Research Objectives

The ecologically meaningful metrics will be incorporated into a GIS for the spatial analysis of habitat-landscape interactions to be used for balancing grizzly bear habitat with human resource needs. In addition to providing baseline fragmentation information, the overall goal of this thesis is to determine the relationship of landscape structure metrics with grizzly bear habitat fragmentation and population density, in order to provide
a quantitative relationship that can facilitate wildlife and land management planning. It is expected that the level of habitat class aggregation (i.e. attribute scaling) will affect fragmentation information within BMUs as measured by the landscape metric approach, and will be assessed. The two main hypotheses to be tested in pursuit of this research are:

**Hypothesis 1:** Grizzly bear density class estimates within a BMU are predictable by landscape structure metrics.

Grizzly Bear Density $= f$ (Landscape Structure Metrics)

**Hypothesis 2:** BMUs having lower fragmentation (resulting from human disturbance) will be similar in landscape structure to actual grizzly bear home ranges.

Low-Fragmented BMUs (Structure) $\equiv$ Bear Home Ranges (Structure)

To test these hypotheses, the following analysis steps are conducted and discussed:

1. Using an existing satellite remote sensing classification map (Franklin et al. 2001), representative BMUs will be selected and quantified for habitat patch structure at different attribute scales.

2. The differences between BMUs will be statistically compared and ecologically interpreted based on information available in the larger project (Stenhouse and Munro, 2000) to predict bear density.
3. A comparison between BMUs and grizzly bear home range structural measures will be interpreted to illuminate the effects of fragmentation. By integrating remote sensing, landscape metrics, and GIS, this study will provide an important component to effective management that will enable land managers to monitor and maintain critical grizzly bear habitat.

1.3 Organization of the Thesis

Chapter 1 introduces the problem and provides background information that is more completely covered in subsequent chapters. Chapter 2 provides a review of the scientific literature on what grizzly bear habitat is, in what types of ecosystems it can be found, and how it can be mapped and quantified. Similar wildlife habitat studies that have been done are also detailed. The study area and data used for this thesis are described in Chapter 3. The Yellowhead Ecosystem is described as an important area for both ecological and human reasons. The digital and field data collected for the area are summarized and assessed for representativeness of the study area and problem.

To address the methods for quantifying landscape structure and understanding its relationships with grizzly bear characteristics, Chapter 4 explores the sensitivity of patch metrics to the level of attribute scaling used to describe the habitat-related land cover and applies spatial metrics to management units and ecological areas of analyses. A discussion of the results follows as Chapter 5 considers the use of habitat structure in
predicting bear density by applying classification tools and examines which land
management units are comparable in habitat structure to actual bear home ranges.

Chapter 6 summarizes the major findings, addresses implications for management, and
outlines issues for future research. This final chapter provides a discussion of the
contributions of this thesis to the overall research goal of relating landscape structure
metrics obtained from satellite remote sensing classification maps to habitat
fragmentation and grizzly bear population density. Ways to incorporate the findings into
management are also offered.
2.0 Grizzly Bear Habitat Structure

2.1 Introduction

Research on habitat structure and fragmentation typically involves a base map for habitat, knowledge of the wildlife species' habitat characteristics, and methodology for an integrative spatial analysis (e.g. Deuling, 1999; Mladenoff et al., 1995; Sachs et al., 1998). This chapter provides background information on all these aspects, as well as on the disciplines that the thesis encompasses. Because this is applied research in geographical techniques to assess wildlife habitat, a comprehensive review of remote sensing classifications, grizzly bear habitat, geographical information systems (GIS), and landscape ecology is needed.

The first section describes the ways in which remote sensing has been used to map an ecosystem-wide land cover classification for use in wildlife habitat studies. This is followed by a characterization or definition of grizzly bear habitat, where habitat can be found, and the various ways in which it can be interpreted from a satellite remote sensing land cover classification product (e.g. Butterfield and Key, 1985; J.L Kansas, MSc Thesis in progress, University of Calgary). A discussion follows concerning how habitat structure and fragmentation can be quantified and assessed using principles and quantitative methods of landscape ecology applied in a GIS. Lastly, similar wildlife habitat research integrating the spatial technologies is detailed.
2.2 Remote Sensing Classifications

Assessments of wildlife habitat typically rely on intensive and expensive field campaigns to obtain the input parameters, and are mostly limited in areal coverage (Frohn, 1998). For small watersheds or where maps are available this practice is feasible. But with the larger, more remote watersheds containing grizzly bear habitat, fieldwork and initial mapping becomes more difficult and expensive, and is especially problematic where the habitat crosses jurisdictional boundaries. Provided that reliable models can be developed to relate image classification to habitat variables, remote sensing enables widespread regional coverage of both natural and human-impacted watershed habitats.

Remotely sensed imagery is commonly used in land cover type classification, and has often been applied to wildlife habitat research. The repetitive, consistent coverage over large, regional areas makes remote sensing systems ideal for such applications (Lillesand and Kiefer, 2000). In addition, the spectral resolution of Landsat's Thematic Mapper (TM) satellite series have been designed to provide optimal spectral data for use in discerning various vegetation, geological, and hydrological cover types on the earth's surface. An added advantage of remote sensing is the capability of monitoring these habitats repeatedly over time with similar technology, making the project less expensive and less subjective.
However, the spectral data alone may not suffice, and the incorporation of ancillary data into the remote sensing classifier often improves the accuracy (Butterfield and Key, 1985; Craighead et al., 1985; Franklin et al., 2001; Franklin et al., in press; Lillesand and Kiefer, 2000). This is the advantage of modified approaches using decision trees such as the Integrated Decision Tree Approach (IDTA) (Franklin et al., 2001).

The general concept of the IDTA is a supervised classification strategy in which the land cover classes are known and the data are guided to provide the maximum separability possible. This separability of classes is measured statistically and can be directly related to the classification accuracy, typically measured in training areas and independent test areas. The production of the IDTA map for the area of study in this thesis is described by Franklin et al. (2001) and followed the earlier mapping techniques described by Deuling (1999) and Hansen et al. (2001). They determined in these several tests that the IDTA could produce the optimal classification map for this region because it provided the most effective way of integrating the available GIS data (in the form of Alberta Vegetation Inventory or AVI maps), DEM, and spectral image data. Other methods, such as evidential reasoning (ER) (Peddle, 1995) can also provide this integration but are not thought to be an operational remote sensing classification approach at this time (Franklin et al. 2001). The simple mechanical integration of different data types in the IDTA method is based on the earlier development of 'layered-classifiers' (Jensen, 1978) and is conceptually and operationally effective in regional classifications in which land cover interpretations – such as grizzly bear habitat – are required.
2.3 Grizzly Bear Habitat in the Canadian Rocky Mountains

Base classifications of land cover type are generally required for the mapping of habitat quality or suitability (Butterfield and Key, 1995; Craighead et al., 1985; Purves and Doering, 1998; Turner and Gardner, 1991). Spectral land cover classes and interpreted habitat classes are not the same; therefore the land cover base may be integrated with other physical (e.g. Digital Elevation Models, distance to water) and ecological (e.g. biophysical and forestry inventories, time since last burn) inputs into a sophisticated habitat suitability model. Or, the land cover map may simply be reclassified for more general habitat purposes. Since the objective of this study is to analyze landscape structure and not to apply metrics to a habitat suitability model, simple reclassification or aggregation of original land cover classes into habitat-related cover types is performed using the interpretations described below.

Habitat classes are interpretations associated with land cover types that rely on assumed or predictive characteristics, such as presence/absence of food and cover. According to wildlife biologists (Gibeau, 1998; Kansas and Riddel, 1995; Mace et al., 1999; Waller and Mace, 1997), basic grizzly bear habitat requirements can be inferred from certain land cover types. Grizzly bears are habitat generalists and obtain their food from a variety of sources, including berries, roots and corms, particular green succulent vegetation (e.g. Hedysarum spp. and Equisetum spp.), and ungulate carrion. Land cover types capable of supporting these important foods, such as the high berry production and ungulate areas that are especially important for pre-winter fattening of
grizzly bears, can be interpreted as more suitable habitat. Land cover types providing cover and/or minor food types can be interpreted as fair habitat.

Table 1 lists the interpretations that can be made from the IDTA classes based upon the following critical habitat characteristics in the Canadian Rocky Mountains (Herrero, pers. comm. 2000; Gibeau, 1998; Kansas and Riddle, 1995). Several environmental variables affect the understory or production capability of a particular land cover type. Moist, sunlit, open crown, and/or deciduous areas predict more favorable habitat than dry, nonsunlit, closed crown, or conifer areas. Proximity to water is important for any wildlife species, and vegetation/cover types associated with moister areas (i.e. shrubs in avalanche chutes and riparian deciduous forest) indicate good habitat. Sites receiving greater insolation will be higher in berry production and ungulate habitat. Open canopied forests tend to have berry understory and southern slopes tend to support the grasslands important to both bears and ungulates.

Forest crown closure is highly indicative of berry production: with less than 50% crown closure berry production is optimal, and with increasing crown closure beyond 50% berry production falls quickly to zero. Similarly, deciduous stands (as opposed to conifer stands) allow more sunlight to reach the more productive understory, which is usually dominated by berries or green succulent vegetation. In general, grizzly bears avoid dense conifer landscapes and prefer sunnier, moister sites. Moist alpine meadows support ground squirrels, which bears occasionally eat; dry alpine tundra is not good bear habitat and may only be used for travel. Prime ungulate habitat includes grasslands, deciduous forests, and riparian shrub/forests and is, therefore, important to
grizzly bears. It should be noted that the spatial pattern of land cover types is just as important as the inferred habitat suitability of the landscape, since grizzly bears are habitat generalists with large home ranges encompassing a variety of cover types. The structure, or what types and where the habitat-related land cover types are located on the landscape and relative to each other can be linked to wildlife population characteristics.
<table>
<thead>
<tr>
<th>IDTA Class</th>
<th>Description</th>
<th>Interpretation</th>
<th>Habitat Inference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 CICon</td>
<td>Closed coniferous forest; canopy closure &gt;50%</td>
<td>Provides cover; minor bear foods</td>
<td>Fair</td>
</tr>
<tr>
<td>2 CIDec</td>
<td>Closed deciduous forest; canopy closure &gt;50%</td>
<td>Provides cover and some bear foods, especially berry understory</td>
<td>Good</td>
</tr>
<tr>
<td>3 Mix</td>
<td>Mixed forest; varying ratios of coniferous to deciduous</td>
<td>Provides cover and some bear foods, especially berry understory; habitat suitability depends on crown closure</td>
<td>Fair - Good</td>
</tr>
<tr>
<td>4 OpCon</td>
<td>Open coniferous forest; canopy closure &lt;50%</td>
<td>Provides cover and some bear foods, especially berry understory</td>
<td>Good</td>
</tr>
<tr>
<td>5 OpDec</td>
<td>Open deciduous forest; canopy closure &lt;50%</td>
<td>Provides cover and major bear foods, especially berry understory</td>
<td>Good</td>
</tr>
<tr>
<td>6 AlpSub</td>
<td>Alpine and subalpine meadows</td>
<td>Seasonal foods; especially roots and corms, may have ground squirrels which bears occasionally eat</td>
<td>Good</td>
</tr>
<tr>
<td>7 Herb&lt;18</td>
<td>Herbaceous under 1800 meters</td>
<td>Good ungulate habitat; some bear foods</td>
<td>Good</td>
</tr>
<tr>
<td>8 HerbRec</td>
<td>Herbaceous vegetation for mine reclamation</td>
<td>Homogeneous herbaceous vegetation not bear food, but may attract ungulates</td>
<td>Fair</td>
</tr>
<tr>
<td>9 Shrub&lt;18</td>
<td>Shrub under 1800 meters</td>
<td>Very high berry production; also provides browse for ungulates</td>
<td>Good</td>
</tr>
<tr>
<td>10 WetOpen</td>
<td>Open marshy herbaceous areas</td>
<td>Proximity to water; good moose habitat; some bear foods</td>
<td>Good</td>
</tr>
<tr>
<td>11 WetTreed</td>
<td>Swampy or marshy treed/shrub areas</td>
<td>Proximity to water; good moose habitat</td>
<td>Good</td>
</tr>
<tr>
<td>12 Rock</td>
<td>Rock</td>
<td>Lack of vegetation</td>
<td>Nonhabitat</td>
</tr>
<tr>
<td>13 Snow</td>
<td>Snow and glaciers</td>
<td>Lack of vegetation</td>
<td>Nonhabitat</td>
</tr>
<tr>
<td>14 Burnteal</td>
<td>Areas not illuminated due to topography</td>
<td>Lack of vegetation</td>
<td>Nonhabitat</td>
</tr>
<tr>
<td>15 Water</td>
<td>Water</td>
<td>Lack of vegetation</td>
<td>Nonhabitat</td>
</tr>
<tr>
<td>16 Urban</td>
<td>Human town site</td>
<td>Disturbed landscape; little or no vegetation</td>
<td>Nonhabitat</td>
</tr>
<tr>
<td>17 Road/Rail</td>
<td>Roads and rail line</td>
<td>Disturbed landscape; little or no vegetation</td>
<td>Nonhabitat</td>
</tr>
<tr>
<td>18 CutO-2</td>
<td>Recent cut; forest harvest within 0 – 2 years</td>
<td>Disturbed landscape; little or no vegetation</td>
<td>Nonhabitat - Fair</td>
</tr>
<tr>
<td>19 Cut3-12</td>
<td>Cut within 3 – 12 years</td>
<td>Disturbed landscape; regeneration of berry shrubs and other bear foods</td>
<td>Fair - Good</td>
</tr>
<tr>
<td>20 Burn</td>
<td>Recent burn, i.e. the 1997 Gregg River fire</td>
<td>Disturbed landscape; little or no vegetation; may have good regeneration of bear foods</td>
<td>Fair</td>
</tr>
</tbody>
</table>
2.4 GIS and Landscape Ecology: Spatial Analysis of Habitat

Structure

Land cover type and habitat classifications can be used in spatial analyses that quantify and assess landscape-level structure (Frohn, 1998; McGarigal and Marks, 1995; Turner and Gardner, 1991). That landscapes are comprised of patches (i.e. distinct areas that visually differ from surrounding areas) of varying land cover types or habitats is the underlying concept in such studies (Forman, 1995; Forman and Godron, 1986). The spatial patterning of patches at the landscape level is the focus of landscape ecology, and the quantification of the patterning of landscape heterogeneity can be linked to ecological phenomena (Forman and Godron, 1986; McGarigal and Marks, 1995; O'Neill et al., 1988).

Landscape ecology is the "study of the structure, function, and change in a heterogeneous land area composed of interacting ecosystems" (Forman and Godron, 1986). McGarigal and Marks (1995) have developed an operational definition that landscape ecology is the study of landscape patterns that are made up of interacting elements or patches. Structure, function, and change in the landscape mosaic of patches are the fundamental principles applied to solving ecological questions (Forman, 1995; Forman and Godron, 1986; McGarigal and Marks, 1995). Structure deals with the spatial relationships among ecosystem patches by relating distributions of energy and matter to patch type, number, size, shape, and configuration. Quantifying the structure is a necessary precursor to analyzing the interactions or flows among patches (function).
and alterations in the landscape over time (change). This heavy emphasis placed on structure has led to development of quantitative methods in landscape ecology (Frohn, 1998; Haines-Young and Chopping, 1996; McGarigal and Marks, 1995; O'Neill et al., 1988; Turner and Gardner, 1991).

Landscape metrics, or computations of statistical indices that involve area, density, size, variability, edge, distance, shape, core area, proximity, diversity, and isolation of patches, are common in quantifying structure (McGarigal and Marks, 1995). These calculations characterize the composition and configuration of patches in a landscape pattern. The number and variety of patch types is referred to as the composition of the landscape, and is important to many wildlife studies because required habitat types can be directly quantified and assessed. The spatial distribution of the types of patches is referred to as the configuration of the landscape, and is indicative of population-influencing distances between and spatial arrangements of suitable habitat patches.

Compositional metrics include measures of patch type, area or proportion of the landscape, and size (McGarigal and Marks, 1995). Configuration can be measured by inter-patch distance and adjacency, among other metrics. The definitions and utility of selected landscape metrics (i.e. those examined in this study) are listed in Table 2. The main eight metrics of patch class area, number of patches, mean patch size, coefficient of variance, edge density, shape, mean nearest neighbour, and interspersion-juxtaposition index quantify the landscape composition and configuration. Appendix A provides the equations for calculating the main metrics used in this research.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Name (Units)</th>
<th>Description</th>
<th>Interpretation (Landscape/Class)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLA</td>
<td>Total Landscape Area (ha)</td>
<td>Combined area of all patch types within the area of analysis</td>
<td>Measures the overall area; useful when comparing different areas of analysis</td>
</tr>
<tr>
<td>CA</td>
<td>Class Area (ha)</td>
<td>Area, or proportion of the patch type in the landscape</td>
<td>Measures the amount of each patch type; indicates abundance of patch types relative to one another</td>
</tr>
<tr>
<td>NUMP</td>
<td>Number of Patches</td>
<td>Number of separate patches in the landscape</td>
<td>Measures patch abundance to determine if patches are more or less numerous; indicative of spatial heterogeneity; indicates landscape fragmentation with higher values</td>
</tr>
<tr>
<td>MPS</td>
<td>Mean Patch Size (ha)</td>
<td>Average size of patches (area)</td>
<td>Quantifies landscape composition; indicates landscape fragmentation smaller values</td>
</tr>
<tr>
<td>PSCOV</td>
<td>Patch Size Coefficient of Variance</td>
<td>Relative variation; patch size standard deviation as a percentage of mean patch size</td>
<td>Conveys direct comparison of variability information between landscapes; interpretation may require NUMP or MPS when PSCOV between landscapes has same value</td>
</tr>
<tr>
<td>ED</td>
<td>Edge Density (m/ha)</td>
<td>Standardized length of all edges per unit area (perimeter/area)</td>
<td>Relative measure of all patch edges; enables direct comparison between landscapes; indicates fragmentation with increasing value</td>
</tr>
<tr>
<td>AWMSI</td>
<td>Area Weighted Mean Shape Index</td>
<td>Average perimeter-to-area ratio with individual patch area weighting applied to each patch (sum of patch edges/square root of patch areas, adjusted by constant X patch area/total area)</td>
<td>Measures shape complexity adjusted for square standard, as weighted by patch size; indicates square shape when value is one and more complex shape with increasing value; larger patches are weighted more heavily than smaller patches, which may be more useful in landscapes where larger patches are more important to a particular landscape function</td>
</tr>
<tr>
<td>MNN</td>
<td>Mean Nearest Neighbour (m)</td>
<td>Average, shortest distance between patch edges of the same type (class level) or the average of class distances (landscape level)</td>
<td>The greater the measure, the more isolated the patch is from similar types; greater overall measure indicates highly fragmented landscape</td>
</tr>
<tr>
<td>IJI</td>
<td>Interspersion-Juxtaposition Index</td>
<td>Adjacency measure between patches</td>
<td>Ranges from 0 (uneven adjacencies) to 100 (equal adjacencies)</td>
</tr>
</tbody>
</table>
Landscape structure measures are useful in assessing wildlife habitat quality (Frohn, 1998; Riiters, et al., 1995; Patton, 1992). Various metrics of patch and matrix relationships can indicate where fragmentation or connectivity of bear habitat occurs. The spatial arrangement of human activities, such as forest harvesting, mining, and their related infrastructure, largely determines the degree of habitat fragmentation, which in turn affects wildlife populations and their movement across the landscape (Sachs, et al., 1998). Generally, the harvested or otherwise human-impacted patches have simpler shapes than undisturbed or naturally disturbed habitat patches, and landscape metrics illustrate this distinct difference. Effective habitat management requires consistent data that completely covers large areas in order to understand landscape scale effects. Satellite remote sensing imagery provides data at the landscape level from which landscape metrics can be calculated to describe the overall pattern and structure for assessing habitat. The commonly implemented metrics recommended by similar forest habitat analyses include the number of attribute classes, number of patches, average patch size, average patch compaction, average patch shape (perimeter to area ratio), edge density, patch perimeter, inter-patch distance, contagion, and fractal dimension (Deuling, 1999; Frohn, 1998; Riiters, et al., 1995). The literature has presented a very large number of metrics for quantifying landscape structure (Riiters, et al., 1995) and few of these have been scientifically validated; therefore, a reduced metric set based on those suggested in the literature will be used and tested in this research.
2.5 Previous Research in Wildlife Habitat Structure and Fragmentation

Table 3 provides a brief overview of selected studies on metric sensitivity and carnivore habitat applications using GIS and remote sensing. The spatial structure of patches in the landscape influences ecological characteristics, such as wildlife distribution and populations (Bissonnette, 1997; Forman and Godron, 1986; McGarigal and Marks, 1995). Understanding how spatial metrics respond to the classification is fundamental to understanding how landscape structure is quantified and subsequently applied to wildlife ecology questions to yield meaningful results.

Landscape metrics have been applied to research into a variety of wildlife habitats, including those of ungulates (Deuling, 1999) and birds and small mammals. (See Andren, 1994, for a synopsis.) Comparable research on carnivores has been limited to such species as wolves (Mladenoff et al., 1995), American marten (Chapin et al., 1998; Hargis et al., 1999), and raccoons, opossums, and striped skunks (Dijak and Thompson, 2000). A search of the published literature did not provide equivalent landscape-level analyses of grizzly bear habitat.

As can be seen in the literature, there is no definitive set of landscape metrics applicable in all wildlife habitat studies. There are a large number of metrics available, some of which are interrelated and redundant (Riters et al., 1995; Turner and Gardner, 1991). The recommendations of available, related studies could aid in choosing which metrics
to apply to a particular question. As Table 3 shows, a common approach is to implement a set of spatial metrics that quantify an array of landscape characteristics. Riitters et al. (1995) found that only six independent types of landscape metrics span the important dimensions of landscape pattern and structure. These can form the starting point for metric set selection.

Table 3. Previous studies.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Application / Analysis</th>
<th>Spatial Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andren, 1994</td>
<td>Relationships between patch size, isolation of patches and the proportion of original habitat remaining in the landscape, and the effect of fragmentation on wildlife populations and total species diversity</td>
<td>NUMP, MPS, Inter-patch distance</td>
</tr>
<tr>
<td>Benson and MacKenzie, 1995</td>
<td>Effects of increasing spatial resolution on patches of water in a matrix of land</td>
<td>NUMP, CA, MPS, Mean patch edge, Fractal dimension, Texture</td>
</tr>
<tr>
<td>Cain et al., 1997</td>
<td>Effects of resolution, number of attributes, and method of delineating landscape unit boundaries for two watersheds</td>
<td>Contagion, Dominance, Patch shape, Fractal dimension, and 24 others</td>
</tr>
<tr>
<td>Chapin et al., 1998</td>
<td>Habitat fragmentation potential of forest clear cutting on habitat use by American marten</td>
<td>NUMP, CA, Patch density, MPS, Maximum patch size, Inter-patch distance, Proximity to edge</td>
</tr>
<tr>
<td>Deuling, 1999</td>
<td>Determination of the spatial effects of timber harvesting and wildfires on caribou habitat fragmentation</td>
<td>NUMP, Patch density, MPS, PSCOV, ED, Mean shape index, Mean proximity index, Mean core area, UI</td>
</tr>
<tr>
<td>Dijak and Thompson, 2000</td>
<td>Distribution and abundance of raccoons, opossums, and striped skunks related to landscape characteristics and edge effects</td>
<td>CA, MPS, PSSD, Inter-patch distance, Contagion, Adjacency, and 5 others</td>
</tr>
<tr>
<td>Franklin and Forman, 1987</td>
<td>Ecological consequences of human-imposed landscape patterns (i.e. clear cutting) on forest lands</td>
<td>TLA, NUMP, MPS, Patch density, Inter-patch distance, Total edge</td>
</tr>
<tr>
<td>Hargis et al., 1998</td>
<td>Testing artificially fragmented landscapes for landscape metric sensitivity to size, shape and spatial distribution of patches, and mode of disturbance growth</td>
<td>ED, Contagion, Inter-patch distance, Mean proximity index, Fractal dimension</td>
</tr>
<tr>
<td>Reference</td>
<td>Application / Analysis</td>
<td>Spatial Metrics</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------</td>
</tr>
<tr>
<td>Hargis et al., 1999</td>
<td>Forest fragmentation effects on American marten with different levels of fragmentation resulting from clear cutting and natural openings</td>
<td>CA, ED, Mean proximity index, Inter-patch distance, Fractal dimension</td>
</tr>
<tr>
<td>Metzger and Müller, 1996</td>
<td>Evaluation of land cover spatial distribution within the landscape by characterizing the complexity of landscape boundaries (i.e., edges)</td>
<td>PA, ED, Patch shape, Coverts proportion, Richness, Diversity</td>
</tr>
<tr>
<td>Mladenoff et al., 1995</td>
<td>Prediction of favorable Gray wolf habitat based on regional landscape characteristics</td>
<td>NUMP, CA, Total edge, Fractal dimension, Diversity, Dominance, Contagion</td>
</tr>
<tr>
<td>Reed et al., 1996</td>
<td>Quantification of forest fragmentation due to roads (and clear cuts)</td>
<td>NUMP, MPS, Mean core area, Mean patch edge, Total edge, Mean shape index, Diversity, Dominance, Contagion, Contrast</td>
</tr>
<tr>
<td>Ritters et al., 1995</td>
<td>Determination of a reduced set of landscape structure and pattern metrics</td>
<td>Perimeter-area ratio, Contagion, Patch shape, ED, NUMP, Patch density</td>
</tr>
<tr>
<td>Sachs et al., 1998</td>
<td>Detection of landscape change due to fragmentation by forest harvesting</td>
<td>MPS, Percent core area, Perimeter-area ratio, Area-weighted mean patch fractal dimension, AWMSI, Landscape shape index</td>
</tr>
<tr>
<td>Tinker et al., 1998</td>
<td>Quantification of landscape patterns for 12 watersheds with differing degrees of clear cutting and road density</td>
<td>NUMP, Patch core area, MPS, Patch density, ED, Diversity, and others</td>
</tr>
<tr>
<td>Turner et al., 1989</td>
<td>Comparison of landscape pattern indices as affected by changing the spatial scale</td>
<td>Diversity, Dominance, Contagion</td>
</tr>
<tr>
<td>Wickham et al., 1997</td>
<td>Effects of land cover misclassification and differences in land cover composition on landscape pattern</td>
<td>Average patch compaction, Contagion, Fractal dimension</td>
</tr>
<tr>
<td>Wickham and Ritters, 1995</td>
<td>Effect of changing land cover pixel size on landscape metrics</td>
<td>Diversity, Evenness, Adjacency, Contagion</td>
</tr>
</tbody>
</table>

Properties of the data also influence the landscape metrics to be used and how they are interpreted (Cain et al., 1997; Haines-Young and Chopping, 1996; McGarigal and Marks, 1995; O'Neill et al., 1988; Turner et al., 1989). The classification base for metric calculation may have several characteristics in response to which a single metric may
Type (raster versus vector) and scale of data have been the focus of much of the previous research in landscape metric sensitivity. Haines-Young and Chopping (1996) provide a good summary on understanding the factors constraining the use of spatial metrics. For example, edge indices tend to be larger when calculated on raster data as opposed to vector data due to the increased perimeters around square pixels.

Benson and MacKenzie (1995), Cain et al. (1997), Hargis et al. (1998), Turner et al. (1989), and Wickham and Ritters (1995) have examined the response of metrics to spatial scale. The common theme in their research is that spatial resolution has an important effect on most landscape indices and, therefore, the choice of scale (i.e. pixel size of satellite image) must be appropriate to the landscape ecology question under investigation and subsequently to the choice of metrics employed.

Other investigations consider temporal scale, boundary delineation, and categorical questions. Sachs et al. (1998) examined which landscape metrics, when applied to a temporal scale problem, best describe changes in the landscape pattern. Land cover misclassification was found to affect metric sensitivity when it resulted in differences in land-cover composition of greater than 5% (Wickham et al., 1997). Metzger and Muller (1996) developed new metrics to characterize boundary complexity. Cain et al. (1997) also looked at boundary characteristics, the modifiable areal unit problem, and number of attributes. They varied the attribute scale of a twelve-class map by reclassifying it into five classes, and by using factor analysis found that measures of diversity, texture, and fractal dimension explained more of the landscape pattern variance than patch shape or compaction. Many metrics were redundant across a range of spatial scales and across
two attribute scales. However, as found by Cain et al. (1997), the biological meaning of landscape metrics may be more important in analyzing landscape patterns than are their statistical properties. Attribute scaling is a good candidate for further investigation because there are many methods to reclassify a base classification, some of which may be more ecologically relevant than others.

Another important issue involves the relationship between landscape structure metrics and specific wildlife characteristics. Relationships for grizzly bears have not been found in the literature, but related ideas have been presented in which certain structure parameters may be of greater importance in predicting individual species. For example, pine marten populations (Hargis et al., 1998) were highly related to patch size and edge density. The appropriate landscape metrics depend on the particular species under investigation. Mladenoff et al. (1995) incorporated spatial metrics into their predictive model for identifying gray wolf pack home range habitat. They found that of the seven landscape metrics employed that fractal dimension (determined by logistic regression) was one of the most important predictor variables. The results of a study on American marten by Chapin et al. (1999) showed a relationship between habitat patch use by resident martens and large patch size, small inter-patch distance, and close proximity to edge. Also pertaining to marten, Hargis et al. (1999) used measures of landscape pattern (i.e. edge density, mean proximity index, inter-patch distance, and fractal dimension) to show the influences of landscape structure on prey availability in fragmented forests. The research by Dijak and Thompson (2000) on the distribution and abundance of raccoons, opossums, and striped skunks resulted in different metrics associated with each species. Among other landscape characteristics, relative
abundance of raccoons was related to mean patch size of agricultural lands, opossum abundance was related to contagion and inter-patch distance, and striped skunk abundance was not related to any of the metrics examined.

2.6 Summary

This thesis is concerned with the use of satellite remote sensing classification maps in quantifying landscape structure for the purpose of predicting grizzly bear density within different management units and assessing the level of fragmentation due to human impacts. Therefore, the basic ideas in satellite remote sensing classification of large areas and the integration of GIS data are discussed leading to a summary of similar fragmentation studies that rely on the use of landscape metrics. It appears that this landscape ecology approach has provided much food for thought in wildlife management of a variety of species. The selection of spatial metrics that might be of interest in a grizzly bear management study is large, and not yet fully explored in the literature. The number of ways in which these metrics can be assembled for use in predictive and other types of models is also large, and not yet understood nor reasonably well considered. There appears to be a significant opportunity to contribute to the knowledge and management of grizzly bears by increasing understanding of the relationship between landscape structure, as measured over large areas by satellite remote sensing classifications, and grizzly bear population characteristics (e.g. bear density). The clarification and documentation of this relationship is the objective of this thesis and the subject of the remaining chapters.
3.0 The FMF GBRP Study Area and 1999 Baseline Data

3.1 Geographic Setting

This chapter describes the study area and the data used in the 1999 baseline analysis of habitat structure and fragmentation for the Foothills Model Forest Grizzly Bear Research Project. First, synopses on the human and physical environments are provided. Then, the field and digital data collected for the remote sensing classification and landscape structure study are described.

In 1999, the Foothills Model Forest (FMF) – an organization of federal, provincial, and private sectors collaborating in forest-related research in the Yellowhead Ecosystem of West-Central Alberta – began a five-year Grizzly Bear Research Program (Stenhouse and Munro, 2000). The current range of grizzly bears in the province of Alberta is shown in Figure 1. Sixty-nine percent of it is located in the Alberta Yellowhead Ecosystem, which is home to 68% of all grizzlies in the province of Alberta (Stenhouse and Munro, 2000).
Figure 1. Study Area, Home Ranges, and location of present grizzly bear range in Alberta.
The FMF spans Jasper National Park, other public lands within the Rocky Mountains and Foothills, and includes industrial forestry management agreements, town sites, mines, transportation corridors, recreational areas, and oil and gas exploration/developments (Figure 1). The 5342-km² heart of the Yellowhead Ecosystem was subdivided into 16 BMUs identified for the convenience of planning for grizzly bear population and habitat research and management planning. The Yellowhead Highway (Highway 16) parallels the northern boundary of the study area, the divide between the Maligne River and Rocky River watersheds bounds the west, the Brazeau River marks the southern limit, and the Forestry Trunk Road (Highway 40) follows the eastern boundary.

3.2 Human Environment

The study area provides the opportunity to contrast landscape conditions associated with both lower levels and higher levels of disturbance and human impact. As previously mentioned, human activities on this landscape include forest harvesting, open-pit coal mining, establishment and operation of seismic lines and well sites from oil and gas exploration/development, outdoor recreation, and building and maintenance of the associated infrastructure of highways, gravel roads, railroads, trails, and power lines. The towns of Hinton, Robb, and Cadomin border or are found within the GBRP boundary (Figure 1). Natural disturbances, such as fire, insect infestations, windfall, and landslides, have also historically occurred in the area, with the Gregg River Burn of 1997 being the most recent major event (GEOWEST, 1997). Within Jasper National Park and
other protected areas, tourism and recreation have left "footprints" on the landscape in
the form of roads, trails, and tourist developments (hotel and hot spring resorts,
campgrounds, and guiding outfits). The sedimentary geology of the Foothills portion of
the study area has resulted in coal mining operations, including the present and former
mines of Cadomin, Cardinal, Gregg River, Mountain Park, and Coal Valley. In the
majority of the Foothills, industrial forestry and oil and gas exploration/development have
covered the landscape with cut blocks, well sites and access roads. Access and
maintenance roads and trails associated with the resource extraction activities have
opened up further recreational opportunities, enabling motorized penetration deeper into
grizzly bear habitat.

3.3 Physical Environment

The FMF Grizzly Bear study area tapers from the high relief of the Rocky Mountain
Eastern Main and Front Ranges in the west to the rolling Foothills in the east
(GEOWEST, 1997). The sedimentary topography ranges from 950 to 3400 meters in
elevation and is controlled by the Rocky Mountain Thrust Belt, which causes northwest
to southeast oriented ranges. Along with glacial erosion and deposition, this has
resulted in a landscape of glaciers, alpine meadows, rugged mountain peaks, broad U-
shaped valleys, foothills, and moraine and glaciofluvial landforms. Glacier-fed rivers and
streams that generally drain to the northeast dissect the uplands. Moderately to poorly
drained soils have developed on deposits of glaciofluvial sand, lacustrine clay,
discontinuous glacial till, and some organics.
There are five natural ecoregions in the study area consisting of the alpine, subalpine, and montane ecoregions of the Cordilleran Ecoprovince, and the upper boreal cordilleran and lower boreal cordilleran ecoregions of the Boreal Ecoprovince (Strong and Leggat, 1992). The ecoregions are bounded and distinguished by elevation and vegetation communities. Appendix B lists the vegetation species found in the study area plots during the 2000 field campaign. The Cordilleran and Boreal climate is primarily determined by altitude, the interaction of high mountain relief with major air mass systems, and latitudinal control on insolation. Temperature decreases while precipitation and wind generally increase with altitude, especially in the alpine and subalpine. The warmer, wetter Pacific westerlies of summer are replaced by or interact with the cold, dry Arctic air mass of winter to bring bitterly cold conditions or high elevation snow. The orographic effect of the mountains results in a "rainshadow" of drier conditions on the eastern slopes and interior montane valleys. Due to the low insolation of these northerly latitudes, average annual temperatures are near 0 degrees Celsius. There is a great range in temperature from summer to winter, as is also true in the upper and lower boreal cordilleran ecoregions, with the majority of precipitation resulting from winter snow.

The alpine ecoregion occurs above the subalpine at elevations above a lower limit varying from 1800 to 2000 meters. Here above the tree line, heather (Phyllodocae spp., Cassiopeae spp.), willow (Saltix spp.), white mountain avens (Dryas octopetala), and lichens dominate the vegetation communities growing on Gleysols, Brunisols, and Regosols. The subalpine ecoregion occurs between the alpine and montane, and
ranges in elevation from approximately 1300 to 2000 meters. The Dystric and Eutric Brunisols of the subalpine support forested and parkland type communities of Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), alders (*Alnus spp.*), willows, grasses and sedges (*Carex spp.*). The montane is found in the major river valleys below the subalpine at 1400 meters and lower before giving way to parkland and grassland. Lodgepole pine (*Pinus contorta*), Douglas fir (*Pseudotsuga menziesii*), aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), grasses and willows are found on the Eutric Brunisols, Gray Luvisols, and Gleysols that follow the major river valleys of the montane. The upper boreal cordilleran, ranging from around 1000 to 1500 meters, occurs in the Front Ranges and foothills between the subalpine and lower boreal cordilleran. In Eutric and Dystric Brunisols and Gray Luvisols grow lodgepole pine, white spruce (*Picea glauca*), birch (*Betula spp.*), willow, and sedge. The lower boreal cordilleran occurs between the upper boreal cordilleran and montane/parkland ecoregions from approximately 300 to 1300 meters. The main vegetation consists of aspen, balsam poplar, lodgepole pine, birch, spruce, balsam fir (*Abies balsamea*), tamarack (*Larix laricina*), willows, and sedge on Gray Luvisols, Gleysols, and Organics.

The mixture of species depends on site history as well as geographical location (Strong and Leggat, 1992). Within the forested ecoregions, i.e. all except the alpine, fire regime and moisture availability determine the dominant vegetation communities at various sites. For example, fire-successional lodgepole pine dominates the low to mid-elevations due to natural historic fire occurrence. At lower elevations in areas of seeps or standing water, wetlands dominated by black spruce (*Picea mariana*), willow and birch, or sedge complexes occur.
The five ecoregions of the study area provide important ecological functions and resources (Strong and Leggat, 1992). Major wildlife species in the area include bears (Ursus americanus and Ursus arctos horribilis), mule deer (Odocoileus hemionus), white-tailed deer (Odocoileus virginianus), elk (Cerus elephas), and bighorn sheep (Ovis canadensis). The distinctive, fragile fragments of the alpine ecosystem provide habitat for pika (Ochotona princeps) and ptarmigan (Lagopus spp.), late summer forage for bears and ungulates, and is used for watershed management as well as recreation. The subalpine contains important forest, riparian, and avalanche communities for wolverine (Gulo gulo), ungulates, and birds, and provides early spring forage for bears and ungulates. The main habitat importance of the montane is for wintering of ungulates. The conifer-dominated upper boreal cordilleran is important for production of wood fiber and ungulate forage; it also occurs on bedrock that is involved in oil and gas developments. As an ecotone between cordilleran and boreal conditions, the lower boreal cordilleran has the highest diversity of tree and understory species. This mixedwood-dominated ecoregion has important riparian communities and habitat for moose (Alces alces), grouse (Bonasa umbellus and Dendragapus spp.) and other birds. The forested ecoregions are intricately linked with human activities in the study area because all are important in forestry, watershed management and protection, recreation, and by happenstance with coal and hydrocarbon extraction.
3.4 Vegetation Plot Field Data Collection and Analysis

An extensive field campaign was undertaken during the summer of 2000 to obtain detailed information on the habitat types that contain the above-mentioned physical and vegetal characteristics. These data were required to provide training and accuracy assessment data for the remote sensing classification that was performed on Landsat TM-5 imagery the following fall.

Originally, twenty-two habitat/land cover classes were determined for grizzly bear habitat mapping in the Foothills Model Forest study area (Franklin et al., in press); the IDTA classification used in this thesis ultimately has 20 classes (Franklin et al., 2001). The twenty-two classes resulted from the collaborative efforts between the Foothills Model Forest, University of Calgary, GeoAnalytic Ltd., and Geospatial Software Solutions, and were incorporated into a preliminary habitat classification product using the Evidential Reasoning classifier (Franklin et al., in press). The classes of ice, snow, water, rock, shadow, and cultural features did not require the extensive ground-truthing that the sixteen vegetation habitat classes did and therefore were not sampled.

In situ data were required on the vegetation composition (species, percent cover) and structure (height, DBH, crown closure) in order to calibrate and validate the remote sensing classification product. Depending upon the class plot type (Air-Called via helicopter, Forest, Vegetation), one of three sampling techniques was performed. For example, forested vegetation was sampled using general timber cruising practice,
shrublands and herbaceous meadows were sampled using quadrants of percent cover, and the more inaccessible sites (as well as others) of alpine and wetlands were sampled using aerial survey descriptions from a helicopter. The methodology for sampling each plot type is outlined in Appendix C.

During the summer 2000 field campaign 326 plots were sampled for use in classifying the satellite imagery into grizzly bear habitat. One hundred eighty-two plots were sampled using the Air-Call method, of which 79 were Forest, and 65 were Vegetation. The resulting field data were stored in a MS Access database, and the GPS coordinates with associated attributes were used as training sites in the IDTA habitat classification (described in section 3.5.2).

A discriminant function analysis was conducted on the assembled field data set to determine how well the field data agreed with the pre-determined habitat and land cover classes. Percent cover of vegetation species and non-vegetation (deadfall, rock, litter, soil, water) were the structural variables primarily used in the analysis. Table 4 indicates reasonable representation – 82% overall – of the field plot variables for all classes, and is based on the lowest reported: the Air-Called plots. Plot data from field locations having the same species but of different classes due to moisture and topography resulted in class confusion and is the main reason for less than perfect accuracy. The Vegetation plots were somewhat improved with an accuracy of 85%, and the Forest plots were the highest at 95%. Overlap was most apparent among the Mixed, Open Conifer, and Treed Wetland forest-type classes, and among the upland Shrub and Open Wetland classes. These sources of confusion help explain the lower (71%) accuracy of
the spectral data derived by extracting pixel values from the satellite imagery under the field plot coordinates.

Table 4. Discriminant function analysis of field data.

<table>
<thead>
<tr>
<th>Collection Method</th>
<th>Classification Accuracy</th>
<th>Confused Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-Called Plots</td>
<td>82 %</td>
<td>Mixed and open conifer</td>
</tr>
<tr>
<td>Forest Plots</td>
<td>95 %</td>
<td>Open conifer and tree wetland</td>
</tr>
<tr>
<td>Vegetation Plots</td>
<td>85 %</td>
<td>Shrub and open wetland</td>
</tr>
<tr>
<td>Overall</td>
<td>82 %</td>
<td>N/A</td>
</tr>
<tr>
<td>Spectral/DEM Data</td>
<td>71 %</td>
<td>N/A</td>
</tr>
</tbody>
</table>

3.5 Spatially Explicit Digital Data

Table 5 shows the attributes of the various digital data sources utilized for this research. All data, provided courtesy of the Foothills Model Forest, Alberta Environment, and Jasper National Park, are projected in Universal Transverse Mercator (UTM) Zone 11 grid and North America Datum 1983 (NAD83) ellipsoid. The primary data sources include a Landsat Thematic Mapper-5 satellite image and a Digital Elevation Model (DEM). The secondary data sources include compilations of Bear Management Units (BMUs), Home Ranges, and Bear Density.
Table 5. Spatially explicit digital data (Projection/Datum: UTM Zone 11 NAD83).

<table>
<thead>
<tr>
<th>Data</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat TM-5</td>
<td>Raster</td>
<td>September 8, 1999&lt;br&gt;Path 45 Row 23&lt;br&gt;TM123457 30 meter pixel size&lt;br&gt;Sun Elevation: 40, Sun Azimuth: 153&lt;br&gt;Center: 1175304.0935W, 530542.2162N (&lt;Latitude/Longitude&gt;) 439702.799, 5882448.193 (&lt;Easting/Northing&gt;) 3448, 2865 (&lt;Pixel/Line&gt;)</td>
</tr>
<tr>
<td>Digital Elevation Model</td>
<td>Raster</td>
<td>100 meter resampled to 30 meter&lt;br&gt;1 meter elevation step</td>
</tr>
<tr>
<td>IDTA Classification</td>
<td>Raster</td>
<td>20 habitat-related land cover types&lt;br&gt;Clipped to 1999 Grizzly Bear Research Area&lt;br&gt;83% accuracy based on training sites</td>
</tr>
<tr>
<td>Home Ranges</td>
<td>Vector</td>
<td>6 individuals: 4 females, 2 males&lt;br&gt;Based on Minimum Convex Polygon method</td>
</tr>
<tr>
<td>Bear Management Units</td>
<td>Vector</td>
<td>16 Watersheds; delineated to approximate the size of a female home range</td>
</tr>
<tr>
<td>Human Features – Towns</td>
<td>Vector</td>
<td>Towns within the Foothills Model Forest</td>
</tr>
</tbody>
</table>

3.5.1 Landsat TM-5 and Digital Elevation Model

A mid-summer date was desired for the Landsat TM-5 satellite image; however, the September 8, 1999, was the only image having zero cloud cover for the summer season, so this was chosen. The DEM, containing one-meter step elevation information for each 100X100 meters square on the earth, was resampled to 30 meters to match the pixel resolution of the Landsat TM-5. The Landsat TM-5 bands 1-5 and 7 contain information in the visible, near and mid-infrared portions of the electromagnetic spectrum (Lillesand and Kiefer, 2000). Each band was radiometrically corrected to account for atmospheric effects. Using the DEM, the Landsat image was orthorectified to account for topographic effects and so that the imagery coordinates in the UTM system would match that of the
actual location measured in the field on the surface of the earth. Medina Hansen, RS/GIS Analyst at the University of Calgary, performed this pre-processing of imagery.

### 3.5.2 IDTA Classification

A 1999 remote sensing classification using the Integrated Decision Tree Approach (IDTA) was produced for grizzly bear habitat-related land cover in the study area and is shown in Figure 2 (Franklin et al., 2001). The methodology (documented in a flowchart in Appendix D) was implemented by Medina Hansen, RS/GIS Analyst at the University of Calgary. It incorporated tasseled cap transformations of the spectral data from the Landsat TM-5 satellite imagery, DEM variables (elevation, slope, and shaded relief), and Alberta Vegetation Inventory and Jasper National Park Biophysical categorical data into a multi-step classification based on both unsupervised, supervised, and decision tree methods.
Integrated Decision Tree Approach (IDTA) Classification
1999 GBRP Study Area

Figure 2. IDTA classification map.
First, a K-Means unsupervised classification was implemented to separate vegetated and non-vegetated areas. Lakes were distinguished from shadows based on a slope decision rule, and low-elevation forest from shadows based on an elevation decision rule. Second, a Maximum Likelihood supervised classification was performed to separate the forest and non-forest vegetated classes. The field plot data points were used as training sites at this step. Decision rules based on slope and proximity to water were used to distinguish conifer and shrub from spectrally similar wetland types. Third, the disturbance classes that had been extracted from GIS layers of human attributes were overlaid to combine the spectrally indistinct classes of forest cut blocks, roads, urban, and burn with the vegetation and land cover classes. Finally, post-classification smoothing using a modal 3X3 filter was used to produce the final classification map. Based on the training site statistics, the classification has 83% overall accuracy.

Biologists and remote sensing scientists developed the land cover classes for the 1999 iDTA classification (previously described in Sections 2.2 – 2.3 and Table 1). The habitat classes include closed and open forest stands, shrub and herbaceous types, alpine/subalpine, and wetlands. The general land cover types present throughout the Rocky Mountains are water, rock, snow, and shadow. It should be noted that due to the restriction of 30-meter pixel resolution, the human-related cover classes are broad and indicate only the major ‘footprints’ of habitat disturbance: forest cut blocks, roads, urban, and burn.
3.5.3 Bear Management Units

Figure 3 displays the Bear Management Unit (BMU) polygons for the 1999 study. Sixteen BMUs were delineated according to watershed boundaries using a GIS function on the DEM (Stenhouse and Munro, 2000). The areal extent of each BMU is meant to approximate the average size of female home ranges — generally 300-400 square kilometers. These are convenient landscape units that can be used by land managers in assessing grizzly bear habitat and the effects of resource industry activities.

3.5.4 Grizzly Bear Population Density Classes

During the 1999 season, DNA data were collected on the grizzly bear population in the FMF GBRP study area (Stenhouse and Munro, 2000). The study area was divided into sixty-four 9-by-9 km square grids, into which barbed-wire enclosure hair traps (based on Woods et al., 1999) were placed at three different locations for ten-day durations in all grids. The collected hair samples were analyzed in a laboratory by DNA microsatellite profiling to determine species (grizzly versus black bear), sex, and individuality to estimate population count and familial relationships for the sampled grizzly bears.

With the help of Robin Munro, Wildlife Biologist for FMF GBRP, Low, Medium, and High bear density classes were determined for each BMU based on equal interval groupings of the number of individual bears (Figure 3). It must be stressed that, due to limitations of the DNA sampling, the density classes are estimates and no actual population counts can be associated with each class. The low-density class comprises six of the BMUs, and the medium- and high-density classes are each made up of five BMUs.
3.5.5 Minimum Convex Polygon Home Ranges

The data used for representing where individual grizzly bears spent time within their habitat are the individual bear home ranges. Joining radio telemetry locations from the 1999 season by the Minimum Convex Polygon method developed the home range polygons (cf. White and Garrott, 1990). Thirteen bears had suitable GPS collar data for
home range delineation, but not all could be analyzed in this research because part of their ranges fell outside of the IDTA classification.

Table 6. Grizzly bear data for individual home ranges.

<table>
<thead>
<tr>
<th>Bear ID</th>
<th>Birth Date</th>
<th>Sex</th>
<th>Collar On</th>
<th>Collar Off</th>
<th>Number of GPS Points</th>
<th>General Location</th>
<th>Collar Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>G005</td>
<td>1988</td>
<td>M</td>
<td>11-May-99</td>
<td>20-Aug-99</td>
<td>481</td>
<td>Drinnan Creek Gregg</td>
<td>Televitt</td>
</tr>
<tr>
<td>G008</td>
<td>1985</td>
<td>M</td>
<td>14-May-99</td>
<td>22-Sep-99</td>
<td>393</td>
<td>Drummond Creek Whistler</td>
<td>Televitt</td>
</tr>
<tr>
<td>G010</td>
<td>1986</td>
<td>F</td>
<td>25-May-99</td>
<td>02-Sep-99</td>
<td>483</td>
<td>Cairn Creek Medicine Tent</td>
<td>ATS</td>
</tr>
</tbody>
</table>

Descriptions of the six individual bears having home ranges completely within the study area are in Table 6, the Minimum Convex Polygons of which are mapped in Figure 1. All bears had been captured using the same heli-darting technique (Stenhouse and Munro, 1999). Four are reproductive-aged females without cubs (G003, G004, G010, and G016), five years of age (except G010 is 13 years), and had collars on for approximately the same duration from May to October (6 to 7 months each). The two males (G005 and G008) are 11 and 14 years, and had collars on for five to six months.
3.6 Summary

The 1999 FMF GBRP study area encompasses 5432 km² within the Yellowhead Ecosystem of West-Central Alberta. The boreal and cordilleran ecosystems are dominated by coniferous forest interspersed with areas of alpine and subalpine in the Rocky Mountains to the west and wetlands in the lower-relief foothills to the east. The great diversity of vegetation provides important habitat for wildlife, such as grizzly bears, and is a source of natural resources for humans. The overall study area provides the opportunity to analyze lower and higher levels of human disturbance on landscape conditions and the effects on grizzly bear habitat.

The data utilized for this research include a Digital Elevation Model (DEM) and a Landsat TM-5 satellite image that was classified into grizzly bear habitat-related land cover types using the Integrated Decision Tree Approach (IDTA) facilitated by field data. Bear Management Units (BMUs), Home Ranges, and Bear Density are the GIS coverages used in analyzing the habitat structure.
4.0 Methods

4.1 Introduction

A common spatial analysis is the use of landscape metrics to quantify the structure — i.e. the composition and configuration — of the landscape (Forman, 1995; Haines-Young and Chopping, 1996; Turner, 1989). The spatial metrics, which describe and quantify the various landscape cover types, are useful in assessing wildlife habitat potential, human impacts on regional ecosystems, and overall landscape inventories.

Landscape metrics are sensitive to a number of properties inherent in the data used to represent the landscape. Previous studies in landscape metric sensitivity have pertained to spatial or temporal resolution of the satellite imagery and raster versus vector comparisons (Andren, 1994; Benson and MacKenzie, 1995; Cain et al., 1997; Haines-Young and Chopping, 1996; Hargis et al., 1998; Metzger and Muller, 1996; Turner et al., 1989; Wickham et al., 1997; Wickham and Riitters, 1995).

In Section 4.2, this study first applies landscape metrics describing landscape composition and structure to two Grizzly Bear Management Units (BMUs) having low and high human impact to determine metric sensitivity to the scaling of attributes (i.e. aggregation of patch types) from multiple to binary classes within BMUs of known fragmentation.
The premise is that metrics may be more ecologically meaningful when applied to structurally different patch types (McGangal and Marks, 1995). By scaling the attributes from an original land cover classification into more generalized habitat-related classes, such as the major life forms of vegetation or simple presence/absence of vegetation patches, the landscape metrics are expected to elucidate important compositional and spatial properties of habitat.

In order to understand landscape metric sensitivity to attribute scaling, the resolution and type of map data is held constant. Then the results of metrics calculated on multiple habitat/cover type patch schemes and binary patch schemes (vegetation/nonvegetation) are compared. This will aid in understanding landscape metric sensitivity to the numbers and types of patches at the landscape level. Upon further analysis, an assessment of landscape metric sensitivity to human activities that fragment the landscape is undertaken by comparing results from relatively low and high human-impacted BMUs of similar size and natural environment. It is expected that the metrics will respond in a predictable fashion to the differences in fragmentation levels, and this will aid in examining the effects of attribute scaling.

Analyzing how the landscape metrics respond to the base classification on which they are implemented is key to interpreting and determining which spatial statistic calculations will be most ecologically significant in understanding the fragmenting effects of human activity upon the landscape, and ultimately on grizzly bear habitat.
Previous research has shown that wildlife population characteristics can be related to habitat structure (Andren, 1994; Dijak and Thompson, 2000; Hargis et al., 1999; Mladenoff et al., 1996). These studies have found that a particular set of landscape metrics for a wildlife species’ habitat is statistically related to data on population abundance, density, or distribution. Therefore, the first hypothesis to be tested is that grizzly bear density class estimates within a BMU are predictable by a set of landscape structure metrics.

The prior studies have utilized multivariate statistical techniques, such as regression, that rely on continuous population data variables. For the 1999 FMF GBRP data set, reliable population density estimates are available as discrete categorical data only. Therefore, the multivariate statistical techniques of discriminant functions, which can handle discrete data (Tabachnick and Fidell, 1989), are applied to determine the relationships between grizzly bear density and habitat structure.

Discriminant function analysis is a powerful statistical tool for predicting dependent variables from a set of independent variables, essentially the reverse of multivariate analysis of variance (Tabachnick and Fidell, 1989). In other words, group membership or classification is discriminated from predictors. In this thesis, the grizzly bear density class of each BMU is treated as the dependent variable, which is to be predicted by landscape structure metrics acting as the independent variables. If there is a significant difference among bear density classes within BMUs as measured by habitat structure metrics, then the discriminant functions should predict which bear density class a BMU belongs to. The discriminant function is developed using training data, which can also
be used to test the power and accuracy of the function. Alternatively, independent training areas can be used to assess the discriminant function performance.

The set of spatial metrics and attribute scaling scheme that proves to be the optimal predictor of grizzly bear density class are used to test the second hypothesis that BMUs having lower fragmentation (by human disturbance) will be similar in landscape structure as grizzly bear home ranges. To do this, quantification and comparison of the composition and spatial configuration of habitat/land cover patches among the areas of analysis are conducted to assess fragmentation of BMUs and compare the habitat structure to actual home ranges.

Structural and fragmentation differences are quantified through analysis of both landscapes and classes. The landscapes and class patches appropriate to the research objective must be defined. The two landscape-level areas of analyses are BMUs and home ranges. The patch or class-level corresponds to the attributes of the Cover Type reclassification of the IDTA map into 14 classes of grizzly bear habitat-related land cover.

Both landscape and class level is important because each level illuminates fragmentation information at a different scale (McGangal and Marks, 1995). Wildlife ecologists are more aware that the effect of habitat variation on ecological processes and wildlife populations occurs at many levels. Understanding the landscape level structure is important for managing entire ecosystems due to the increasing loss of regional and global biodiversity due to the fragmenting effects of human activities.
(Saunders et al. 1991). The class level is the common research and management scale since wildlife ecologists assume that the more important ecological processes operate at local scales (Dunning et al. 1992). The difference or direction of change in spatial metrics among the class level disturbance and habitat-related land cover patches are of primary interest because the amount and distribution of each patch type indicate fragmentation for that class. To compare fragmentation among BMUs and home ranges, the BMUs at the class-level focuses on certain patch types that are determined from the percentage of dominant cover types in the home ranges and amount of human disturbance classes in the BMUs.

For the purposes of this research, the Patch Analyst extension to ESRI's ArcView 3.x GIS software was used to calculate spatial metrics. Patch is defined as a relatively discrete area differing in environmental characteristics and appearance from its surroundings (Forman and Godron, 1986; McGarigal and Marks, 1995) and is represented by the grizzly bear habitat-related land cover classes mapped by the IDTA classification technique. A flow chart depicting the methods used for quantifying the landscape structure analysis using GIS is shown in Figure 4.
Figure 4. Cartographic model/flow chart depicting the methods used for attribute scaling and measuring landscape structure.
4.2 Attribute Scaling

In order to test the effect of attribute scaling, the classes of the IDTA map were aggregated into patch types according to ecologically meaningful criteria as listed in Table 1 and discussed in Chapter 2 (Table 7). Three maps of different patch types were produced: Cover Type (CT), Life form/Disturbance (LD), and Vegetated and Nonvegetated (VN).

<table>
<thead>
<tr>
<th>IDTA</th>
<th>Cover Type (CT)</th>
<th>Life form / Disturbance (LD)</th>
<th>Vegetated and Nonvegetated (VN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CICon</td>
<td>1</td>
<td>Forest</td>
</tr>
<tr>
<td>2</td>
<td>CIDec</td>
<td>2</td>
<td>Forest</td>
</tr>
<tr>
<td>3</td>
<td>Mix</td>
<td>3</td>
<td>Forest</td>
</tr>
<tr>
<td>4</td>
<td>OpCon</td>
<td>4</td>
<td>Forest</td>
</tr>
<tr>
<td>5</td>
<td>OpDec</td>
<td>5</td>
<td>Forest</td>
</tr>
<tr>
<td>6</td>
<td>AlpSub</td>
<td>6</td>
<td>Forest</td>
</tr>
<tr>
<td>7</td>
<td>Herb&lt;18</td>
<td>7</td>
<td>Forest</td>
</tr>
<tr>
<td>8</td>
<td>HerbRec</td>
<td>7</td>
<td>Forest</td>
</tr>
<tr>
<td>9</td>
<td>WetOpen</td>
<td>9</td>
<td>Forest</td>
</tr>
<tr>
<td>10</td>
<td>WetTreed</td>
<td>9</td>
<td>Forest</td>
</tr>
<tr>
<td>11</td>
<td>Rock</td>
<td>10</td>
<td>Non-C 6</td>
</tr>
<tr>
<td>12</td>
<td>Snow</td>
<td>10</td>
<td>Non-C 5</td>
</tr>
<tr>
<td>13</td>
<td>Shadow</td>
<td>10</td>
<td>Non-C 5</td>
</tr>
<tr>
<td>14</td>
<td>Water</td>
<td>10</td>
<td>Non-C 5</td>
</tr>
<tr>
<td>15</td>
<td>Urban</td>
<td>10</td>
<td>Non-C 5</td>
</tr>
<tr>
<td>16</td>
<td>Road</td>
<td>11</td>
<td>Disturb 6</td>
</tr>
<tr>
<td>17</td>
<td>Cut0-2</td>
<td>12</td>
<td>Disturb 6</td>
</tr>
<tr>
<td>18</td>
<td>Cut03-12</td>
<td>13</td>
<td>Disturb 6</td>
</tr>
<tr>
<td>19</td>
<td>Burn</td>
<td>14</td>
<td>Disturb 6</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The original IDTA classification contains twenty habitat-related land cover classes. Due to errors and/or too much detail it was not suitable to use all twenty classes for the landscape structure analysis. The following outlines the reasoning for aggregating the classes into Cover Types (CT) that are mapped in Figure 5:

- The high incidence of confusion between Herb<18 and HerbRec made it logical to lump these similar life forms together into one Herb. For example, HerbRec had been misclassified within cut blocks and open wetlands. The association of HerbRec with mining was ignored for this landscape structure analysis, since the cover type is comparable in terms of bear foods.

- Due to similarity in the vegetation of wetland and riparian (and consequent overlap in their spectral classification) both WetOpen and WetTreed were grouped into a new wetland/riparian – WetRip – class.

- The nonhabitat cover types (i.e. cover types not containing bear food or cover) Rock, Snow, Ice, Water, and Urban were reclassed as NFC - No Food or Cover. The application of a landscape metric such as edge density would be meaningless between Rock and ice, for example.

- Road was kept separate in order to determine the effects of this class.

- The Urban class was miniscule and since it was deemed not important in terms of bear food and cover (Munro and Stenhouse, pers. comm.) it was lumped with the nonhabitat in NFC.
Figure 5. Cover Type (CT) map.
Figure 6. Life form/Disturbance (LD) map.
landscape area (TLA), class area (CA), number of patches (NUMP), mean patch size (MPS), patch size coefficient of variance (PSCOV), area weighted mean shape index (AWMSI), mean nearest neighbour (MNN), and interspersion-juxtaposition index (IJI); equations are given in Appendix A. For the investigations in this thesis, all landscape and class structure metrics available in Patch Analyst were selected for calculation and subsequent analyses.

4.4 Quantifying Grizzly Bear Habitat Structure

Proportional statistics were used to compare and contrast among the patch classification schemes by BMU. As previously mentioned, landscape metrics are sensitive to scale, and although some measures are standardized for area (e.g. ED, AWMSI) most are indices that cannot be directly compared. Indirect comparison can be made by assessing the proportional or percent differences and trends. In assessing the effect of attribute scaling, qualitative and quantitative observations were made for each attribute scaling method and were compared between the Brazeau and Gregg BMUs to determine if there was a trend of increasing or decreasing metric values. Percent differences among the landscape indices quantified the sensitivity of the spatial statistics to patch classification scheme. The prediction of bear density involved the multivariate statistical discriminant analysis and the comparison of BMU and home range structure used proportional trends in means. These analyses are described in the appropriate sections below.
4.4.1 Predicting Grizzly Bear Density using Landscape Metrics

Discriminant function analysis was used to predict bear density class from habitat structure as measured by landscape metrics (Figure 4). At first, all landscape-level metrics calculated by Patch Analyst were input as the independent variables for each of the three patch schemes. The dBase tables from Patch Analyst were imported into SPSS 9.0, a column for bear density was added and the appropriate value for each BMU entered. Discriminant analysis was selected and various sets of parameters were applied. Density was the grouping (dependent) variable and the landscape metrics were the predictors (independent variables).

The discriminating power of various combinations was examined and the set of metrics on a particular patch scheme achieving the highest classification accuracy was tested for independent accuracy on random BMUs. The first set evolved from combining the results from two initial discriminant functions. All metrics were entered into the analysis forwards and then backwards for each patch scheme. The SPSS discriminant function tested for variable tolerance, and after reaching the highest possible classification accuracy with the first successive set of variables it rejected the last remaining ones, which may or may not have been better predictors. Therefore, entering the variables backward allowed the function to apply these metrics in the discrimination. The first run (C12) used a combination of the variables from both runs that were common to all patch schemes (Table 8).
The second variable set, selected from a review of the literature, of 8 main metrics (M8) was entered into discriminant analysis for all patch schemes. Those, coincidentally, are the same as the statistically selected metrics above with the exception of the interspersion-juxtaposition (IJI) metric. It should be noted that mean patch fractal dimension (MPFD) was omitted due to complexity in interpretation for management applications.

From the above inputs, the highest classification accuracies were noted and the variable set and patch scheme of highest overall accuracy was assessed (Table 9) and used to test the power of the discriminant function in predicting bear density from landscape metrics. Ideally, BMUs not used in the initial analysis would have been desired for testing. Since these were not available, an independent accuracy assessment was performed: separate discriminant functions were run to test whether functions determined on 10 randomly-selected BMUs could accurately predict the 6 held-out BMUs.

4.4.2 Relating Habitat Structure of Home Ranges to BMUs

Determining the correspondence of habitat structure between BMUs and home ranges involved applying landscape metrics and statistically comparing the structure among BMUs and home ranges by assessing the proportional differences of means.

Both landscape and class level analyses were performed. The landscape analysis provides a general overview of the structure, while the class indices provide an
assessment of the landscape-level habitat structure results. Focus patches for the fragmentation analysis of BMUs are determined from the percentage of dominant cover types in the home ranges and amount of human disturbance classes in the BMUs.

Rather than using an extensive set of indices, four of the Main 8 metrics (M8) from the scientific literature were applied to the Cover Type (CT) reclassification of the IDTA (Table 2). The CT M8 patch scheme and metric set were found by discriminant analysis (Section 4.4.1) to be optimal in predicting bear density class and were targeted for closer analysis among BMUs and home ranges. These four metrics – number of patches (NUMP), mean patch size (MPS), edge density (ED), and mean nearest neighbour (MNN) – had the largest absolute correlations with bear density classes, and were calculated at both landscape and class levels for each area of analysis. Class area, converted to percentage of the landscape covered by each class, was utilized at the class level to quantify the amount of Cover Types in each area of analysis.

Proportional differences and means of the various metrics were used to compare and contrast among the areas of analyses. Although some measures are standardized for area (e.g. ED) most are indices that cannot be directly compared between different sized areas. Indirect comparison was made by assessing the proportional differences and the trends when the areas of analysis are ranked in order of increasing fragmentation. An increase in number of patches (NUMP), decrease in mean patch size (MPS), decrease in edge density (ED), and decrease in mean nearest neighbour (MNN) generally indicates increasing fragmentation. Qualitative and quantitative observations were made among BMUs, among home ranges, and between BMUs and home ranges. Aggregates
of the areas of analysis were averaged to assess the relative ranking of Foothill BMUs (FH), Mountain BMUs (MT), female home ranges, and male home ranges with respect to each other. Because the areas are not equal in size, relative differences among the landscape and class level indices quantified the relative correspondence of habitat structure among the areas of analysis when they were ranked.

4.5 Summary

Analyzing how landscape metrics respond to the base classification on which they are implemented is important when interpreting and determining which spatial metrics will be most ecologically significant in understanding the fragmenting effects of human activity upon the landscape, and ultimately on grizzly bear habitat. Three different patch schemes were applied to the 1999 IDTA, areas of analysis were clipped out using an overlay function, spatial metrics were calculated, and then statistics were used to analyze and answer the questions put forth by this thesis. Proportional trends were used to understand the effect of attribute scaling on two BMUs of comparable natural environment and known fragmentation. Discriminant analysis was applied to sets of metrics and patch scheme combinations to predict grizzly bear density class from BMU landscape structure. Proportional differences and means for the optimal predictor metrics were used to compare BMU and home range structure to determine which BMUs had landscape structure comparable to actual home ranges.
5.0 Results and Discussion

5.1 Introduction

The results of the spatial analyses are presented here with discussions on how they evaluate the hypotheses put forth by this thesis. First, the impact of the base classification upon which landscape metrics were applied is described and explained. Next, the two hypotheses are examined. The results from the discriminant analysis are analyzed with respect to the first hypothesis that landscape structure metrics may be able to predict grizzly bear density class. The landscape level and more detailed class level metrics are then evaluated among home ranges and BMUs to determine which BMUs are most similar to actual grizzly bear home range structure.

5.2 Effect of Attribute Scaling on Habitat Fragmentation

Upon selecting appropriate BMUs for comparison, the three patch schemes (Cover Type, Life form/Disturbance, and Vegetated and Nonvegetated) were analyzed for fragmentation information at the landscape level for each BMU.
5.2.1 BMU Selection

The BMUs that were selected for this portion of the analysis were chosen based on similarity in natural environment. Due to natural variability, each of the sixteen BMUs consists of differing proportions of ecoregions. The BMUs in the Rocky Mountains contrast with those in the Foothills with respect to the climate, geomorphology, soils, and vegetation, as well as human activity.

In order to confidently compare the landscape metric results, the two BMUs for analysis were selected based on similarities in natural environmental characteristics of geomorphology, soils, and vegetation. The selection process involved qualitative measures of the proportion of ecoregions (Strong and Leggat, 1992) within two BMUs of fairly equivalent areal extent in the Rocky Mountain Foothills portion of the GBRP study area. Visual observations of the ecoregions encompassed by each BMU showed that the Brazeau and Gregg River BMUs were constant in their natural environments: both consist of only subalpine and upper boreal cordilleran, and both were dominated by coniferous forest in the glaciated, sedimentary foothills.

The only difference between the BMUs was the contrasting amount of human resource extraction activities as observed in the “footprint” of related human disturbance classes. By consulting NTS map sheets, GIS coverages of human area features, and personal knowledge of the study area, it was determined that the Brazeau BMU visibly contained less human impact (e.g. roads, forest harvesting) than the Gregg BMU. The selected BMUs are in the Foothills portion of the study area since this is where the majority of
human activity occurs; the 400 km$^2$ Brazeau contains a little less human impact than the 398 km$^2$ Gregg. The Brazeau has minor amounts of forestry and roads, whereas the Gregg River has large cut blocks, an extensive open-pit coalmine, more roads, and a human-caused burn. Other nonhabitat areas, i.e. rock and water, are the most similar for both BMUs as compared to comparable BMUs in the Foothills.

5.2.2 Patch Type Maps and Landscape Metrics

Figures 5, 6, and 7 show the patch classification maps resulting from each attribute scaling method. For the selected BMUs: BRCT and GRCT (Figure 8a) are the Cover Type classifications of the Brazeau and Gregg BMUs respectively. BRLD and GRLD (Figure 8b) map major Life forms/Disturbances in both BMUs. BRVN and GRVN (Figure 8c) depict the simplification of attributes into habitat-related classes based on vegetation yielding the Vegetated and Nonvegetated designations for the Brazeau and Gregg.

A comparison of the patch class area statistics for the two BMUs is shown in Figure 9. The class compositions of the Brazeau and Gregg BMUs are described below for each of the three patch classification schemes (percent differences are noted in parentheses). The abbreviations of CT, LD, and VN are used to represent the attribute scaling methods.
Figure 8. Attribute scaling maps of Gregg and Brazeau BMUs: a) CT; b) LD; c) VN
Figure 9. Class area comparison for Brazeau and Gregg by patch scheme.
The main CT classification is composed of fourteen habitat-related cover types (Figure 9a). There are no Burn or Cut classes in Brazeau, but there are in Gregg (1.47% Burn, 2.21% Cut3-12, and 0.49% Cut0-2). Both BMUs have similar amounts (within 2.00%) of OpCon, OpDec, Shrub, and Road. The Brazeau consists of more CICon (16.40%), WetRip (5.60%), and NFC (5.81%) than the Gregg BMU. There are smaller amounts of CIDec (-6.47%), Mix (-9.09%), AlpSub (-2.88%), and Herb (-2.25%) in Brazeau compared to Gregg. The most abundant patch types of both BMUs are, in descending order, CICon, NFC, WetRip, OpCon, and Mix.

Figure 9b show the composition of six vegetation life forms and disturbance classes of the LD classification. There is relatively little disturbance class in Brazeau, but there is more in Gregg (-5.56% Disturb). The Herb, WetRip, and NFC classes remain unchanged from the GBHT scaling scheme. With the aggregation of the forest classes, the Brazeau and Gregg BMUs have similar amounts of this major life form (difference of less than 1.00%). The AlpSub class and Shrub classes of the GBHT scheme were combined into the Shrub major life form class. Brazeau has less area of these two classes (-4.30%). Again, the forested, wetland and NFC classes dominate the landscapes.

The scaling of classes into vegetated and nonvegetated patches in the VN classification is quantified in Figure 9c. Both BMUs contain higher proportions of vegetated than of nonvegetated. However, the area of each class is more or less equal for both BMUs.
Figure 10 graphically displays the basic habitat structure by patch classification scheme for the Brazeau and Gregg BMUs. For the most part, metrics applied to the Brazeau and Gregg BMUs respond as expected to the low or high human impact on the landscapes. The following descriptions of the landscape metric values are presented by classification and BMU.
Figure 10. Landscape structure comparison for Brazeau and Gregg.

- a) Number of Patches
- b) Mean Patch Size
- c) Patch Size Coefficient of Variance
- d) Edge Density
Figure 10. Landscape structure comparison for Brazeau and Gregg.
  
  e) Area Weighted Mean Shape Index
  f) Mean Nearest Neighbour
  g) Interspersion-Juxtaposition Index
Similar differences in patch number (NUMP), size (MPS), and coefficient of variance (PSCOV) are exhibited by the two BMUs across all patch types: there are fewer patches in the Brazeau and they are of greater size and variation than those in the Gregg (Figures 10a through 10c). Edge density (Figure 10d) is greater in Gregg than in Brazeau for the CT and VN schemes. The area weighted mean shape index (Figure 10e) has higher values, overall, in the Brazeau BMU; however, there are great proportional differences.

Patch number (NUMP), size (MPS), coefficient of variance (PSCOV), edge density (ED), and mean nearest neighbour (MNN) show constant, general trends in the response of the metrics to attribute scaling for both landscape types. As the number of attributes decreases from CT classes to binary VN types, the number of patches, variation, and edge density decrease (Figures 10c and 10d), while mean patch size and mean nearest neighbour increase (Figure 10b and 10f).

The trends in area weighted mean shape (AWMSI) and interspersion-juxtaposition (IJJI) indices vary with classification method, and the proportional difference between BMUs is inconsistent (Figures 10e and 10g). Metric sensitivity is exhibited in the scaling from CT to LD, and varies by spatial metric. Figure 10e shows that the area weighted mean shape index for Gregg decreases in value as the number of attributes decreases, but for Brazeau the value both increases and decreases. The interspersion-juxtaposition index (Figure 10g) has an opposite trend in values between BMUs – lower in Brazeau than in Gregg – but the proportional increases and decreases are greater for certain
classification schemes in the Brazeau BMU. The anomalies in the trends are the main focus of the discussion below.

5.2.3 Comparison of Brazeau and Gregg

For the most part, metrics applied to the Brazeau and Gregg BMUs respond as expected to the low versus high human impact on the landscape. Regardless of attribute scaling, the lower human-impacted BMU of Brazeau has patches that are fewer and larger-sized, with less edge, more complex in shape, less varied in type, and less evenly distributed in the landscape than the higher human-impacted Gregg. This is highly indicative of the landscape fragmentation effects that are more prevalent in Gregg.

The attribute scaling methods represent decreasing landscape heterogeneity from the CT through VN classification schemes. The importance of how much a particular patch type contributes proportionally to the landscape composition is dependent on the ecological application (McGarigal and Marks, 1995) and therefore on the attribute scaling method to be used (e.g. cover versus habitat types). The landscape metrics indeed show sensitivity to attribute scaling, as evidenced in the measures of class area and anomalies in six of the structure indices.

How much a particular patch type dominates the landscape is measured by class area, which when assessed over time becomes an important indicator of habitat loss (McGarigal and Marks, 1995). Class area (CA) metric differences in the Brazeau and Gregg River BMUs may be partially due to natural differences in the landscapes, and
partially due to possible misclassifications. These differences may be compounded or
diluted with class aggregation. For example, aggregating NFC with the disturbance
classes will likely result in higher levels of fragmentation information if one BMU has
more water bodies present than another – as is the case when the VN scheme is applied
showing similar structure for both BMUs.

Gregg River has an extensive forest harvesting history; therefore, there are high
amounts of forest regeneration of varying ages that may have been spectrally classified
as a number of different cover types. The young regeneration areas contain mostly
herbs, shrubs and some amount of faster growing deciduous trees, interspersed with
planted conifers. The older regeneration areas consist of more mature deciduous and
mixedwood stands. This overlap in composition of classes may contribute to the higher
proportions of herb, shrub, deciduous, and mixedwood in Gregg (Figure 9a). Brazeau
has a much higher proportion of conifers, most likely due to the lower harvesting rates
relative to Gregg. Overall, the dominant cover types of conifer and wetland/riparian in
both BMUs are consistent with cordilleran and boreal conditions.

The LD scheme exhibits the compounding effects of attribute scaling on class area. The
proportional differences in the Herb, WetRip, and NFC classes are the same as
previously mentioned (Figure 9b). Slightly higher forest in Brazeau is likely due to less
harvesting. The greater amount of Herb class in the Gregg River BMU is mainly from
extensive areas of herbaceous reclamation associated with the mine. As well, the more
numerous herb and shrub areas may be attributed to forest harvesting: regeneration in
cut blocks and along roadsides. The higher amount of NFC habitat class in Brazeau is
due to naturally greater amounts of rock and water in the landscape.

Figure 9c further demonstrates the effects of class aggregation. The more vegetated
values result from the dominant cover types of Forest and WetRip and are fairly similar
for both BMUs. There is not much class compositional difference between BMUs using
this attribute-scaling scheme. Therefore, the binary classes may be too general for any
ecological application.

Class area (CA), along with patch number (NUMP) and size (MPS), help explain why the
landscape structure metrics examined vary in their response to attribute scaling and
fragmentation. Overall, the greater number of patches (NUMP) in the Gregg River
means it has a finer-grained more heterogeneous landscape than the Brazeau (Figure
10a). However, as attribute scaling decreases, the number of patches becomes fewer
and more similar for both BMUs. The ecological meaning of fewer patches means a
more homogeneous landscape and less structural difference between BMUs. The
inverse occurs with mean patch size – it increases – as attribute scaling decreases
(Figure 10b). Smaller patch size is consistent with a higher number of patches in the
Gregg River BMU and vice versa for the Brazeau.

Variability in patch size (PSCOV) shows a general trend in response to differences in
landscape fragmentation and in attribute scaling (Figure 10c). The huge proportional
difference from the LD to VN schemes is striking, and is a function of the aggregation of
vegetation life form types into Vegetated resulting in a larger jump in mean patch size
A direct comparison of this relative measure shows higher variability in Brazeau than Gregg. Mean patch size of the VN is larger in Brazeau than in Gregg. The proportional increase in mean patch size for Gregg is similar to Brazeau and results in lower variability of the aggregated classes.

The edge index (ED) exhibits moderate sensitivity to attribute scaling. Edge density (Figure 10d) is higher on average in Gregg than Brazeau; this results from the higher number of patches having larger perimeters divided by smaller patch size, and supports the interpretation of higher fragmentation in this landscape (McGarigal and Marks, 1995). There is a general decreasing trend in edge density with decreasing attribute scaling. However, the difference between Brazeau and Gregg is reversed in the LD scheme. It could be interpreted that Brazeau is more fragmented than Gregg because of the higher edge density at this level. The VN scheme indicates a very small edge density resulting from fewer patches of larger size.

The area weighted mean shape index (AWMSI) is quite variable in response to patch classification scheme and level of fragmentation. Patch shape is important because the complexity may influence animal foraging strategies (Forman and Godron, 1986). The shape index (Figure 10e) shows regularity or how most like a square the patches are when values are close to one; values greater than one indicate the more complex shapes of low human influence (McGarigal and Marks, 1995). As attribute scaling decreases, patch shape becomes more regular. The trend between BMUs is as expected: more shape irregularity in the Brazeau than the fragmented Gregg. The aggregation effect on the human disturbance classes in the Gregg LD and VN may be
the cause for the decrease in shape complexity relative to the Brazeau. This indicates that the larger patches are more regular in shape than the average. Patches are most complex at the LD and least complex at the VN classification schemes in both BMUs. Across all schemes, Brazeau area weighted mean shape indices are higher than the Gregg; the higher Brazeau values indicate more complex shapes. In this case, attribute scaling does not dilute the effects of fragmentation differences between the BMUs. However, the large change from the CT to LD schemes appears to be exaggerated when comparing this metric between the low and high human impacted BMUs.

Interspersion-juxtaposition index (IJI) cannot be applied to maps of less than three patch types, such as the two-class VN; therefore, the response of this metric to attribute scaling is restricted to analyzing the CT and LD schemes only (Figure 10f). Higher values, as seen in Gregg, indicate patch types that are more interspersed and equally adjacent to each other. Fragmented landscapes are expected to have higher IJI values (McGarigal and Marks, 1995). There is no trend observed when comparing IJI results in the two BMUs. In Brazeau, IJI values decrease with decreasing patch types, whereas in Gregg, IJI shows an increase. In this admittedly limited example of only two BMUs, it appears that IJI is sensitive to attribute scaling, but in either case is still able to indicate differences in the level of landscape fragmentation.
5.3 Optimal Landscape Metric Predictors of Grizzly Bear Density

Class

The three different patch schemes (CT, LD, and VN) are analyzed for strength of landscape structural relationship to bear density (Table 8). The best discriminant results are found by using the M8 metrics on the CT scheme and the C12 metrics on the VN scheme. Discriminant functions respond better to fewer independent variables, therefore the relatively more accurate M8 metric set calculated on the CT patch scheme is selected for further analysis and independent accuracy testing.

Table 8. Classification results of the discriminant function analyses for predicting bear density.

<table>
<thead>
<tr>
<th>Variable Sets</th>
<th>Description</th>
<th>Landscape Metrics (Variables)</th>
<th>Classification (n=16) Accuracies per Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>C12 Combined 12</td>
<td>Common metrics from entering all forward and backward</td>
<td>TLA, NUMP, MPS, PSCOV, PSSD, TE, ED, MSI, AWMSI, MPPD, MN, LPI</td>
<td>81.3 87.5 93.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 df = 22 1 df = 24 1 df = 22</td>
<td>Sig = .710 Sig = .938 Sig = .456</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 df = 10 2 df = 11 2 df = 10</td>
<td>Sig = .722 Sig = .945 Sig = .616</td>
</tr>
<tr>
<td>M8 Main 8</td>
<td>Main metrics selected from literature</td>
<td>TLA, NUMP, MPS, PSCOV, ED, AWMSI, MNN, LPI</td>
<td>93.8 81.3 87.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 df = 16 1 df = 16 1 df = 14</td>
<td>Sig = .331 Sig = .596 Sig = .465</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 df = 7 2 df = 7 2 df = 6</td>
<td>Sig = .370 Sig = .685 Sig = .707</td>
</tr>
</tbody>
</table>

Notes: CT = Cover Type; LD = Life form/Disturbance; VN = Vegetated and Nonvegetated
No variables qualified for stepwise analysis; results are for independents entered together
Degrees of freedom (df) and significance (Sig) are indicated for functions 1 and 2

Using the first two discriminant functions results in 93.8% of original grouped cases being correctly classified. The first function separates high density BMUs from low and
medium cases by relying on the highly correlated ED and MPS (Figure 11 and Table 9); the second function separates low from medium BMUs using MNN and PSCOV. The means and standard deviations indicate less fragmentation in BMUs having both lower ED and greater MPS – these same BMUs have high bear density as classified by the first function. These statistics also show more fragmentation in BMUs having greater PSCOV and MNN, which the second function classifies into low bear density, thereby discriminating these cases from medium density. The randomly split BMU test samples achieve 80% to 100% independent accuracies (Table 10).

Table 9. Structure matrix for the variables used in the discriminant function analysis of CT M8.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Function</th>
<th>Bear Density Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>ED</td>
<td>0.295*</td>
<td>0.216</td>
</tr>
<tr>
<td>MPS</td>
<td>-0.186*</td>
<td>0.183</td>
</tr>
<tr>
<td>MNN</td>
<td>0.032</td>
<td>0.037*</td>
</tr>
<tr>
<td>NUMP</td>
<td>0.203</td>
<td>-0.276*</td>
</tr>
<tr>
<td>PSCOV</td>
<td>0.034</td>
<td>0.251*</td>
</tr>
<tr>
<td>AWMSI</td>
<td>0.092</td>
<td>0.144*</td>
</tr>
<tr>
<td>TLA</td>
<td>-0.101</td>
<td>-0.127*</td>
</tr>
<tr>
<td>Jill</td>
<td>-0.058</td>
<td>-0.094*</td>
</tr>
</tbody>
</table>

Largest absolute correlation between each variable and any discriminant function

The three patch schemes are used to help select the optimal predictor metrics. Metrics are sensitive to scaling and often redundant in information (Elkie et al. 1999, McGarigal and Marks 1995, Ritters et al 1995). Discriminant functions respond better if fewer metrics can predict bear density on fewer patch types. The highest accuracies (93.8%) resulted from applying several metrics to few patch types (VN C12) and fewer metrics on several patch types (CT M8). The utility of having the more detailed CT patches in the
overall baseline analysis of habitat structure resulted in selecting the CT M8 variable set over the VN C12 set.

Grizzly bear density class estimates within a BMU are shown by discriminant analysis to be predictable using some combination of landscape structure metrics. Except for TLA and the IJI, there is no direct trend in the group statistics of each variable in relation to the density classes. Larger landscapes with greater patch adjacency are expected to support higher bear densities. Incidentally, these two metrics have very low absolute correlation with both discriminant functions. However, the nature of the discriminatory power of each function is supported by differences in magnitude of the metric variables having high correlations with each of the two functions.

Table 10. Testing of discriminant functions on randomly filtered cases.

<table>
<thead>
<tr>
<th>% Classification Accuracies</th>
<th>CT M8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select RANDOM 10 of 16 (6 BMUs tested)</td>
<td>n=6</td>
</tr>
<tr>
<td>Run A</td>
<td>(Maskuta, Pembina, Gregg, Isaak, Fiddle, Upper Rocky)</td>
</tr>
<tr>
<td>100.0</td>
<td>80.0</td>
</tr>
<tr>
<td>Run B</td>
<td>(Fiddle, Upper Rocky, Beaverdam, Lovett, Southesk, Restless)</td>
</tr>
<tr>
<td>83.3</td>
<td>80.0</td>
</tr>
<tr>
<td>Run C</td>
<td>(Beaverdam, Lovett, Southesk, Isaak, Medicine Tent, Brazeau)</td>
</tr>
<tr>
<td>83.3</td>
<td>100.0</td>
</tr>
<tr>
<td>Run D</td>
<td>(Beaverdam, Medicine Tent, Brazeau, Upper Rocky, Maskuta, Whitehorse)</td>
</tr>
<tr>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>% Classification Accuracies</td>
<td>CT M8</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>Select RANDOM 12 of 16 (4 BMUs tested)</td>
<td>n=4</td>
</tr>
<tr>
<td>Run A</td>
<td>(Southesk, Fiddle, Pembina, Gregg)</td>
</tr>
<tr>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Run B</td>
<td>(Gregg, Maskuta, Whitehorse, Restless)</td>
</tr>
<tr>
<td>75.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Run C</td>
<td>(Maskuta, Pembina, Medicine Tent, Brazeau)</td>
</tr>
<tr>
<td>83.3</td>
<td>100.0</td>
</tr>
<tr>
<td>Run D</td>
<td>(Medicine Tent, Brazeau, Whitehorse, Cardinal)</td>
</tr>
<tr>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>
The 80% to 100% test accuracies are very close to the 93.8% accuracy for the entire sample. Fiddle BMU is shown to have low bear density in Figure 11, but the DNA hair-snag results may have underdetermined the bear density for this landscape having low fragmentation as indicated by the metrics; discriminant analysis predicts that it should be high or medium density. The high percent of cases grouped by bear density that are correctly classified, when using all BMUs and when testing random 6 from 10, show that low, medium, and high bear density classes are predictable from selected landscape metrics. The less fragmented BMUs have metric values that predict greater bear density. This supports the expectation that grizzly bears prefer to frequent areas that are not highly fragmented.

Figure 11. Scatterplot of group centroids of the first two discriminant functions.
5.4 Comparison of Habitat Structure Among Home Ranges and BMUs

The following sections take a closer look at the four metrics that were highly correlated with bear density: number of patches (NUMP), mean patch size (MPS), edge density (ED), and mean nearest neighbour (MNN). Each of these metrics is examined with a view to seeing their differences between Foothill BMUs (FH) and Mountain BMUs (MT), and between male and female home ranges. The results assess which BMUs and what geographic areas most closely correspond to the habitat actually within individual bear home ranges. Metrics at the landscape level are discussed (Section 5.4.1) and then further analyzed at the class level (Section 5.4.2).

5.4.1 Landscape-Level Assessment

Each landscape or area of analysis is different in size (Figure 12a). On average, the male home ranges are almost three times larger than female home ranges, and even greater than any of the BMUs. Except for G003, the female home ranges are also larger than the BMUs. The BMUs range from just under 19,000 to over 43,500 hectares. The combined Foothill (FH) BMUs are approximately equal in area to that of Mountain (MT) BMUs. Due to the higher amount of human activity in the FH BMUs, greater fragmentation as indicated by the spatial metrics is expected, as compared to MT BMUs. This is indeed the general trend as shown in Figure 12; each chart has areas of lower fragmentation at bottom and progresses to higher at top.
Figure 12. CT landscape-level metrics
a) Class Area (percent of landscape)
b) Number of Patches
c) Mean Patch Size (hectares)
d) Edge Density (meters/hectare)
e) Mean Nearest Neighbour (meters)

**LANDSCAPE LEVEL**

Mountain BMU  Female Home Range MCP
Foothills BMU  Male Home Range MCP
Male home ranges have the highest number of patches (NUMP) – almost 39,000 – indicating that male grizzlies utilize a diverse habitat (Figure 12b) within the largest areas of analysis (Figure 12a). Female home ranges, being smaller than male home ranges, contain as expected an intermediate number of patches. Female home ranges are more similar to the MT BMUs in number of patches. The FH BMUs have more patches than the MT BMUs; since the FH and MT BMUs are similar in areal extent, the greater number of patches indicates higher fragmentation and a more diverse landscape within the Foothills than in the Mountains.

Mean patch size (MPS) shows a trend comparable to NUMP (Figure 12c). The male home ranges have the smallest patch sizes. The FH BMUs are most similar to male home ranges (AveFH = 4.01 ha; AveM = 3.81 ha). The MT BMUs and female home ranges generally have the largest patches in the study area (AveMT = 6.42 ha; AveF = 6.22 ha).

The greatest amount of edge density (ED) is seen in the FH BMUs and male home ranges (Figure 12d). These areas of analysis are also very similar on average (AveFH = 109.69 m/ha; AveM = 107.44 m/ha). The MT BMUs and female home ranges have less edge (AveMT = 76.67 m/ha; AveF = 75.59 m/ha).

The more fragmented a landscape, the greater the mean distance from the edge of one patch to the edge of the nearest patch of the same class (McGarigal and Marks, 1995). This is more relevant when the patch type is related to habitat. Mean nearest neighbour
(MNN) measures the greatest average distance between patches and shows that the FH BMUs are the most fragmented (Figure 12e). The MT BMUs are intermediate in inter-patch distances (AveFH = 96.04 m; AveMT = 93.33 m). The female home ranges are very similar to the MT BMUs (AveF = 92.25 m). On average, the male home ranges contain the lowest distances between patches (AveM = 89.40 m). There is low variation in MNN values, which range from 82.10 – 115.60 meters.

The most highly fragmented BMUs in the Foothills are the Gregg (GR), McLeod (MC), Beaverdam (BE), and Lovett (LO); in the Mountains the Fiddle (Fl) and Lower Rocky (LR) are most fragmented. Not surprisingly, these particular BMUs occur near the towns and major roads of the study area. The least fragmented BMUs are the Cardinal (CA), Brazeau (BR), and Pembina (PE) in the Foothills, and the Restless (RE), Medicine Tent (MT), Southesk (SO), and Isaak (IS) in the Mountains.

NUMP, MPS, and ED metric values for the female home ranges indicate low fragmentation. Intermediate values for MNN are likely due to greater inter-patch distance caused by separation of habitat areas by expanses of rock (see section 5.4.2). The female individuals in this study area appear to have landscape structure within their home ranges that are most comparable to the more isolated and less human-impacted Mountain BMUs.

The average male home range structure shows great fragmentation with high values in NUMP, MPS, and ED. However, AveM home ranges have the lowest MNN. The large areal extent of male home ranges means that they have the capacity to contain more
patches, which leads to greater edge density. The large number of smaller patches with greater amount of edge means that the home range structure is highly fragmented. The presence of a bear may be facilitated by the shorter inter-patch distance indicated by MNN.

A more diverse landscape (i.e. more fragmented with a greater number of smaller patches) implies shorter distances between patches. Other landscape metrics, such as Shannon’s Diversity and Evenness Indices, may provide further clues to interpreting the inter-patch trends shown here (McGarigal and Marks, 1995). The reverse interpretation may help explain why some of the least fragmented BMUs in the Foothills and Mountains (Figure 12e) have the greatest distances between patches: less diverse landscapes may have greater distances between similar patches because there are larger patches interspersed between them. Section 5.4.2 discusses the patch class composition and provides more data to explain the MNN anomaly.

5.4.2 Class-Level Assessment

A comparison of the structure for each cover type attribute class as mapped for each area of analysis is contained in Figure 13. The Patch Analyst FragStats Interface calculates spatial metrics at the class-level by treating each set of attribute patches as the focal class within a matrix of all the other attribute classes combined (McGarigal and Marks, 1995). The patch types that will receive focus because they represent greater percentages of the landscape are closed conifer (CiCon), mixed (Mix), open conifer (OpCon), alpine/subalpine (AlpSub), shrub (Shrub), wetland/riparian (WetRip), no
food/cover (NFC), and the disturbance classes. The deciduous (CIDec and OpDec) and herbaceous (Herb) classes comprise very little of the study area overall and are not considered further.

The following discussion describes and explains the general trends and differences among the structural metric values for each Cover Type within the areas of analysis. Values of zero indicate that the cover type is either not present in the area of analysis (e.g. %LAND = 0.00%; ED = 0.00) or very few, small patches exist (e.g. NUMP = 1; MPS < 1). Zero for MNN indicates that the patch type is nonexistent or there is only one patch of that Cover Type.
Figure 13a. CT patch class-level metrics
i) Class Area (percent of landscape)
ii) Number of Patches
iii) Mean Patch Size (hectares)
iv) Edge Density (meters/hectare)
v) Mean Nearest Neighbour (meters)

ClCon
Figure 13b. CT patch class-level metrics
i) Class Area (percent of landscape)
ii) Number of Patches
iii) Mean Patch Size (hectares)
iv) Edge Density (meters/hectare)
v) Mean Nearest Neighbour (meters)

CIDec
Figure 13c. CT patch class-level metrics

- Class Area (percent of landscape)
- Number of Patches
- Mean Patch Size (hectares)
- Edge Density (meters/hectare)
- Mean Nearest Neighbour (meters)

Mountain BMU
Foothills BMU

Female Home Range MCP
Male Home Range MCP
Figure 13d. CT patch class-level metrics

i) Class Area (percent of landscape)
ii) Number of Patches
iii) Mean Patch Size (hectares)
iv) Edge Density (meters/hectare)
v) Mean Nearest Neighbour (meters)
Figure 1. CT patch class-level metrics

1. Class Area (percent of landscape)
2. Number of Patches
3. Mean Patch Size (hectares)
4. Edge Density (meters/hectare)
5. Mean Nearest Neighbour (meters)

Mountain BMU
Foothills BMU
Female Home Range MCP
Male Home Range MCP
Herb
Figure 13g. CT patch class-level metrics

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>i)</td>
<td>Class Area (percent of landscape)</td>
</tr>
<tr>
<td>ii)</td>
<td>Number of Patches</td>
</tr>
<tr>
<td>iii)</td>
<td>Mean Patch Size (hectares)</td>
</tr>
<tr>
<td>iv)</td>
<td>Edge Density (meters/hectare)</td>
</tr>
<tr>
<td>v)</td>
<td>Mean Nearest Neighbour (meters)</td>
</tr>
</tbody>
</table>

Mountain BMU

Female Home Range MCP

Male Home Range MCP
Figure 13h. CT class level metrics

i) Class Area (percent of landscape)
ii) Number of Patches
iii) Mean Patch Size (hectares)
iv) Edge Density (meters/hectare)
v) Mean Nearest Neighbour (meters)

Shrub
Figure 13b. C7 patch class-level metrics
(i) Class Area (percent of landscape)
(ii) Number of Patches
(iii) Mean Patch Size (hectares)
(iv) Mean Nearest Neighbour (meters)
(v) Mean Nearest Neighbour (meters)

Shrub
Figure 13i. CT patch class-level metrics

i) Class Area (percent of landscape)
ii) Number of Patches
iii) Mean Patch Size (hectares)
iv) Edge Density (meters/hectares)
v) Mean Nearest Neighbour (meters)
Figure 13j. CT patch class-level metrics

i) Class Area (percent of landscape)
ii) Number of Patches
iii) Mean Patch Size (hectares)
iv) Edge Density (meters/hectare)
v) Mean Nearest Neighbour (meters)
Figure 13k. CT patch class-level metrics

i) Class Area (percent of landscape)

ii) Number of Patches

iii) Mean Patch Size (hectares)

iv) Edge Density (meters/hectare)

v) Mean Nearest Neighbour (meters)

Road
Figure 131. CT patch class-level metrics
i) Class Area (percent of landscape)
ii) Number of Patches
iii) Mean Patch Size (hectares)
iv) Edge Density (meters/hectare)
v) Mean Nearest Neighbour (meters)
Figure 13m. CT patch class-level metrics

<table>
<thead>
<tr>
<th>Class</th>
<th>Area (percent of landscape)</th>
<th>Number of Patches</th>
<th>Mean Patch Size (hectares)</th>
<th>Edge Density (meters/hectare)</th>
<th>Mean Nearest Neighbour (meters)</th>
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</thead>
<tbody>
<tr>
<td>Mountain BMU</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Foothills BMU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female Home Range MCP</td>
<td></td>
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</tr>
</tbody>
</table>

Cut3-12
### Class Area (percent of landscape)

- **Class Area (percent of landscape)**

### Number of Patches

- **Number of Patches**

### Mean Patch Size (hectares)

- **Mean Patch Size (hectares)**

### Edge Density (meters/hectare)

- **Edge Density (meters/hectare)**

### Mean Nearest Neighbour (meters)

- **Mean Nearest Neighbour (meters)**

---

**Figure 13.** CT patch class-level metrics

- (i) Class Area (percent of landscape)
- (ii) Number of Patches
- (iii) Mean Patch Size (hectares)
- (iv) Edge Density (meters/hectare)
- (v) Mean Nearest Neighbour (meters)

**Burn**

**Mountain BMU**

**Foothills BMU**

**H Female Home Range MCP**

**22 Male Home Range MCP**
Compositionally, the coniferous forest, AlpSub, WetRip, and NFC classes dominate the study area (Figures 13.a.i, 13.d.i, 13.g.i, 13.i.i, and 13.j.i). CICon is the dominant cover type in the Foothill BMUs at over 45%; it is intermediate in male home ranges (approximately 40%) and not as important in female home ranges (about 20%). There is a smaller amount of CIDec in the study area, with most of it occurring in the FH BMUs (around 5%) and the male home ranges. The quantity of Mix is highly variable among the areas of analysis, but is somewhat important for male home ranges and in the FH BMUs. OpCon is important in almost all bear home ranges (around 5%), except for G003 and G010 that remain at higher alpine elevations. There is more OpCon in the FH BMUs (5-10%) than in the MT BMUs. There is not a lot of OpDec and Herb mapped, but what exists appears primarily in male home ranges in the FH BMUs. AlpSub occurs primarily in the MT BMUs and makes up over 10% of female home ranges. Shrub is most concentrated in female home ranges and in the MT BMUs. WetRip is more prevalent in the FH BMUs (10% or greater) and makes up over 9% of male home ranges. NFC, which is mostly rock and ice, is the most abundant nonvegetated class: 30-60% in the MT BMUs and female home ranges, and 10-20% in male home ranges. The disturbance classes, which make up a relatively small proportion of the overall study area (up to 4%), occur in the Foothills and to a lesser extent in the male home ranges. Only three female home ranges contain Road (G004, G016, and G003 at less than 1% each). The cut classes dominate the same BMUs as CICon, but only the older Cut3-12 occupies a higher proportion of male home ranges (less than 3%). Only two BMUs in the Foothills have as much as 1% Burn; the Burn is in the male G005 home range.
There are generally more numerous patches of all Cover Types in the male home ranges and FH BMUs (Figures 13.a.ii-13.n.ii). This is because the male home ranges are the largest areas of analysis (Figure 13) and the FH are both more diverse in composition and more fragmented by human activities. Most AlpSub and Shrub patches occur in home ranges, fewer occur in MT BMUs, and the least in FH BMUs. This landscape measure is absolute rather than relative to area, and so cannot be directly compared among the areas of analysis and provides only a general overview of fragmentation based on patch number.

Mean patch size (MPS) is essentially the inverse of patch density (the number of patches per unit area) and can be compared among the areas of analyses as a relative measure. Larger patches generally indicate lower fragmentation. Figures 13.a.iii-13.n.iii show that the forested and Herb class patches occupy a larger percentage in the FH BMUs and male home ranges. OpCon, AlpSub, and WetRip patches are comparatively larger in the female home ranges. There are many smaller WetRip and Shrub patches within male home ranges.

The edge density (ED) metrics show very similar trends to those of class area as a percentage of the landscape (%LAND) and NUMP (Figures 13.a.iv-13.n.iv). The forested, Herb, and WetRip classes dominate the male home ranges and FH BMUs; therefore, the amount of edge corresponding to these classes is similarly high. AlpSub, Shrub, and NFC classes have the most amounts of edge in the female home ranges and MT BMUs.
The mean nearest neighbour (MNN) statistics indicates greater inter-patch distances within FH BMUs and male home ranges over the majority of patch classes (Figures 13.a.v-13.n.v). Two exceptions of note are that MNN is less for the CICon and WetRip classes in the FH BMUs and male home ranges. Upon comparison to the BMUs, the male and female home ranges have relatively low MNN for the OpCon, AlpSub, Shrub, and WetRip classes.

The disturbance-related Cover Types of Road, Cuts, and Burn compose proportionately smaller areas of the landscape: well under 5% each (Figures 13.1-13.n). However, these patch types are significant in assessing fragmentation of the landscape. The NUMP statistic indicates more disturbance patches in the FH BMUs and male home ranges. MPS of the Road class is based on the mean of all road patches within the area of analysis; therefore, the fewer the number of roads, the relatively larger this index is. For example, the Fiddle (Fl) BMU has only one road mapped in the Cover Type classification, and shows up as having the greatest MPS. MNN shows that those FH and MT BMUs that are less fragmented have the longest inter-patch distances (or is zero where the Cover Type does not exist or has only one patch). The more fragmented FH BMUs have shorter MNN. This is due to the spatial clustering of human activities – especially forest cut blocks. The male home ranges that contain the disturbance classes have intermediate MNN distances between Road patches and Cut3-12 patches and the largest MNN for the Cut0-2 class.

BMUs containing proportionately more forest, AlpSub, WetRip and fewer disturbances correspond most closely to the habitat structure of the individual grizzly bear home
ranges under investigation. However, BMUs based on average female home range size of 300-400 square kilometers may not be adequate for general bear habitat requirements, which must take both female and male home ranges into account. This theoretical average may not be applicable in this study area.

The MT BMUs are structurally similar to female home ranges; these BMUs are inside Jasper National Park and therefore, there is no immediate threat of further fragmentation by the human activities of forestry and road building. The FH BMUs are structurally similar to male home ranges. The two male individuals have some disturbance class patches within their large home ranges, but proportionately less than the highly fragmented BMUs surrounding them. The BMUs that are most fragmented by human activities are the McLeod (MC), Gregg (GR), Pembina (PE), Lovett (LO), Maskuta (MA), and Beaverdam (BE). The other FH BMUs appear to be less fragmented and would be structurally appropriate for inclusion within male home ranges. The Mountain BMUs of Fiddle (Fi) and Lower Rocky (LR) are structurally similar to the Foothill BMUs and show signs of being fragmented.

5.5 Summary

The three patch classification schemes applied to the IDTA map exhibited various responses to landscape metrics within the BMUs of low fragmentation (Brazeau) and high fragmentation (Gregg). Mean patch size (MPS), patch size coefficient of variance (PSCOV), and mean nearest neighbour (MNN) were shown to not be sensitive to
attribute scaling for the Brazeau and Gregg landscapes. Number of patches (NUMP) and edge density (ED) displayed moderate sensitivity, and area weighted mean shape index (AWMSI) and interspersion-juxtaposition index (IJI) exhibited the highest sensitivity to attribute scaling. At the Cover Type aggregation level, the metrics quantified the fragmentation as expected: the lesser disturbed Brazeau had fewer, larger, more variable, more complex shaped patches with less edge than the Gregg BMU. The LD scheme showed variable response in metric values and the dilution of information at the VN level makes this scheme not valuable for land management. The CT patch classification scheme was also optimal in the discriminant analysis. The Main 8 metrics (determined from the scientific literature) as applied to the CT patch classification scheme predicted grizzly bear density estimates with 93.8% accuracy. These metrics quantified the proportional differences in landscape structure among BMUs and home ranges. Female home ranges have comparable structure to BMUs in the Mountains. Male home ranges, which are large in size overlap both Foothills and Mountain BMUs, but are most similar in structure to BMUs in the Foothills, indicating that their large size may be able to compensate for disturbance patches.
6.0 Conclusion

6.1 Summary of Major Findings

Analyzing the sensitivity of landscape metrics to the level of patch aggregation on which they are implemented will aid in determining which spatial statistic calculations and which patch classification scheme will be most ecologically significant in understanding the landscape-level effects of human activity upon grizzly bear habitat. Mean patch size (MPS), patch size coefficient of variance (PSCOV), and mean nearest neighbour (MNN) have been shown not to be sensitive to differences in attribute scaling for the Brazeau and Gregg landscapes. They responded as expected between low and high fragmentation landscapes with a clear trend as the attributes decreased. Number of patches (NUMP) and edge density (ED) displayed moderate sensitivity in the expected response to fragmentation due to attribute scaling effects. Area weighted mean shape index (AWMSI) and interspersion-juxtaposition index (IJI) exhibited the highest sensitivity to attribute scaling, and also displayed differences in the way they responded to fragmentation.

The metrics examined in this study respond to differences in level of fragmentation. Five of the metrics indicated sensitivity to attribute scaling and should be applied with caution; the other three show "predictable" trends and may be applied with more confidence in how they respond to fragmentation. In some cases, the metrics show constant response
to fragmentation effects with no regard to attribute scaling; in other cases, the metrics are more sensitive to attribute scaling than to differences in the human impact on landscapes. Generally, fragmentation (as indicated by dispersal of isolated and small-sized patch types throughout the landscape) is seen as similar patterns in all attribute-scaling methods. The Brazeau has less fragmentation than the Gregg River, and the more aggregated and general the classification, the more visible the differences are between the two BMUs. As in all data representations, interpretation must be made with caution since how the data are classified will affect how they get interpreted. The LD patch classification scheme is a good example since the originally dominant cover types will impart heavier weight to the more general habitat classes. Aggregation of the classes may result in more structurally different patch types that are more ecologically meaningful, but too much generalization may dilute the effects of important patch types and have a profound impact on landscape metric response.

Discriminant function analysis has been shown to predict grizzly bear density classes from landscape structure metrics in the Foothills Model Forest Grizzly Bear Research Project 1999 study area containing sixteen Bear Management Units. The main purpose of discriminant function analysis is to determine the dimensions along which groups differ and to predict group membership through classification. The first discriminant function enables separation of High bear density groups from Low and Medium groups; the second function separates Low from medium bear densities. This research has also found the most optimal landscape metrics for use in grizzly bear habitat analysis for the FMF GBRP study area. The high percent of cases grouped by bear density that were correctly classified using all sixteen BMUs, testing random 6 from 10, and testing
random 4 from 12 show the predictability of Low, Medium, and High bear density classes from the following set of landscape metrics: total landscape area (TLA), number of patches (NUMP), mean patch size (MPS), patch size coefficient of variance (PSCOV), edge density (ED), area weighted mean shape index (AWMSI), mean nearest neighbour (MNN), and interspersion-juxtaposition index (UII). Provided the density classes are appropriate, the results show a range of original grouped cases correctly classified, with an overall accuracy of 93.8%.

The discriminatory power of the functions applied to this data set resulted from systematic testing of sets of independent variables. Three sets of landscape metrics that were selected from the standard output of Arc View’s Patch Analyst were examined. Better discrimination, i.e. accuracy higher than the lowest random test result of 89.6%, may be attained through the incorporation of alternative metric variables not tested here. A larger population of cases may improve upon the robustness of this methodology. How to predict the bear density group that an unknown BMU probably belongs to can be seen in interpreting Figure 11; the unknown BMU would be categorized as whichever cluster or group centroid the unknown’s functions are closest to. Future research could also build on the predictive ability of the discriminant functions in a temporal analysis of grizzly bear densities, through “what if” scenarios that alter the habitat structure based on resource extraction agendas. For example, change in the landscape structure of a BMU could be modeled and a new bear density class predicted from discriminant function analysis.
The discriminant functions support the use of the Main 8 metrics in further analyses of landscape structure. The four metrics having the highest absolute correlations with each function were assessed among BMUs and home ranges to find similarities and determine which BMUs were most like actual grizzly bear home ranges. The proportional differences among number of patches (NUMP), mean patch size (MPS), edge density (ED), and mean nearest neighbour (MNN) for the areas of analysis showed that female home ranges are comparable to BMUs in the Mountains, and male home ranges are most similar to Foothill BMUs.

Compositionally, the closed conifer (CICon), mixed (Mix), open conifer (OpCon), alpine/subalpine (AlpSub), shrub (Shrub), wetland/riparian (WetRip), and no food/cover (NFC) classes dominate the study area. OpCon, AlpSub, and Shrub are the habitat-related classes found most often within female home ranges. WetRip and Shrub patches are more prevalent in male home ranges. The BMUs containing proportionately more forest, AlpSub, WetRip and fewer disturbances correspond most closely to the habitat structure of the individual grizzly bear home ranges under investigation. Based on these results, the most highly fragmented BMUs (i.e. the least like actual grizzly bear home range structure) are the McLeod (MC), Gregg (GR), Pembina (PE), Lovett (LO), Maskuta (MA), and Beaverdam (BE). The other FH BMUs appear to be less fragmented and would be structurally appropriate for inclusion within male home ranges. The Mountain BMUs of Fiddle (Fl) and Lower Rocky (LR) are structurally similar to the Foothill BMUs and show signs of being fragmented.
6.2 Implications for Management

The scaling of CT classes into LD and even VN can dilute the information relevant to grizzly bear habitat, for example, differences between the crown closure of forest types and level of regeneration of cut blocks are lost in aggregation. Although discriminant analysis shows a strong relationship between density and all attribute scaling schemes, caution should be applied since fragmentation information is different for some metrics from one attribute-scaling scheme to another. Even with the optimal fourteen-class CT scheme, there are implications for management: not all types of disturbance are mapped, micro scale habitats of riparian corridors and avalanche chutes are not included, and levels of human activity are not accounted for.

The coarseness of the density data means that the discriminant functions are more useful for land and wildlife management applications, and not directly for wildlife population assessment and monitoring since there is no actual population count associated with the predictive ability. More robust DNA analysis results could provide more confident density estimates to be used in the discriminant function methodology built in the present study. The conclusions allow confidence that certain kinds of fragmentation are unfavorable to bears, and show definitively that this fragmentation can be measured by landscape metrics. Therefore the discriminant functions developed here are usable in planning how changes to the landscape will affect bear habitat structure and density. However, the presently sparse bear data means that only very broad classes of bear density can be predicted. This is not sufficiently precise to
determine wildlife management objectives such as hunting quotas, culling, or introduction of specific numbers of bears in specific places.

Land managers should be able to utilize appropriate spatial metrics when planning for such habitat structure altering human activities as forest harvest and road building. Patch class area (%LAND) is an obvious choice because it shows the percentage of each Cover Type within a grizzly bear home range. %LAND is a good indicator of the habitat-related vegetation cover a bear uses and the amount of disturbance patches it may be tolerating. Mean patch size (MPS), edge density (ED), and mean nearest neighbour (MNN) can provide clues on how much fragmentation the habitat may be able to sustain and remain viable. Shorter MNN distances are desirable for the habitat-related Cover Types. For example, both male and female home ranges have low MNN for the OpCon, AlpSub, Shrub, and WetRip classes. By ensuring that the inter-patch distance remains within the range of MNN values found in actual home ranges, structural changes to these patch types within BMUs that would be harmful to grizzly bear habitat needs can be avoided. Greater MNN distances are appropriate for the disturbance-related Cover Types. The road and cut classes have larger MNN values within home ranges as compared to BMUs; the longer inter-patch distances probably mean that bears are avoiding these undesirable patch types.

It must be noted, however, that presence of a particular patch type may not actually be meaningful given the nature of the Minimum Convex Polygon method of delineating home ranges (White and Garrott, 1990). Since the outermost point locations from telemetry data are joined, patch classes that are not even used by bears become part of
the MCP because these patch types are surrounded by actual habitat. Also, this is one snapshot in time for grizzly bear habitat structure in the FMF GBRP study area. It must be noted that there is no proof that the bears tracked in 1999 are entirely representative of the population. The baseline data gathered and analyzed here should be compared with that gathered in future years in a continual monitoring program to determine the average habitat structure within the grizzly bear home ranges before any “hard numbers” can be determined for landscape threshold targets.

6.3 Recommendations for Future Research

Recommendations for addressing present and future research and planning in the Foothills Model Forest study area for the continual monitoring of grizzly bears using landscape structure measures are offered as follows:

- To assess changes over time, annually or over some other time step that is more ecologically meaningful to the study of grizzly bears, digital imagery and classification methods comparable to the present study must be used. Simple image algebra, such as the subtraction of a future classification from the 1999 baseline, could easily be implemented to detect and quantify changes in the landscape due to human activities. For example, the effects of forest harvesting and road building can be accurately measured through the application of landscape metrics.
- In a similar vein, “what-if” scenarios could be applied to the baseline classification. Such scenarios would alter the habitat structure according to proposed resource
extraction and development plans, and effects on the landscape structure could then
be quantified and assessed. The a priori results would enable mitigation or
prevention of potentially fragmenting activities on grizzly bear habitat.

- The FMF GBRP is species driven; that is, the size and distribution of grizzly bear
  home ranges under investigation defines the scale of the study. Therefore, the areal
  extent of the IDTA map limits the bear data that can be incorporated into the
  landscape structure analysis. Another example of the modifiable areal unit problem,
  the method of delineating home ranges affects the structure information contained in
  these areas of analysis. For example, Kernel home ranges (White and Garrott,
  1990) are an alternative method that depicts concentrations of telemetry locations,
  thereby revealing the higher use habitat. Also, experimenting with the minimum
  mapping unit may provide further ecological insight into the habitat structure.

- In the year 2000, the study area expanded to encompass areas farther east in the
  foothills; therefore, the number of BMUs increased from sixteen to twenty nine.
  When a habitat classification within the extended boundary becomes available for
  the 1999 baseline year, the methodology from this research should be applied to the
  new BMUs to facilitate direct comparisons between years for the entire area. With
  the addition of more BMUs, the population available for discriminant function analysis
  is increased. This should enable a more robust testing of the ability of landscape
  metrics to predict bear density within a BMU. Also, predictions could be made by
  applying the discriminant functions to BMUs, which have as yet unknown bear
  density. Conducting future DNA studies, thus eliminating the potential for any bias in
  selecting training and testing areas, would then test the correctness of the
  predictions.
• The coarseness of bear density groups limits their utility to management; actual population counts are more useful, especially if they provide interval rather than ordinal data. Alternative multivariate statistical techniques, such as multiple regression, could be applied to grizzly bear population counts, when and if this data becomes available, to predict landscape structural change on actual numbers of bears, to aid in hunting quotas, and other land activities.

• This study has focused on the large-scale human disturbance classes of forestry and transportation. Other human activities, such as certain forms of mining and oil and gas development, have small “footprints” in at least one dimension, making them difficult to detect reliably using the present image classification methods. In order to address the fragmenting effects of these activities, alternative classification methodologies would need to be implemented using finer resolution and incorporating more detailed classes.

This research has quantified and assessed the baseline habitat structure for the Foothills Model Forest Grizzly Bear Research Project that was implemented in 1999. Theoretical issues relating to interpreting landscape metrics have been addressed and have shown that the best results are obtained when analyzing moderately detailed habitat classes. Methodology has also been developed that would allow resource managers to easily monitor habitat structure over time and predict the effects on grizzly bear population densities. Continual monitoring is the key to understanding grizzly bear habitat structure so that land managers may be able to implement the optimal conservation practices and maintain a viable Canadian grizzly bear population.
7.0 References


Appendix A: Equations for Selected Spatial Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Equation (for use with raster data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Landscape Area (ha)</td>
<td>( TLA = A \times \left(\frac{1}{10,000}\right) ) where ( A = \text{total area (m}^2) )</td>
</tr>
<tr>
<td>Class Area (ha)</td>
<td>( CA = \sum_{j=1}^{n} a_i \times \left(\frac{1}{10,000}\right) ) where ( a_i = \text{area (m}^2) ) of patch ( i )</td>
</tr>
<tr>
<td>Number of Patches</td>
<td>( NUMP = n_i ) for patch type (class) ( i )</td>
</tr>
<tr>
<td>Mean Patch Size (ha)</td>
<td>( MPS = \sum_{j=1}^{n} a_i \times \left(\frac{1}{10,000}\right) / n_i )</td>
</tr>
<tr>
<td>Patch Size Coefficient of Variance</td>
<td>( PSCOV = \frac{PSSD}{MPS} ) where ( PSSD = \sum_{i=1}^{n} a_i \times \left(\frac{1}{10,000}\right) )</td>
</tr>
<tr>
<td>Edge Density (m/ha)</td>
<td>( ED = \frac{\sum_{k=1}^{m} e_k}{A} \times \left(\frac{1}{10,000}\right) ) where ( e_k = \text{total length (m) of edge in landscape between patch type (class) } i \text{ and } k )</td>
</tr>
<tr>
<td>Area Weighted Mean Shape Index</td>
<td>( AWMSI = \sum_{i=1}^{n} \sum_{j=i}^{n} \left(\frac{25a_i}{a_i + a_j}\right) ) where ( a_i = \text{perimeter (m) of patch } ij )</td>
</tr>
<tr>
<td>Mean Nearest Neighbour (m)</td>
<td>( MNN = \frac{\sum_{k=1}^{m} h_k}{n_i} ) where ( h_k = \text{distance (m) between patch } ji \text{ and nearest patch of same type} )</td>
</tr>
<tr>
<td>Interspersion / Juxtaposition Index</td>
<td>( IJI = \frac{\sum_{k=1}^{m} \left(\frac{e_k}{n_i}\right) \ln \left(\frac{n_i}{\sum_{k=1}^{m} e_k}\right) \left(\frac{n_i}{\sum_{k=1}^{m} e_k}\right)}{\ln (m_i - 1)} ) where ( m_i = \text{number of patch types (classes)} )</td>
</tr>
</tbody>
</table>
Appendix B: Vegetation Species in the Study Area

This is a listing of the vegetation found in the field plots, as sorted by Type and then alphabetized by Common Name. Abbreviations were derived from Alberta Vegetation Inventory for tree species, from concatenating the first two letters in both genus and species names, or simply from the genus.

Note: Type is abbreviated as T = tree, S = shrub, GV = ground vegetation.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Latin Name</th>
<th>Abbreviation</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspen</td>
<td>Populus tremuloides</td>
<td>Aw</td>
<td>T</td>
</tr>
<tr>
<td>Balsam fir</td>
<td>Abies balsamea</td>
<td>Fb</td>
<td>T</td>
</tr>
<tr>
<td>Balsam poplar</td>
<td>Populus balsamifera</td>
<td>Pb</td>
<td>T</td>
</tr>
<tr>
<td>Black spruce</td>
<td>Picea mariana</td>
<td>Sb</td>
<td>T</td>
</tr>
<tr>
<td>Douglas fir</td>
<td>Pseudotsuga menziesii</td>
<td>Fd</td>
<td>T</td>
</tr>
<tr>
<td>Engelmann spruce</td>
<td>Picea engelmannii</td>
<td>Se</td>
<td>T</td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td>Pinus contorta</td>
<td>Pl</td>
<td>T</td>
</tr>
<tr>
<td>Paper birch</td>
<td>Betula papyrifera</td>
<td>Fa</td>
<td>T</td>
</tr>
<tr>
<td>Subalpine fir</td>
<td>Abies lasiocarpa</td>
<td>Bw</td>
<td>T</td>
</tr>
<tr>
<td>Tamarack</td>
<td>Larix laricina</td>
<td>Li</td>
<td>T</td>
</tr>
<tr>
<td>Water birch</td>
<td>Betula occidentalis</td>
<td>Sw</td>
<td>T</td>
</tr>
<tr>
<td>White spruce</td>
<td>Picea glauca</td>
<td>Sw</td>
<td>T</td>
</tr>
<tr>
<td>Bearberry</td>
<td>Arctostaphylos uva-ursi</td>
<td>ARUV</td>
<td>S</td>
</tr>
<tr>
<td>Blueberry</td>
<td>Vaccinium myrtillus</td>
<td>VAMY</td>
<td>S</td>
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<tr>
<td>Buckbrush</td>
<td>Symphoricarpus occidentalis</td>
<td>SYOC</td>
<td>S</td>
</tr>
<tr>
<td>Buffaloberry</td>
<td>Shepherdia canadensis</td>
<td>SHCA</td>
<td>S</td>
</tr>
<tr>
<td>Bush honeysuckle</td>
<td>Diervilia lonicera</td>
<td>DILO</td>
<td>S</td>
</tr>
<tr>
<td>Choke cherry</td>
<td>Prunus virginiana</td>
<td>PRVI</td>
<td>S</td>
</tr>
<tr>
<td>Common juniper</td>
<td>Juniperus communis</td>
<td>JUCO</td>
<td>S</td>
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<td>Hedysarum boreale</td>
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<td>Sweet-vetch, yellow</td>
<td>Hedysarum sulphurens</td>
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<td>Mentha pulegium</td>
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<td>Achillea millefolium</td>
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<td>Yellow mountain-avens</td>
<td>Dryas drummondi</td>
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Appendix C: Field Plot Methods

Field protocol developed by Monika Moskal and Charlene Popplewell.

Forest

The classes that required ground-based sampling for the forest plot type were the closed and open deciduous and conifer classes, mixedwood stands, and burn sites with standing stems and cut sites with high regeneration: CICon, CIDec, OpCon, CIDec, MixCon, MixDec, Burn, and Cut. WetTreed was also be sampled in this manner.

The standard timber cruising sampling strategy applied to these plots are outlined as follows:
1. Mark plot center with flagging tape
2. Record plot ID, preliminary class, date, and time
3. Obtain GPS reading: UTM coordinates, elevation, and error
4. Photograph representative Overstory (O) and Understory (U) vegetation
5. Measure slope (in percent – clinometer) and aspect (in degrees – compass)
6. Record topographic position, moisture regime, animal use, and any natural or human disturbance
7. Estimate percent cover of non-vegetation (deadfall, rock, litter, soil, water)
8. Determine visibility class (High, Medium, Low)
9. Perform prism sweep (Prism Factor 4) to determine basal area and trees to sample
10. Measure crown closure at five locations (NW, NE, C, SW, and SE) within the plot using the spherical densiometer
11. Record species for each tree in sample
12. Measure Diameter at Breast Height (in cm) with DBH tape
13. Estimate Tree Height and Height to Canopy (in meters) using the clinometer
15. Check off if tree is cored or dead, and record any comments (e.g. lichens or animal markings)
16. Core representative tree to obtain ring count (stand age) and sapwood depth (in cm)
17. Record major understory species and estimate percent cover of each (5% or greater)
18. Write further details on the plot and additional vegetation in the Comments section

Vegetation

Herbaceous, shrub community, and the regeneration classes relied on a sampling strategy that averages the percent cover of species composition within four quadrants. These classes included Herb<18, Shrub<18, HerbRec, CutO-2, Cut3-12, BurnO-2, and Burn3-12. Depending upon accessibility, AlpGr and WetOpen were sampled in this manner as well.
The quadrants were delineated by north-south and east-west lines intersecting at the plot center, and encompassed a total area of 30m X 30m; i.e. each quadrant is 15m X 15m. A 3 m\(^2\) radius from the center of each quadrant was the area sampled (Strong, pers. comm.). The details of sampling are outlined below:

1. Mark plot center with flagging tape
2. Record plot ID, preliminary class, date, and time
3. Obtain GPS reading: UTM coordinates, elevation, and error
4. Photograph representative vegetation
5. Measure slope (in percent – clinometer) and aspect (in degrees – compass)
6. Record topographic position, moisture regime, animal use and any natural or human disturbance
7. Divide 30m X 30m plot into four quadrants (NW, NE, SW, SE)
8. Estimate percent cover for each major species within a 3 m\(^2\) radius at each quadrant center (5% or greater)
9. For each quadrant, estimate the percent cover of non-vegetation (water, deadfall, rock, litter, soil, snags)
10. Perform #8 and #9 four times so that the percent coverage in each quadrant is estimated; these are later averaged for the entire plot
11. Write further details on the plot and additional vegetation in the Comments section

**Air-Call**

Any compositional and structural measure that can be estimated on the ground can be estimated and/or interpreted from the air. The less accessible sites of wetlands and alpine areas were the primary candidates for aerial sampling. These include WetOpen, WetTreed, and AlpGr; however, air calls permitted the time-effective collection of data on all habitat classes and was not restricted to those based on ground inaccessibility.

The sampling methods for air-based plots is outlined below:

1. With the helicopter centered on plot location, obtain GPS reading: UTM coordinates, elevation (estimate based on helicopter height above ground), and error
2. Record plot ID, preliminary class, date, and time
3. Photograph representative vegetation
4. Estimate slope (in percent) and aspect (in degrees converted from cardinal direction)
5. Record topographic position, moisture regime, animal use, and any natural or human disturbance
6. Estimate Crown Closure (in percent) if a forested plot
7. Estimate the percent cover for each major species
8. In addition, for tree species estimate Height (in meters), DBH (in cm), and Crown Width (in meters); for shrub species estimate Height (in meters)
9. Estimate percent cover of non-vegetation (deadfall, rock, litter, soil, snags, water)
10. Write further details on the plot and additional vegetation in the Comments section
Appendix D: IDTA Classification Methods

(from Franklin et al. 2001)