Mapping High Conservation Value and Endangered Forests in the Alberta Foothills Using Spatially Explicit Decision Support Tools

Report by the Conservation Biology Institute for Limited Brands

May 2007

CONSERVATION BIOLOGY INSTITUTE

This report was prepared by James R. Strittholt, Ph.D., Nancy L. Staus, M.S., Gerald Heilman, Jr., M.S. and John Bergquist. The Conservation Biology Institute is a 501(c) 3 tax-exempt organization that works collaboratively to conserve biological diversity in its natural state through applied research, education, planning, and community service.

Table of Contents

List of Figures

List of Tables

Appendices

Executive Summary

1. Protected areas form one of the main pillars of biodiversity conservation throughout the world. Only 1.2 percent of the Alberta Foothills is currently protected, which is woefully inadequate by any scientific standard.
2. Protecting the full array of native biodiversity (representation) is an extremely important consideration in a regional protected areas strategy.
3. Approximately 75 percent of the natural variability present in the Alberta Foothills (measured as enduring features) is not adequately represented in a network of protected areas.
4. Approximately 82 percent of the region is comprised of logging tenures and much of this same area is subjected to intensive oil and gas development.
5. Change detection analysis has shown that nearly 9 percent of the ecoregion (~640,000 ha) has been impacted by activities visible from space since 1990 and much of this has been either by a growing network of oil and gas infrastructure or as clusters of clearcut logging. Impact on some species (e.g., woodland caribou) far exceeds this area.
6. The region contains over 36,000 wells, numerous pipelines, and thousands of kilometers of seismic exploration.
7. The Alberta Foothills no longer possesses large intact forest landscapes (undisturbed blocks >50,000 ha), but approximately 1/3 of the region is comprised of smaller forest remnants (over 2,100 with mean size of 1,500 ha) which forms the natural backbone of the region and form one of the major building blocks for protecting the many ecological values identified in the region.
8. Biodiversity values evaluated in the endangered forest mapping included: (1) rare forest types (old growth and less fragmented forests), (2) locations of rare and endangered species and their special habitats, (3) woodland caribou, (4) grizzly bear, (5) freshwater species such as bull trout and arctic grayling, and (6) forest and water-dependent bird species. Many of these values are being seriously degraded and some threatened with local extinction.
9. Decision support mapping results highlight areas within the Alberta Foothills that still contain high values and some of these values are of global or national significance. The highest scoring areas should be considered as candidates for an expanded protected areas network for the region. Recommended starting target should be approximately 16 percent of the ecoregion including existing and new protected areas. Failure to act will result in numerous species extirpations and significant loss of overall ecological integrity, including the degradation of several important ecosystem services.
10. In addition to new protected areas, landscape connectivity along waterways and over land should remain as an important consideration in an overall regional conservation strategy.
11. To be effective, an expanded protected area network alone will not be enough to maintain the conservation values present in the region today. New protected areas should be established strategically in the context of a region under dramatic pressure from development and extractive use. Management and even restoration in some areas should also be considered in an overall plan to achieve ecological sustainability.
12. The combination of Neatweaver®, EMDS®, and ArcMap® provides a powerful decision support planning tool set that can successfully address the topic of High Conservation Value and Endangered Forests.

Acknowledgements

This project was funded via a grant from the Limited Brands Foundation. GIS software was generously provided by ESRI makers of Arc/Info products and image processing software by Leica Geosystems makers of Erdas Imagine. Global Forest Watch Canada provided valuable change detection and other datasets fundamentally important for this project. In particular, Peter Lee served a critical liaison function for obtaining important datasets, provided review meeting support, and provided valuable document review. Also, staffs from the Foothills Model Forest and Alberta Sustainable Resource Development were extremely helpful in acquiring important datasets.

We also wish to acknowledge the participation and review by Lafcadio Cortesi, Carl Hunt, Aran O'Carroll, Diane Pachal, Glen Semenchuk, Kirby Smith, Gordon Stenhouse, Karen Stroebel, Helene Watch, and Evie Witten.

Introduction

Forests cover approximately 30 percent of the earth's surface, which is about half of what existed prior to the dawn of agriculture roughly 10,000 years ago (FAO 2001). Only about 20 percent of the remaining forested lands, concentrated in only three countries – Brazil, Canada, and Russia, remain as relatively undisturbed (or intact) original forest landscapes (Bryant et al 1997). Approximately 8 percent of the world's remaining forests are considered to be under some form of protection (UNEP 2005), which is widely viewed as inadequate and highlighted in a special section in the Convention of Biological Diversity 2010 Strategy (CBD 2004), and another five percent in high-yield plantations (FAO 2001). Therefore, 87 percent of the world's remaining forests fall into the category of matrix (or multi-use) forests (Lindemayer and Franklin 2002).

Current threats to the world's forests are numerous and ongoing. Forests must contend with cumulative or synergistic disturbances from deterministic impacts such as logging and mining and stochastic ones such as wildfire and disease, which have been widely exacerbated by human-induced environmental changes such as global warming. The leading threats to forests are habitat destruction, alien invasive species, overexploitation, pollution (e.g., nitrogen deposition), and climate change (The Millennium Assessment 2005).

With relatively poor forest protection around the world and ongoing threats to native forests, various initiatives are being developed to define the most ecologically important forests.[1] The Endangered Forest concept is one of the more recent ones being proposed, which is similar to the more widely accepted High Conservation Value Forest concept (Principle 9) under the Forest Stewardship Council (FSC) forestry certification standard (Jennings et al. 2004). High Conservation Value Forests are forests that contain one or more High Conservation Values. The Forest Stewardship Council defines High Conservation Value Forests using six criteria that indicate forests with significant biological, environmental, and social values. Simply stated, Endangered Forests are those High Conservation Value Forests, or portions of them, that are so biologically distinct, rare, or ecologically important that industrial use would be incompatible with maintaining these values (ForestEthics et al. 2006). The relationship between High Conservation Value and Endangered Forests can be most easily represented in diagram form (Figure 1), which plots ecological integrity against forest practice intensity. Dedicated forest reserves theoretically possess the highest ecological integrity, no forestry activity and therefore no timber yield, and the highest levels of biodiversity protection (roughly 8 percent of the world's forests). On the other end of the diagram are plantations which possess less ecological integrity, normally lower biodiversity protection, but produce high timber volumes (5 percent of the world's forests). The natural and semi-natural forests in the middle (matrix forests – 87%) fall along the continuum between the two other extremes. Some portions of the matrix forests possess certain values that could be classified as High Conservation Value and are of higher ecological integrity. And that portion of the High Conservation Value Forests that warrant full protection to maintain the values would be the Endangered Forests.

[1] For example see: The Nature Conservancy (ecoregional assessments), Conservation International (biodiversity hotspots), World Wildlife Fund Canada (enduring features gap analysis), World Resources Institute (frontier forests), Greenpeace (ancient forest definitions), and IUCN-The World Conservation Union.

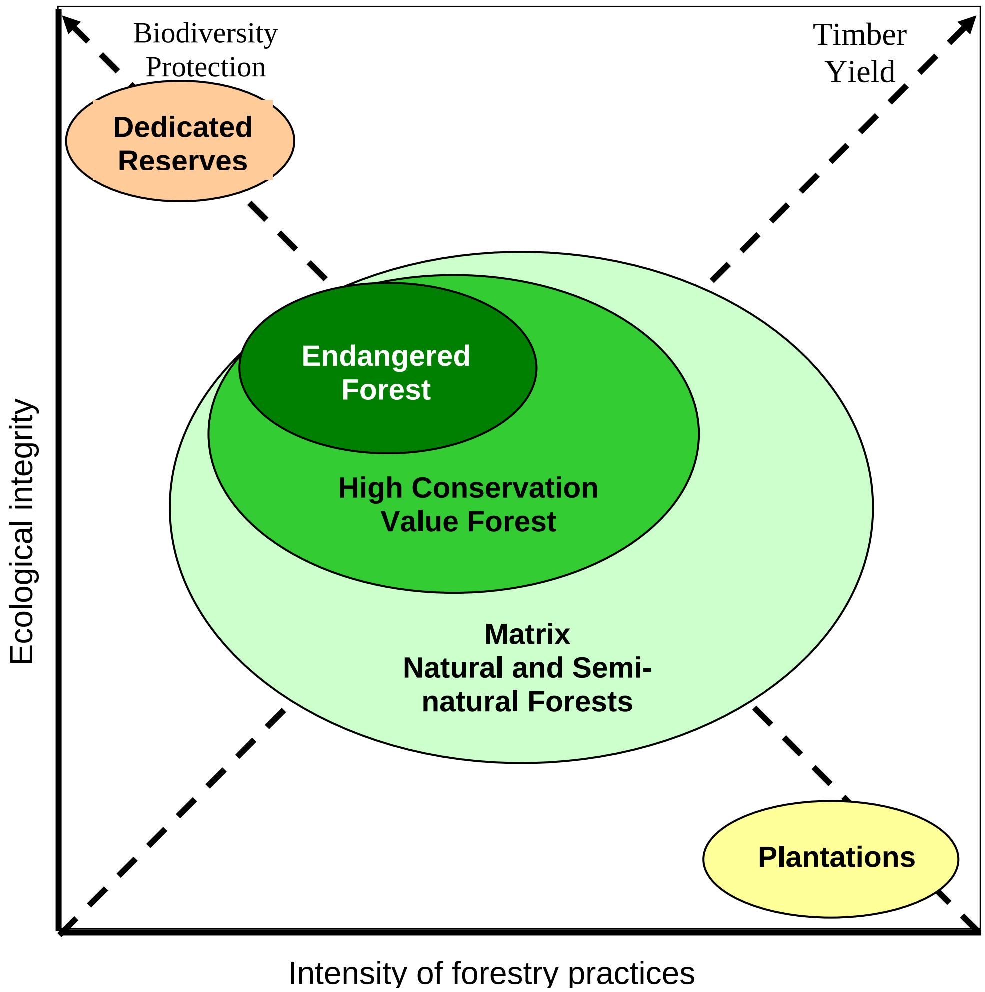

Figure 1. Diagram showing the relationship of Endangered Forests and High Conservation Value Forests in relation to the intensity of forest management and ecological integrity [Adapted from Lindenmayer and Franklin (2002)]. Taken from ForestEthics et al. 2006.

Even though Endangered Forests should be off limits to industrial development, they may still require management – driven by conservation rather than economic imperatives to protect their ecological values. In many cases (i.e., existing large, intact forest landscapes), little or no direct human intervention may be necessary; however, some areas will require active management to counter threats, such as controlling alien invaders or re-establishing natural disturbance regimes through prescribed fire or mechanical thinning. This study focused only on Endangered Forests and the biological components of the High Conservation Value Forest concept. Values 4,5, and 6 of High Conservation Value Forest Principle 9 pertain to human services.[2]

[2] HCV4: Forest areas that provide the basic services of nature in critical situations (e.g., watershed protection, erosion control). HCV5: Forest areas fundamental to meeting the basic needs of local communities (e.g., subsistence, health). HCV6: Forest areas critical to local communities' traditional cultural identity (areas of cultural, ecological, economic, or religious significance identified in cooperation with such local communities).

High Conservation Value and Endangered Forests are identified and mapped based on several ecological components that are globally, regionally, or locally important. These ecological components can be landscape level features or biodiversity related. These components sometimes overlap and at other times are mutually exclusive. Any one component can be enough to identify a specific forest area as a High Conservation Value or Endangered Forest depending on the circumstance, but a full assessment using readily available spatial data of all of the ecological components is warranted before a forest is identified for this purpose.

Guided by conservation biology principles and based on the best spatially explicit data and information available, the determination of High Conservation Value and Endangered Forests includes examining the following:

Landscape Integrity Components

1) Intact forest landscapes
2) Remnant forests and restoration cores
3) Landscape connectivity

Biodiversity Components

4) Rare forest types (composition and structure)
5) Forests of high species richness (alpha and beta diversity)
6) Forests containing high concentrations of rare and endangered species
7) Forests of high endemism
8) Core habitat for focal species (aquatic and terrestrial)
9) Forests exhibiting rare ecological and evolutionary phenomena

Being relatively new and complex, how the concepts of High Conservation Value and Endangered Forests get applied to different forest ecosystems throughout the world has not been fully explored. Different forest types contain different plant and animal species, are governed by different ecological and evolutionary processes, and are impacted by different disturbance regimes. Lack of consistent and relevant data and information further complicates efforts to standardize the identification and mapping of these forests. Social and economic drivers would prefer that the identification and mapping process be easily applied producing mapped outcomes with high levels of certainty. But the lack of (a) ecological understanding, (b) uniform, high-quality spatially explicit data and information, (c) analytical standards, and (d) monitored case studies leaves many challenges. If we are to attain ecological sustainability of the world's forests, we must overcome these challenges.

This study attempts to develop a scientifically defensible analytical approach to mapping High Conservation Value and Endangered Forests using the Alberta Foothills of Canada as a case study. The goal of this project is to help develop solutions for this particular region, but also to develop a decision support approach that can be applied elsewhere advancing the identification and mapping of High Conservation Value and Endangered Forests throughout the world.
This report emphasizes the analytical approach as much as the final results specific to the Alberta Foothills ecoregion.

Ecological Setting

Study Area

The focus of this assessment is the Western Alberta Uplands Ecoregion according to the National Ecological Framework for Canada or simply referred to throughout this report as the Alberta Foothills even though a small portion of the ecoregion is located in British Columbia (Figure 2). The ecoregion covers approximately 73,000 square kilometers and lies in the transition zone between the Rocky Mountains to the west and the Central Boreal Plains to the east.

The area east of the ecoregion is the most developed portion of Alberta containing extensive agricultural lands and the largest urban centers in the province (Calgary and Edmonton). Other smaller cities such as Red Deer, Grande Prairie and Dawson Creek are also located along the eastern and northern edges of the ecoregion. The human population is approximately 55,000 with the largest communities being Edson and Hinton, located on highway 16 between Edmonton and Jasper National Park, and Swan Hills located off highway 33. Road density ranges from 0 – 7.1 km/km^2 with the mean density being 0.64 km/ km^2. Approximately 86,000 ha of First Nation lands and 6 Native communities are found in the ecoregion.

The mean summer temperature is 12.5°C and the mean winter temperature ranges from -11°C in the north to -8.5°C in the south. The mean annual precipitation is approximately 450-600 mm. The Alberta Foothills abruptly rises out of the eastern plains forming mainly rolling linear ridges with broad valleys. The region drains northeastward via three main river systems – Peace, Athabasca, and Saskatchewan Rivers. The mostly strongly dissected uplands are covered by glacial till, peat blankets, clay lacustrine and sandy fluvioglacial deposits. Well-developed Luvisols, Gleysolic and Organic soils dominate the region.

The Alberta Foothills is dominated by forest cover (Figure 3). Drier sites are typically dominated by lodgepole pine (*Pinus contorta*) and trembling aspen (*Populus tremuloides*) with black spruce (*Picea mariana*) and tamarack (*Larix laricina*) most common on wetter sites. Other tree species include white spruce (*Picea abies*), balsam fir (*Abies balsamea*), balsam popular (*Populus balsamifera*), and paper birch (*Betula papyrifera*). Typically, conifer species are favored on cooler, higher elevation sites and deciduous species in the lower elevation plains. According to the Canadian Forest Inventory, the region is largely dominated by lodgepole pine followed by poplar/aspen, black spruce, mixed forest, white spruce, and other forest communities (Table 1).

Table 1. Forest type and percent area for the Alberta Foothills based on Canadian Forest Inventory data. Data obtained from the Boreal Information Centre (www.borealinfo.org).

Lodgepole Pine	33.63%
Poplar/Aspen	28.29%
Black Spruce	10.90%
Mixed Forest	10.21%
White Spruce	10.06%
Other	9.61%

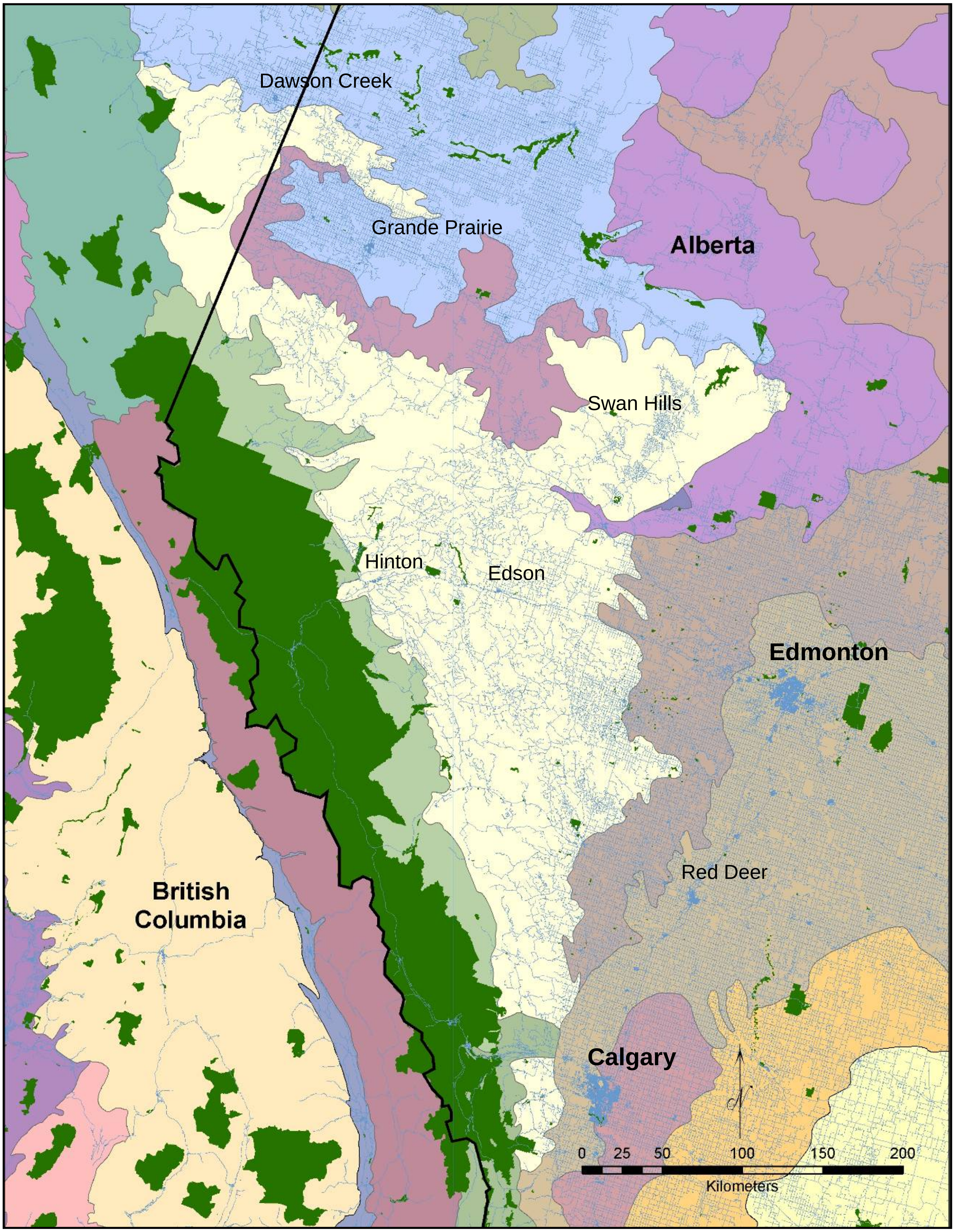

Figure 2. Map of ecoregions (Alberta Foothills in light yellow) with designated protected areas (dark green), roads, and selected cities and towns. Data from the Boreal Information Centre (www.borealinfo.org).

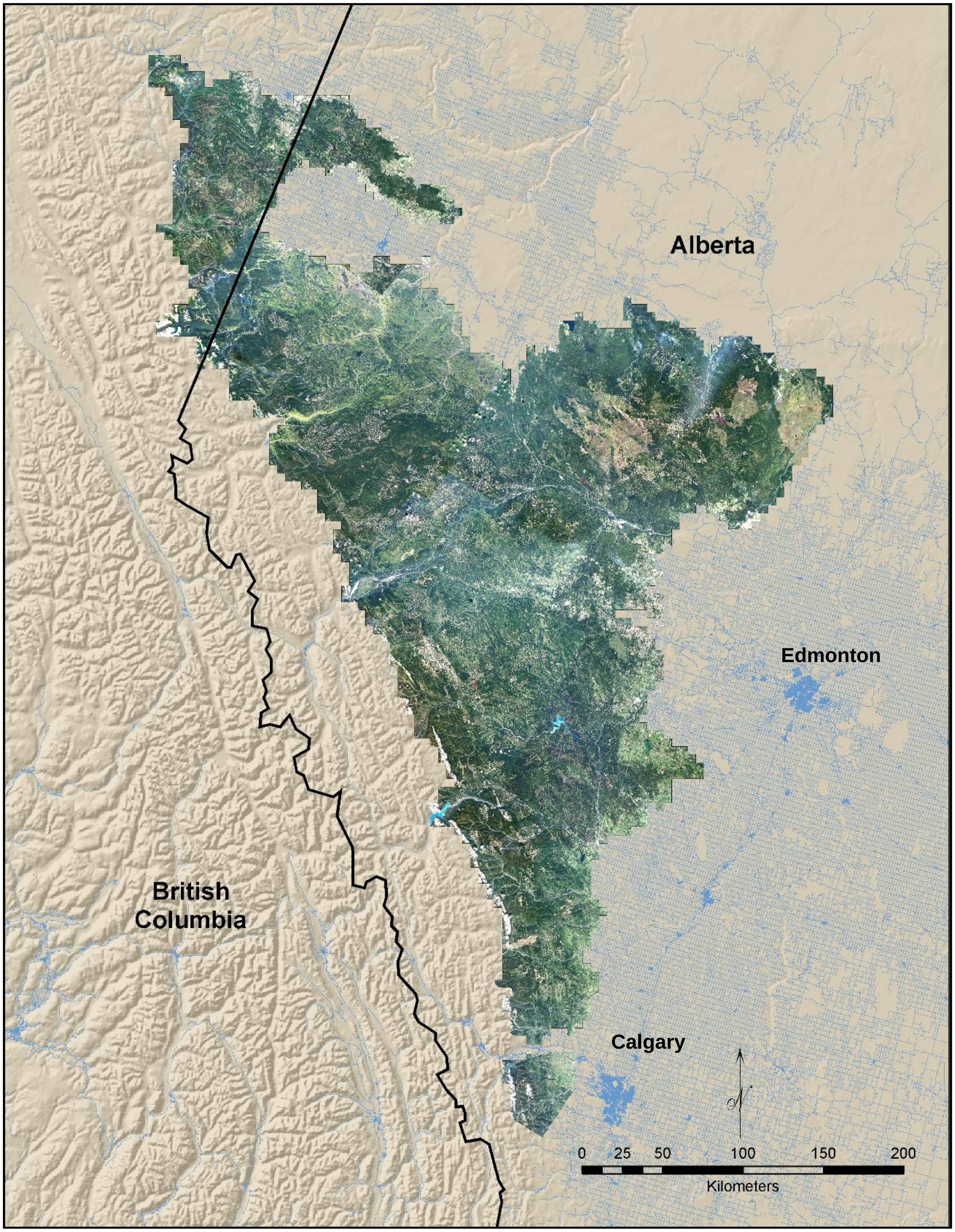

Figure 3. Relief map of the region with composite Landsat 7 ETM+ satellite imagery 2006 for the Alberta Foothills study area. Dark green depicts forest cover.

The major natural disturbance agent is wildfire. According to the Canadian Large Fire Database created by Natural Resources Canada, which tracks fires >200 ha over the last 40 years, the Alberta Foothills has had nearly 100 fires burning a total of 270,000 ha (~4% of the ecoregion). Insects and disease are other important natural disturbance agents.

One forest insect pest of extreme concern is the mountain pine beetle (*Dendroctonus ponderosae* Hopkins), which is most attracted to stands of older conifers. Typically on the edge of its normal distribution (the beetles are controlled by extended periods of cold temperatures), Alberta has not had a sustained infestation since 1985. However, detections are on the rise in portions of the study area attributed to infestations from neighboring British Columbia (the source) and several years of mild winters and hot dry summers. This insect has the potential to damage many trees over large extents.


Canopy-replacing wildfire


Pine bark beetle infestation

The Rocky Mountains to the west of the study area is largely protected by a number of large, designated parks, but only a small portion (1.2%) of the Alberta Foothills ecoregion is formally protected (Figure 2). There are numerous protected polygons in the ecoregion (n=150) but the mean size is only 603 ha. There are only a few protected areas larger than 10,000 ha with the largest including portions of Sheep River Provincial Park/Bluerock Wildlands Park (~19,000 ha) and Bearhole Lake Provincial Park (~18,000 ha).

Protected areas (national parks, nature reserves, and other designations) are widely recognized as a crucial tool for protecting global biodiversity; maintaining environmental services; and protecting cultural, aesthetic, and ethical values (Hockings et al. 2000), and according to the United Nations Environment Program, approximately 8 percent of the world's forests are in some form of legal protection (UNEP 2005). Unfortunately, these protected areas do not cover the full range of forest types or characteristics – or the most productive sites. In many countries, large protected areas mostly represent "the lands nobody wanted" (Sands and Healy 1977). For example, the largest protected areas in the U.S. and Canada are concentrated at higher elevations or in areas of low forest productivity (Scott et al. 2001). However, many of the ecologically most important forests occur at lower elevations and on more productive sites; often times in conflict with economic uses. This pattern is strongly demonstrated in and around the Alberta Foothills. The higher elevations to the west are well-protected in a system of parks, but the more productive sites, which include much of the Alberta Foothills ecoregion, are poorly protected.

One main objective for establishing and maintaining a protected areas network is representation. Representation refers to the protection of the full range of biodiversity of a given region within a system of protected areas (Ricketts et al. 1999) designed in such a way that promotes the long-term persistence of all life and the processes that maintain it. To be ecologically effective, representation must be achieved in all ecosystems at all ecological spatial scales.

In Canada, representation has been roughly addressed using something called "enduring features", which are mapped zones of physical habitats based on soil and terrain characteristics (Hummel 1995). The principle behind mapping and assessing representation using enduring features over more biologically-driven zonations is that by mapping the physical drivers behind biodiversity you can capture the range of variability for areas where you lack biological data and information. Using the Assessment of Representation (or AoR) tool and protocol created by World Wildlife Fund Canada to systematically address the adequacy of representation by protected areas, we evaluated this question for the Alberta Foothills. This tool is more than simply mapping the various physical habitat zones for a region. Based on a series of assumptions about natural disturbance and regional connectivity, the tool attempts to evaluate the adequacy of the protected areas network for a given region. This is still a rough estimation, but it does provide some insight into this important question based on sound ecological parameters. The main data inputs used included: (1) the enduring features data provided by World Wildlife Fund Canada mainly derived from the Soil Landscapes of Canada, (2) designated protected areas, (3) the Canada 3D data (30 arc-seconds ~662 m^2) elevation dataset, (4) National Scale Frameworks Hydrology drainage network (1:1,000,000), and (5) the National Road Network (1:1,000,000) dataset.

The Alberta Foothills ecoregion contains 148 different enduring features (Figure 4). Of these, Only 25 percent involving 28.5 percent of the area were found to be "adequately represented" by the AoR tool (Table 2). All of these were largely located in the adjacent Rocky Mountains, but had small extents crossing into the Alberta Foothills, which brought it into the analysis (Figure 5). Over 53 percent of the mapped enduring features are not represented at all in the current protected areas network and another 13 percent only slightly represented. Almost two-thirds of the Alberta Foothills are either slightly represented or not represented at all.

A related question to representation and one of great interest to many pertains to how much area needs to be protected in a given region. The answer to this question varies depending on the system and is a complex one. For example, it has been shown that for some natural ecosystems (e.g., island systems) as much as 97-99 percent of an area needs to be protected to achieve the specific target of stable populations of all native species (Ryti 1992). Based on a review of multiple studies that have looked at this question, Noss and Cooperrider (1994) suggested that most regions require 25-75 percent protection targets to assure that natural composition, pattern, and process are maintained over time. World Wildlife Fund Canada once estimated that from 17-70 percent of the land area of Canada should be protected (WWF Canada, unpublished data). A proposed political solution offered by the United Nations sets a 12 percent protected areas target (World Commission on Environment and Development 1987) even though Soulé and Sanjayan (1998) criticized this target because it may actually accelerate species declines based on species-area relationships and projected habitat destruction outside reserves.

For some natural regions, the opportunity to protect the full range of native biodiversity is already lost. In others, the progression from a natural state to a predominantly managed one offers a unique set of conservation challenges. With only 1.2 percent of its area currently protected and with the occurrence of globally, nationally, and regionally significant conservation values, the Alberta Foothills is one of these places. Based on the protected areas background assessment provided here, it is clear that 1.2 percent is woefully inadequate, but it is beyond this exercise to accurately specify the absolute area target. That is because the desired goal depends upon the specified conservation targets – the more area-demanding and sensitive to human disturbance the targets are, the larger the area needed in protection. Furthermore, the amount of area needed in protected areas also depends upon how protected areas are spatially arranged and how the lands around them are managed – if resource lands are intensively managed, more land is needed inside protected areas. In regions containing smaller connected parks surrounded by less intensive management, there is less need for large protected areas as this strategy may function adequately at protecting the full suite of native species and natural processes. Another extremely important determinant on the protected area target percentage is the level of ecological risk decision makers are willing to accept with different alternatives.

Table 2. Representation results based on the AoR tool and protocol developed by World Wildlife Fund Canada. Data obtained from the Boreal Information Centre (www.borealinfo.org).

Level of Representation	Number	Area (ha)
Adequate Representation	37	3,304,695
Moderate Representation	12	818,145
Partial Representation	20	4,533,324
No Representation	79	2,922,698
Totals	148	11,578,862

Approximately 82 percent of the region is made up of logging tenures with the remaining area in agricultural or urban land uses (Figure 6). Based on tenure data provided by the Boreal Information Centre, there are 14 logging companies with operations in the Alberta Foothills that effect >80,000 ha. Logging tenures are typically more complex than a single company per tenure, but the level of regional involvement can be derived from the lead company in the existing database. Over half of the tenured region is managed by two companies Weyerhaeuser and West Fraser Mills Ltd., over 24 million ha and nearly 19 million ha respectively. Nine other companies operate on tenured areas >1 million ha (Table 3). Clearcut logging is the dominant forestry method practiced in the ecoregion with varying degrees of tree retention on some sites. As will be shown in the landscape change section, some areas have been impacted heavily over the last 15 years.


Photo courtesy of Peter Lee

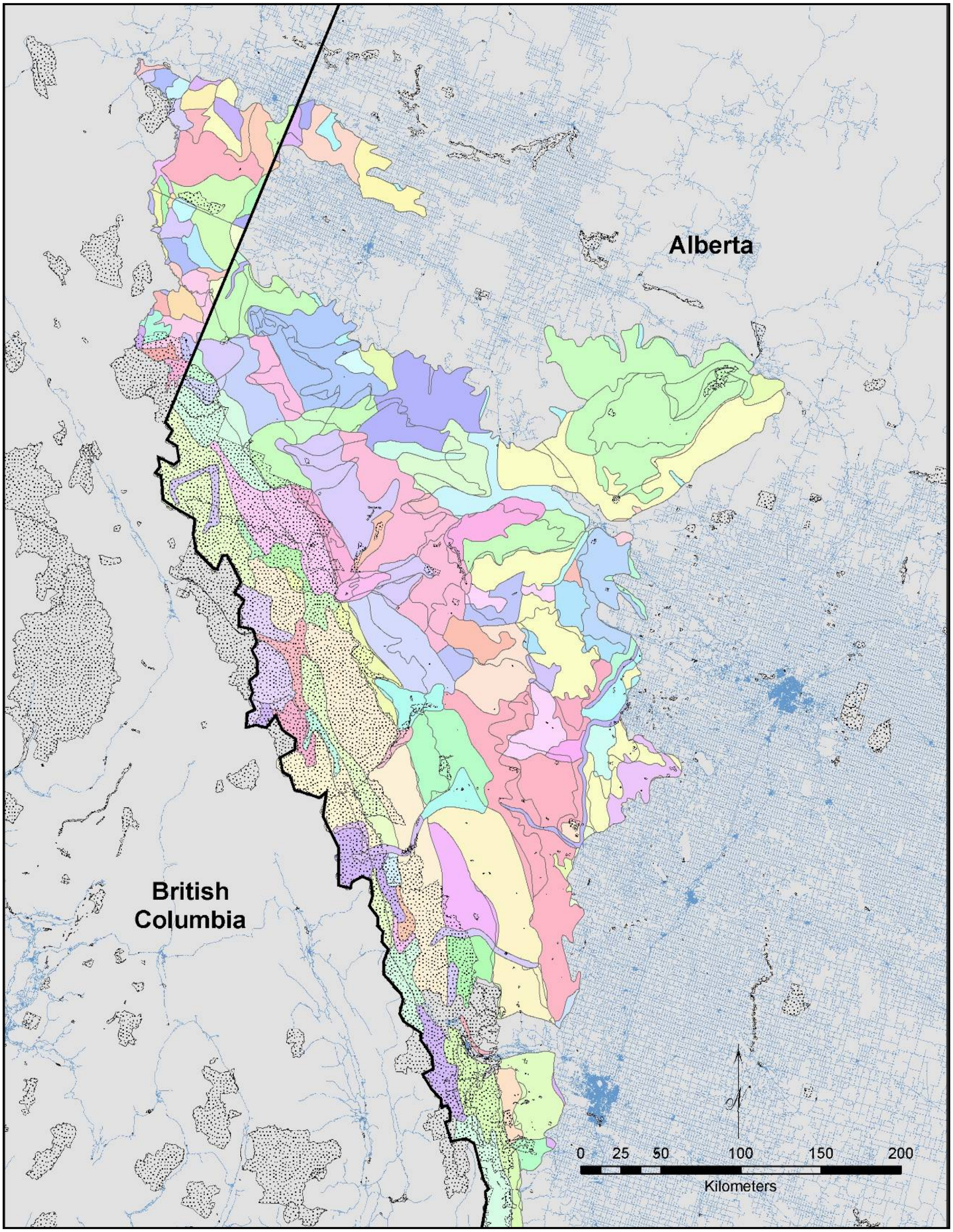

Figure 4. Map showing the 148 enduring features for the Alberta Foothills ecoregion. Note that the colors are not unique for each one. Existing protected areas are highlighted with a stippled pattern. Enduring feature boundary extends beyond the Alberta Foothills ecoregion. Data from the Boreal Information Centre (www.borealinfo.org).

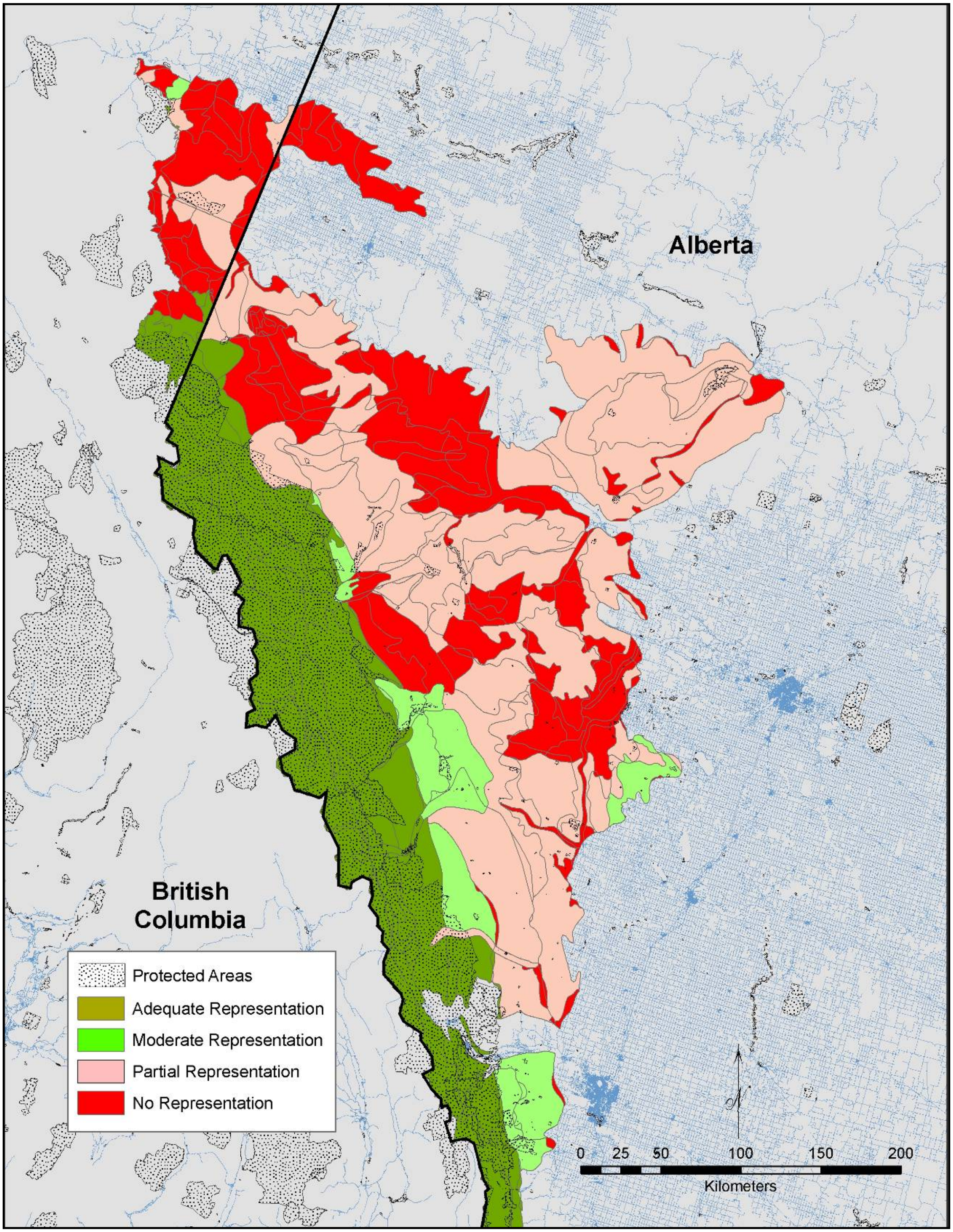

Figure 5. Enduring feature representation results for the Alberta Foothills ecoregion. Data from the Boreal Information Centre (www.borealinfo.org).

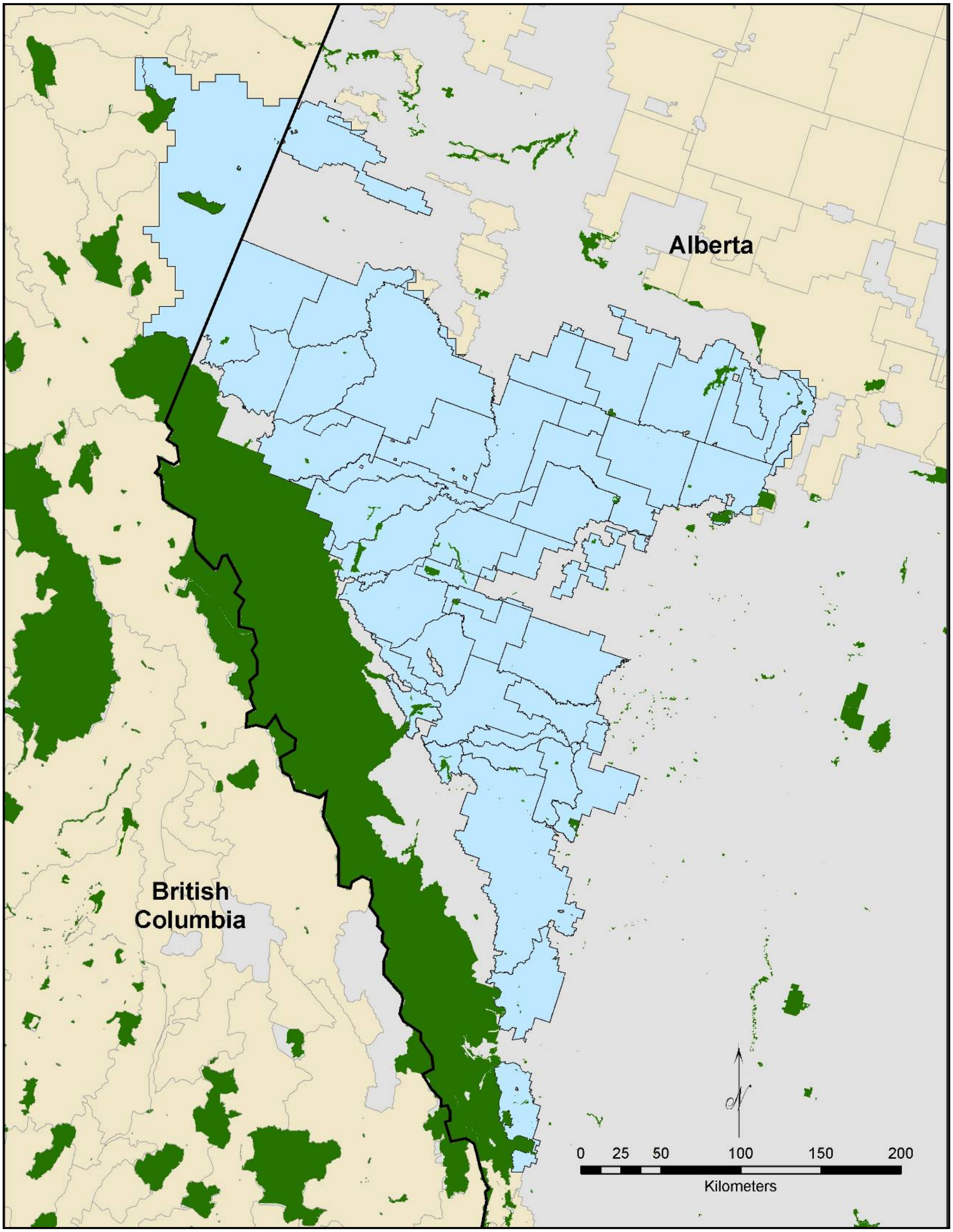

Figure 6. Map showing the logging tenure boundaries that intersect the Alberta Foothills ecoregion (cyan) and neighboring region (light yellow). Protected areas are shown in green. Data from the Boreal Information Centre (www.borealinfo.org).

Table 3. Ranking of leading logging tenure holders in the Alberta Foothills ecoregion.[1] Data obtained from the Boreal Information Centre (www.borealinfo.org).

Company	Area (ha)
Weyerhaeuser	24,251,998
West Fraser Mills Ltd.	18,689,859
Blue Ridge Lumber (1981) Ltd.	6,444,641
Slave Lake Pulp Corporation	6,198,333
Sunpine Forest Products Ltd.	5,670,046
Canadian Forest Products Ltd.	5,447,852
Millar Western Industries Ltd.	4,629,302
Alberta Newsprint Company Ltd.	3,636,812
Spray Lake Sawmills (1980) Ltd.	2,804,426
Sundance Forest Industries Ltd.	2,652,071
Tolko Industries Ltd. & Gordon Buchanan Enterprise	1,380,143
Vanderwell Contractors (1971) Ltd.	736,544
Community Timber Permit Program	429,656
Ainsworth Lumber Co. Ltd.	82,601
Grand Total	83,054,284

[1]- Area total larger than the ecoregion to cover full ownership that intersects the region.

Oil and gas development is also a major human disturbance factor in the Alberta Foothills. The number of wells is nearly 36,000 and that number continues to increase. Figure 7 shows the results of the oil and gas development footprint produced by World Wildlife Fund Canada as part of their 2004 Nature Audit. Oil and gas development in this region can consist of single drilling rigs, clusters of rigs, pipelines, processing centers, and seismic exploration – all negatively impacting many aspects of native biodiversity. The combined impacts from forestry, oil and gas, and the infrastructure needed to sustain these activities have the potential to eliminate entire species such as woodland caribou and seriously degrade the overall composition, structure, and function of the forest ecosystem. The human services provided by a more intact system – clean water and sequestered carbon – is also be severely impacted.


Photo courtesy of Peter Lee


Photo courtesy of Peter Lee

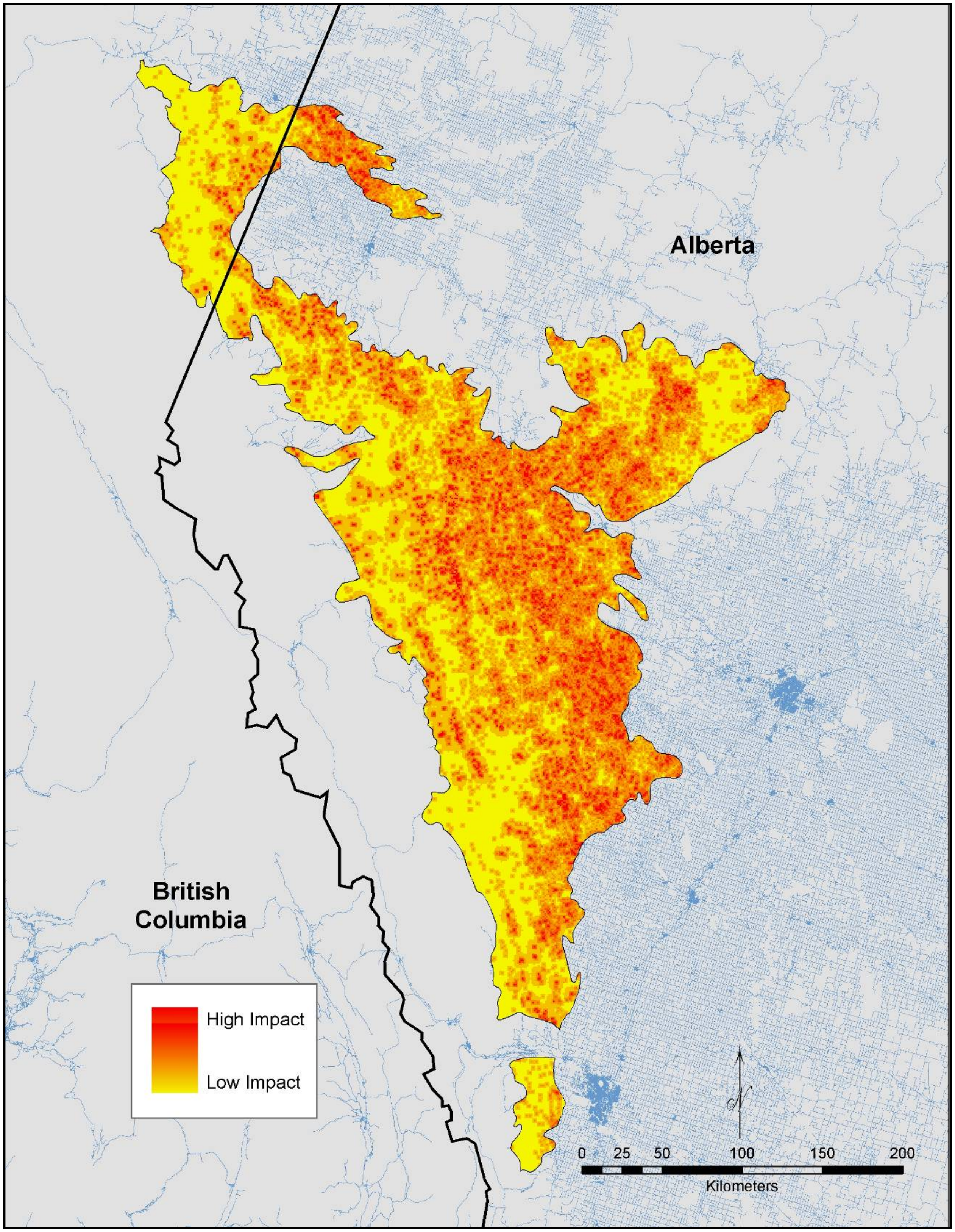

Figure 7. Map showing the oil and gas development footprint in the Alberta Foothills from the Nature Audit (World Wildlife Fund Canada 2004). Data from the Boreal Information Centre (www.borealinfo.org).

Landscape change

In order to better understand the rate of anthropogenic landscape change in the Alberta Foothills due to primarily logging and oil and gas development, we pulled in recent change analysis data from Global Forest Watch Canada based on Landsat TM and ETM+ satellite imagery obtained at three times circa 1990, circa 2000, and circa 2006. The resolution of the input data and analysis was 30m. Using a standard change detection procedure involving a computer pixel-by-pixel comparison of each date, two change themes were created (1990 – 2000 and 2000 – 2006). For a detailed description of the change detection methods, please see GFWC's original two "Recent Anthropogenic Change" publications (Stanojevic et al. 2006a, Stanojevic et al. 2006b) plus the most recent publication for a description of modifications to the methodology from previous work (Lee 2007).

As a part of this particular analysis, an accuracy assessment involving 48 field checks was employed. The points were selected based on confidence/non-confidence levels and accessibility. The geographic extent and number of points selected were of assistance in understanding the level of accuracy and in assessing our confidence level in our change analysis work.

Results showed that approximately 9 percent of the Alberta Foothills has been impacted by anthropogenic change visible from space from 1990 – 2006 (Figure 8). On average, this is approximately 0.54 percent per year. The actual impact is greater but difficult to quantify. Some disturbances are more dispersed, narrow (some roads and seismic lines), or masked by tree canopies, but they are still important ecologically. Also for some species and natural processes, impacts extend far beyond the actual area directly impacted by development. For example, caribou demonstrate avoidance of developed areas by considerable distances (1-5km; Schaefer and Mahoney 2006). If we apply a conservative 500m buffer from the standpoint of caribou of all human disturbances from 1990-2006, approximately 55 percent of the ecoregion was impacted.

Alberta Foothills Values

The Alberta Foothills contains numerous conservation values. The focus of this assessment was on identifying and mapping Endangered Forests for the region, so this is not an exhaustive study on this topic. We incorporated each of the landscape and biodiversity components of Endangered Forests into a spatially explicit decision support model using a systematic analytical unit, which we discuss in the next section. We considered all three landscape integrity components – intact forest landscapes, remnant forest blocks, and landscape connectivity. There are no remaining intact forest landscapes as defined by Global Forest Watch (undisturbed forest landscapes >50,000 ha), but there were considerable remnant blocks (undisturbed forest landscapes 100 – 50,000 ha), which we updated with the most recent disturbance data obtained from the 2006 Landsat 7 ETM+ satellite imagery (Figure 9). Approximately one-third of the region is composed of over 2,100 remnant blocks with the mean size being 1,500 ha. Connectivity was addressed at a number of different scales. We examined forest fragmentation of the remaining forest blocks, connectivity needs for grizzly bear, and riparian corridors.

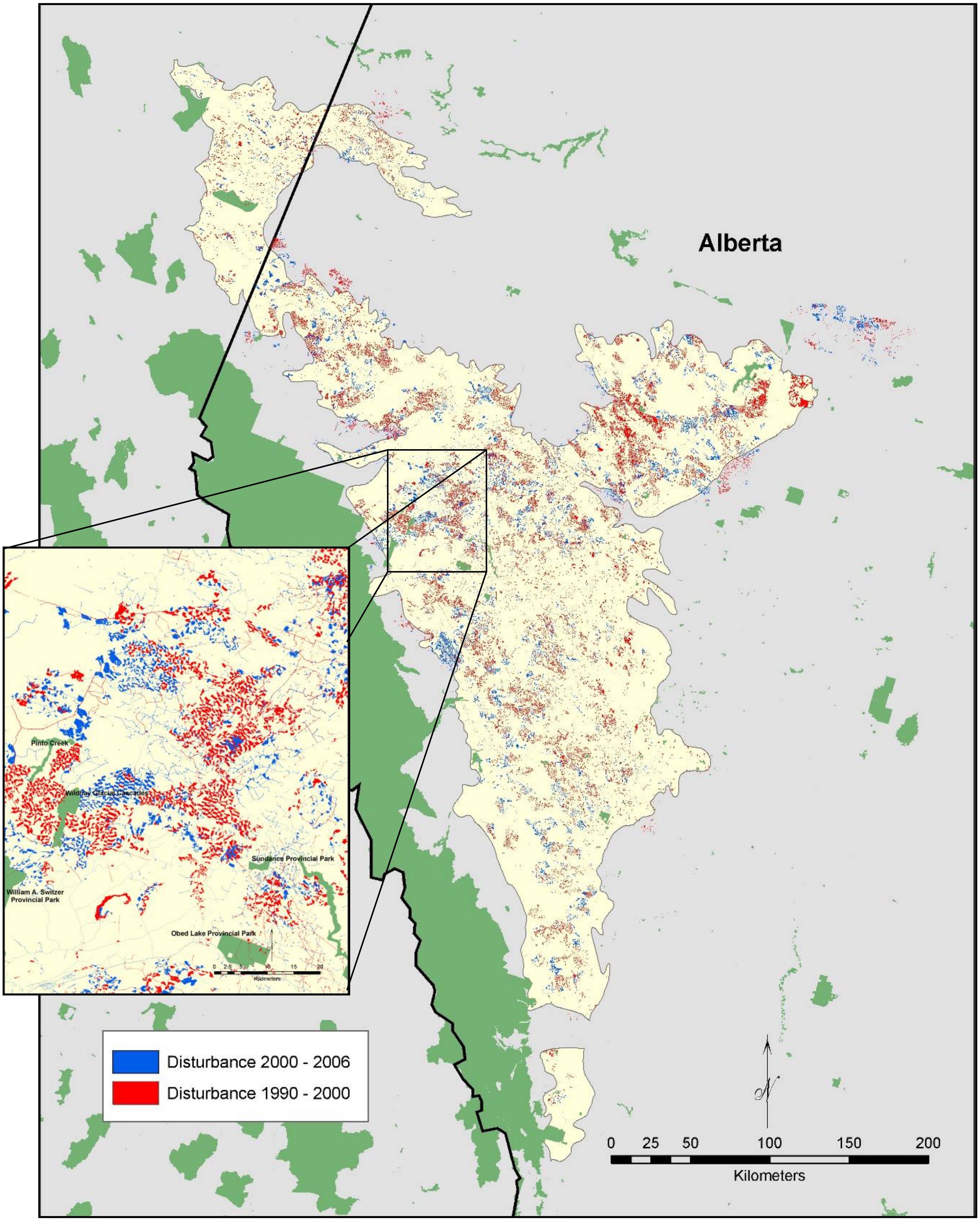

Figure 8. Map showing anthropogenic disturbance from 1990-2000 and 2000-2006 for the Alberta Foothills ecoregion. Data courtesy of Global Forest Watch Canada.

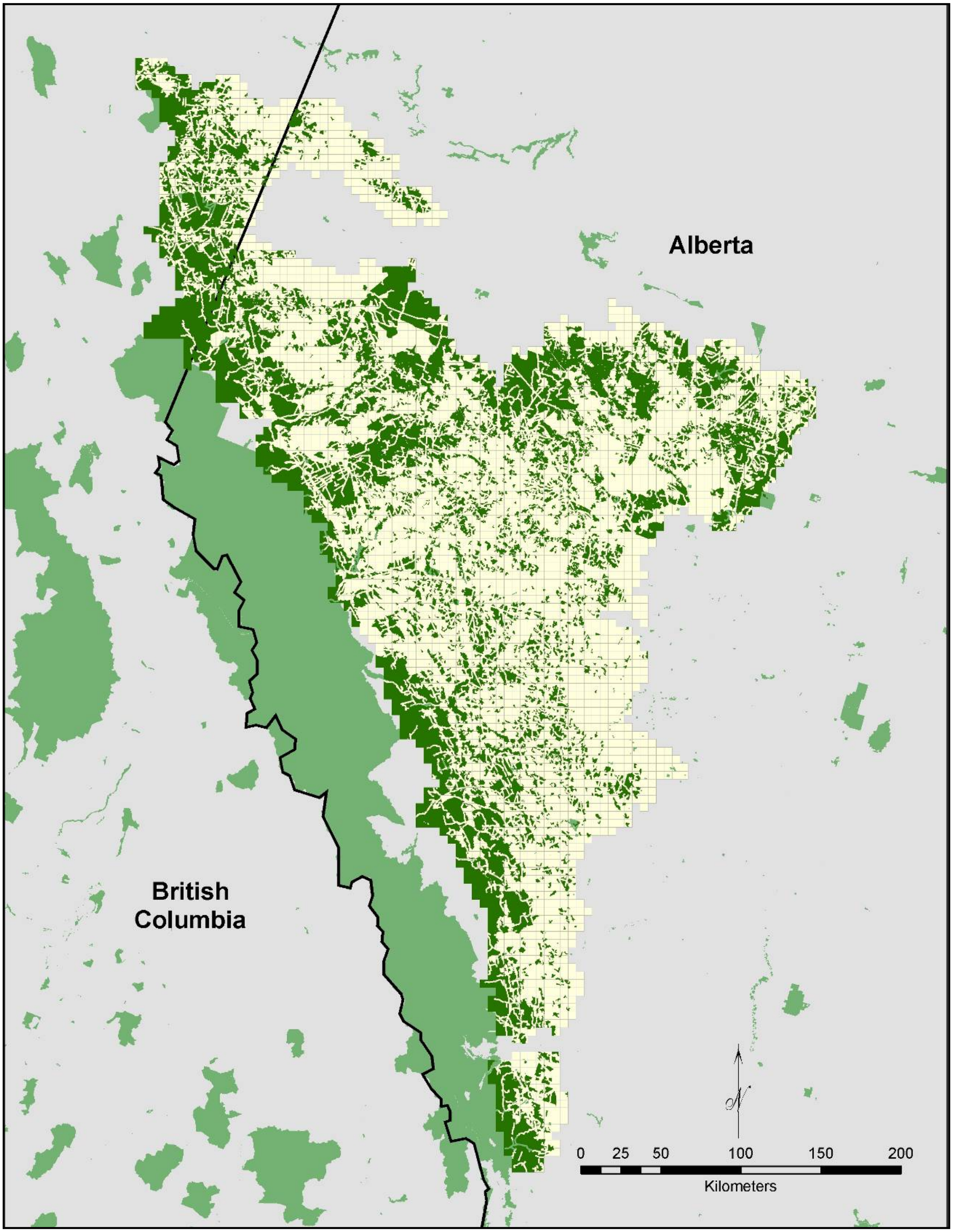

Figure 9. Map showing remnant forest blocks (dark green) in the Alberta Foothills study area (yellow grid). Protected areas are presented in medium green.

Of the biodiversity components, we emphasized rare forest types (specifically old growth and less fragmented forests), concentrations of rare and endangered species and other important heritage elements, and core habitat for a handful of important focal species, including woodland caribou (*Rangifer tarandus*), grizzly bear (*Ursus arctos horribilis*), bull trout (*Salvelinus confluentus*), arctic grayling (*Thyallus arcticus*), and two guilds of birds (forest dependent species and water dependent species). The focal species chosen included some that require large home ranges in a relatively intact state (e.g., woodland caribou) or away from human persecution (e.g., grizzly bear). The two fish species were chosen because they both require clean, cold water and are in decline in the region. The two bird guilds were chosen to capture those species dependent on wetlands and old-growth forests. Species richness and endemism were not easily discernable and minimally important for this region and therefore not considered.

One of the most critically threatened focal species in the ecoregion is woodland caribou. Five herds are located partially or entirely in the Alberta Foothills ecoregion (Figure 10). Two herds are identified as boreal ecotype (Little Smoky and Slave Lake) and three are mountain ecotypes (Narraway, Redrock/Prairie Creek, and A la Peche). The mountain herds utilize portions of the Alberta Foothills as winter range. All of these herds contain relatively low population levels (<200 animals) and numbers continue to fall in some of these herds. The only herd completely restricted to the ecoregion is the Little Smoky herd with the population containing fewer than 60 individuals and falling (citation). Other woodland caribou populations are located in neighboring British Columbia, which are in the southern race.

1 – black-throated green warbler

2 – woodland caribou

3 – grizzly bear

4 – bull trout

5 – Harlequin duck

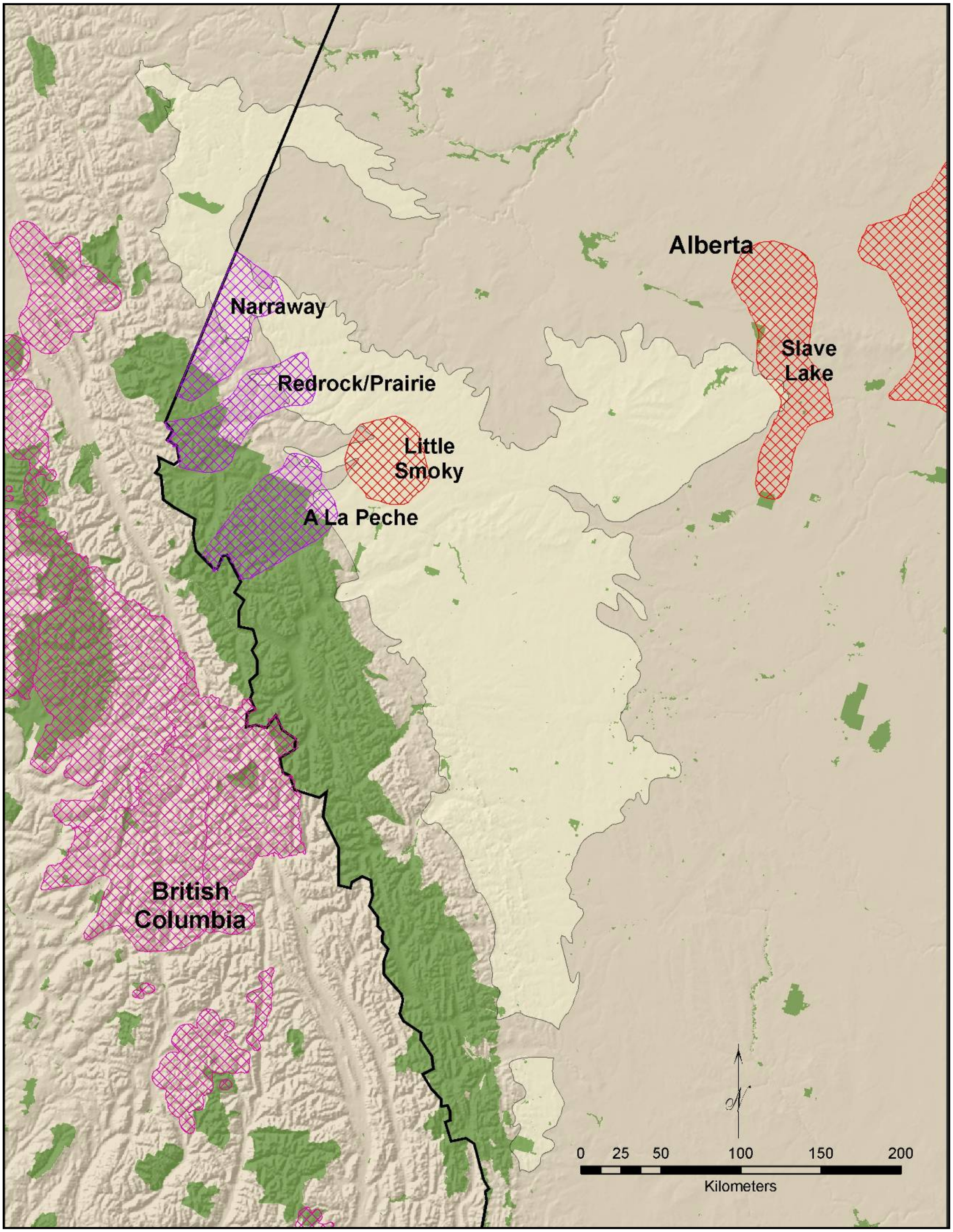

Figure 10. Map showing remaining woodland caribou herds in and around the Alberta Foothills study area in relationship to the existing protected areas network (dark green). Red cross-hatch denotes boreal herds, purple denotes mountain herds, and magenta denotes southern herds located in neighboring British Columbia.

Methods

Decision Support Approach

The decision support tool we used to address the issue of endangered forests is grounded in Geographic Information Systems (GIS) and relies on implementation of decision rules developed in NetWeaver® and Ecosystem Management Decision Support (EMDS®) (Figure 11). This decision support approach was found to be one of the most versatile and comprehensive with regard to forest assessment and planning of over 30 software packages tested (Gordon et al. 2004). The technique uses spatially explicit data from a wide range of sources and evaluates the primary question of site suitability based on a number of ecological considerations at multiple spatial scales. The GIS software used to interface with the decision support software and map the results was ArcMap® version 9.1 by ESRI.

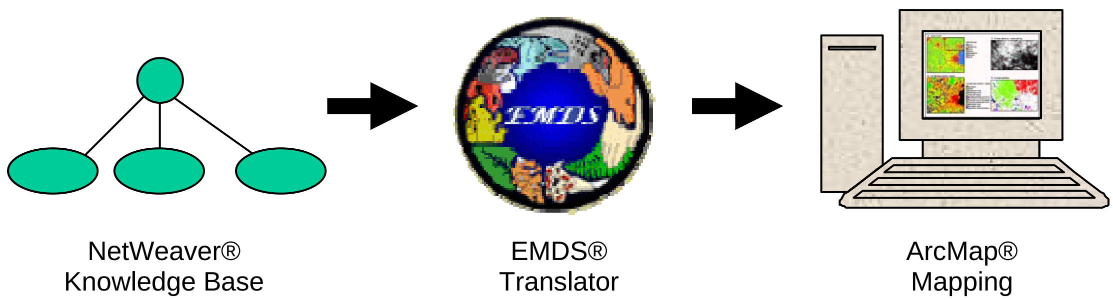

Figure 11. Diagram showing decision support model software interaction.

The Analytical Study Area

The resolution of the decision support modeling exercise was 5km x 5km. A grid cell mesh placed on top of the Alberta Foothills ecoregion resulted in 3,558 individual grid cells totaling nearly 89,000 km^2. In order to include the total area of all of the large logging tenures that intersected the ecoregion, we expanded the study area by an additional 486 grid cells putting the total region analyzed at slightly over 101,000 km^2 (Figure 12).

Data

Over 50 different data themes from around a dozen sources were used in this study (Appendix A). Approximately half of these layers were obtained from the Boreal Information Centre website (www.borealinfo.org) and provided both contextual information as well as a number of analytical themes. As you can see, the data themes used are of various data structure types (raster images, grids, points, lines, and polygons) and constructed or assembled at different scales and resolutions. With only a few exceptions, data themes used for the analytical portion of the study were at a scale of 1:100,000 or better. Forty-four unique data themes/inputs were used in the decision support tool developed for identifying and mapping endangered forests in the Alberta Foothills (Table 4). Some of these inputs were used multiple times in the knowledge base for a total of 68 specific theme/data inputs into the decision support model.

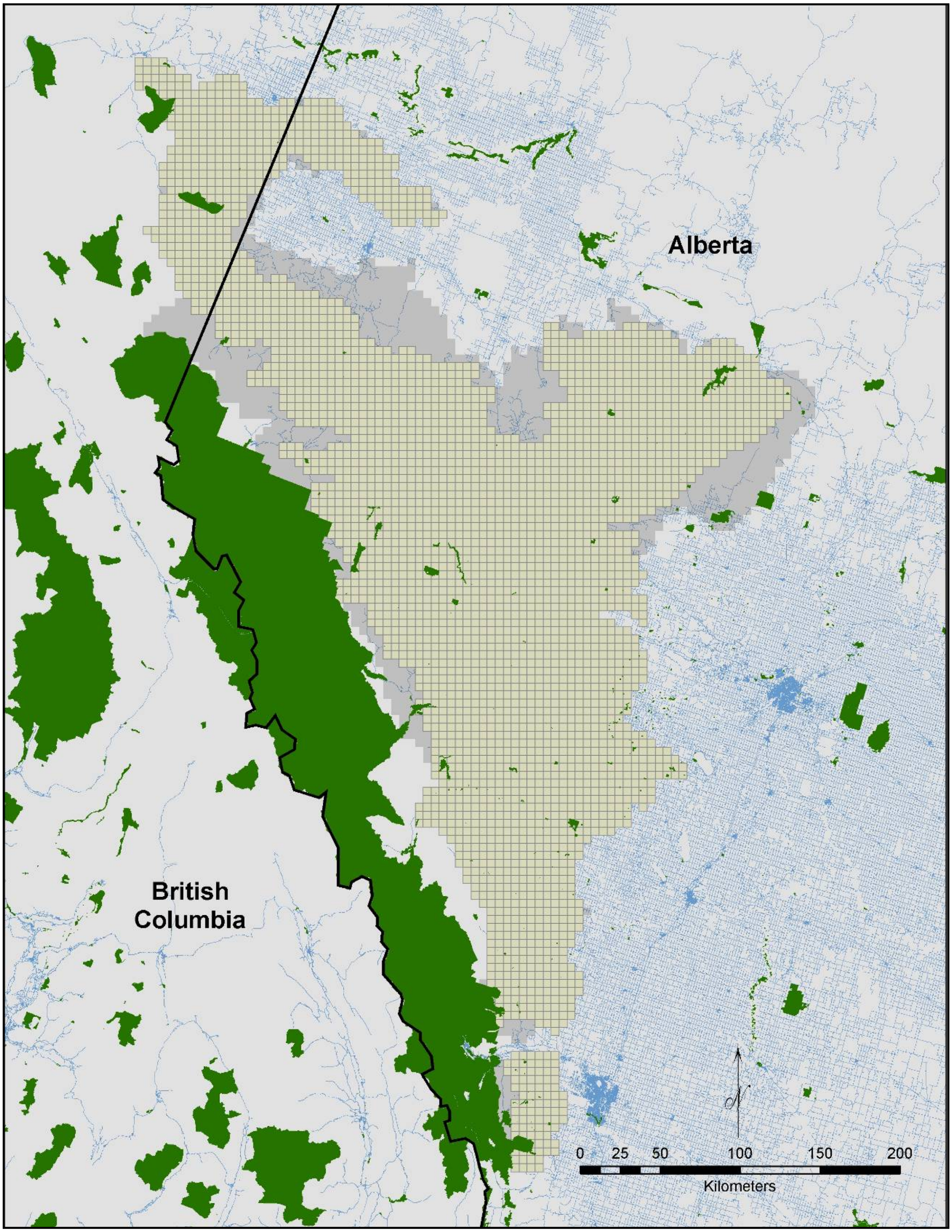

Figure 12. Map showing the analytical grid based on the Alberta Foothills ecoregion and the extension based on tenure coverage (gray shading).

Table 4. List of data inputs in the Endangered Forest decision support model for the Alberta Foothills ecoregion.

Data Input	Code	Source	Use
Arctic Greyling Occurrence	ARCGREY	Alberta Forestry, Lands and Wildlife	Number of occurrence points per cell.
Average Grizzly Bear Habitat Selection	GB_HAB	Foothills Model Forest	Mean of modeled resource selection by grizzly bears for each cell.
Grizzly Bear Connectivity	GCONNECT	Foothills Model Forest	Mean grizzly corridor as modeled by FMF for each cell.
Blue Listed Birds	BLU_LIST	NatureServe	Number of blue listed bird species per cell.
Boreal Bird Richness	POT_BIRD	NatureServe	Number of bird species per cell with >80% of breeding population in the boreal zone.
Bull Trout Class AB Streams	BULL_AB	Alberta Sustainable Resource Development	Length of high quality bull trout streams per cell.
Bull Trout Occurrence	BULL_OCC	Alberta Forestry, Lands and Wildlife	Number of occurrence points per cell
Bull Trout Survey	BTROUT	Berwin and Berwin 1997	Length of stream identified as bull trout occupied for each cell.
Caribou Occurrence	CARIBOU	Alberta Natural Heritage Information Centre, NatureServe, and Alberta Sustainable Resource Development	Percent of cell in known caribou habitat based on a combined map of caribou occurrence.
Cell Contagion	C_CONTAG	Conservation Biology Institute	Based on FRAGSTATS results from a forest/non-forest layer. Mean contagion value for each cell.
Cell Mean Nearest Neighbor	C_MINN	Conservation Biology Institute	Based on FRAGSTATS results from a forest/non-forest layer. Mean mean nearest neighbor value for each cell.

Cell Patch Number	C_NP	Conservation Biology Institute	Based on FRAGSTATS results from a forest/non-forest layer. Mean patch number value for each cell.
Cell Percent Disturbed	C_DIST	Global Forest Watch Canada	Based on satellite image interpretation and change detection analysis. Percent of cell mapped as disturbed between 1990 -2006.
Cell Percent Forest	C_PCTFOR	Conservation Biology Institute	Forest area mapped based on 2006 satellite imagery. Percent forest calculated for each cell.
Cell Road Density	C_RDDEN	Natural Resources Canada, DMTI, and Global Forest Watch Canada	Road density calculated for each cell (km/sq km) based on a composite roads data layer.
Cell Road/Stream Intersect	C_RDSTR	Natural Resources Canada, DMTI, and Global Forest Watch Canada and streams derived from DEM	Number of intersections based on combined roads and generated stream network based on DEM (see Stream Length).
Cell Total Core Area Index	C_TCAI	Conservation Biology Institute	Based on FRAGSTATS results from a forest/non-forest layer. Mean total core area index for each cell.
Cell Well Number	C_WELLS	Global Forest Watch Canada	Number of oil and gas wells per cell.
Environmental Significant Area	ESA_AREA	Alberta Natural Heritage Information Centre	Percent of cell that is contained in an ESA.
Female Grizzly Bear Fall	FGB_FALL	Foothills Model Forest	Mean female fall resource selection function results for each cell.
Female Grizzly Bear Spring	FGB_SPNG	Foothills Model Forest	Mean female spring resource selection function results for each cell.

Focal Contagion	F_CONTAG	Conservation Biology Institute	Based on FRAGSTATS results from a forest/non-forest layer. Mean contagion value for each cell 3x3 moving window neighborhood.
Focal Mean Nearest Neighbor	F_MNN	Conservation Biology Institute	Based on FRAGSTATS results from a forest/non-forest layer. Mean mean nearest neighbor value for each cell 3x3 moving window neighborhood.
Focal Patch Number	C_NP	Conservation Biology Institute	Based on FRAGSTATS results from a forest/non-forest layer. Mean patch number value for each cell 3x3 moving window neighborhood.
Focal Percent Forest	F_PCTFOR	Conservation Biology Institute	Forest area mapped based on 2006 satellite imagery. Percent forest calculated for each cell 3x3moving window neighborhood.
Focal Total Core Area Index	F_TCAI	Conservation Biology Institute	Based on FRAGSTATS results from a forest/non-forest layer. Mean total core area index for each cell 3x3 moving window neighborhood.
Grizzly Bear Mortality	GB_MORT	Foothills Model Forest	Average mortality risk for each cell.
Grizzly Bear Habitat Patches	GBPATCH	Foothills Model Forest	Percent of analysis cell containing grizzly habitat patches of medium or high importance for maintaining overall landscape connectivity.
Grizzly Bear Population Sink	GB_SINK	Foothills Model Forest	Amount of each cell identified as being a highly probable sink area.
Grizzly Bear Population - Spring	P6_SPNG	Foothills Model Forest	The average spring bear population levels for each analysis cell.

Grizzly Bear Population – Summer	P6_SPNG	Foothills Model Forest	The average summer bear population levels for each analysis cell.
Grizzly Bear Population - Fall	P6_SPNG	Foothills Model Forest	The average fall bear population levels for each analysis cell.
Heritage Score	HERITAGE	Alberta Natural Heritage and BC Conservation Data Centre	Number of heritage records since 1985 in each cell. Weighting included S1 = 5, S2 = 3, S3 = 1.
Intactness	INTACT	Conservation Biology Institute	Mapped based on 2006 satellite imagery and most recent disturbance data (e.g., roads and wells).
Lakes Area	LAKES_HA	US National Imagery and Mapping Agency	Area of lakes within each cell.
Major Roads	MAJROADS	Natural Resources Canada and DMTI	Length of major road per cell. Major roads defined as paved two lanes or larger.
Male Grizzly Bear Habitat Selection	MGB_HAB	Foothills Model Forest	Mean male spring resource selection function results for each cell.
Percent Old Growth	OLD_PCT	Foothills Model Forest	Percent old-growth forest (>150 years) of cell based on satellite image interpretation (30m resolution).
Percent Old Growth 100	OLD_100	Foothills Model Forest	Percent old-growth forest (>100 years) of cell based on satellite image interpretation (30m resolution).
Percent Tenured	P_TENURE	Global Forest Watch Canada	Percent of cell in logging tenures.
Percent Wetlands	WET_PCT	Peatlands of Canada - Geological Survey of Canada	Percent of cell that is wetland (bog, fen, swamp, and marsh).
Pipeline Length	PIPELINE	Foothills Model Forest	Length of pipelines in km for each cell. Data missing from some areas.

Stream Length	STREAMS	Conservation Biology Institute	Total length of stream per cell. Streams layer created using 80 m DEM and 1.5km catchments function in ArcHydro.
Wildlife Habitat	HABITAT	Alberta Sustainable Resource Development	Cells containing identified important habitat.

Netweaver® is a logic-based software developed to address questions that depend upon spatial data. Unlike conventional GIS applications, which is often based on Boolean logic (1,0 – true, false) or scored input layers, Netweaver® is built upon fuzzy logic. Individual data layers are assembled into a hierarchical logic framework to address particular questions (or goals). In this case, the main goal is to map where High Conservation Values occur within the Alberta Foothills and to define potential sites for new protected areas needed to protect the values (Endangered Forests). We assembled key data layers and arranged them into a logic diagram (or tree) to answer this primary question. One of the more powerful aspects of this software as opposed to conventional GIS operations is in the fuzzy logic. Simply put, fuzzy logic allows the user to assign shades of gray to thoughts and ideas rather than being forced to see the world as black (false) and white (true). All data inputs (regardless of the type of number inputs being used – ordinal, nominal, or continuous) are assigned relative values between -1 (false) and +1 (true) up to three decimal places. For every data input, the user determines how to assign the range of values along a truth continuum. Suppose we are trying to determine and map the most suitable habitat for conserving wolves. A roads layer is one of several important data inputs and we know from field research how roads impact wolves. The greater the road density to around 1.5km/sq km, the greater the negative impact on wolves. Wolves are essentially eliminated from landscapes with road densities above 1.5km/sq km. In designing a logic framework to address wolf habitat, it is best to think of each layer along a true/false continuum based on a proclamation – "high road densities have a negative impact on wolves." For this example, places with no roads get assigned a value of -1 (false). In other places, as road density increases the closer the assigned value approaches +1 (true). Since we know that wolves respond to a road density threshold (1.5km/sq km), we can assign a +1 value to all locations with road densities >1.5km/sq km. Logic trees constructed in Netweaver® assign every input layer in similar fashion allowing for very detailed and transparent ways of thinking about spatial data. The way in which the data are assembled is controlled by a number of logic operators (e.g., AND, OR, UNION, etc.). EMDS® reads the Netweaver® file and translates it into mapped results within ArcMap®. Finally, the interactive linking of the three software packages allows the user to view how a particular outcome was derived so there is maximum transparency – this is <u>not</u> a black box solution.

The Netweaver® logic diagrams used in mapping High Conservation Value and Endangered Forests for the Alberta Foothills are provided in Figures 13-19. In each logic diagram: (1) ovals depict goals, for which map outcomes are created; (2) operators (UNION, AND, and OR) are clearly marked, which control the logic; (3) all data themes appear in boxes and include the specific values that define true (+1) and false (-1) in the fuzzy logic; and (4) all data themes weighted in the model are indicated by a "W" inside a circle. Figure 13 shows the highest level order of the logic diagram. Conservation Value is shown as the final model goal based on the combined outcomes from the Landscape Value and Biodiversity Value models. Cells showing high Landscape Value are those with the highest level of intact landscapes and least impacted by roads, logging, and oil and gas development. Biodiversity Value represents the combined value of other models for Bird Value, Grizzly Value, Caribou Value, Fish Value, Forest Value, and Heritage Value.

Figure 14 pertains to Bird Value, which is made up by averaging (or the union) Bird Habitat and Bird Species. Bird Species is an <u>average</u> of Boreal Bird Species Richness and Blue Listed

Species. Bird Habitat is comprised of high-quality Forest Bird Habitat, which is the combined high Forest Value and high Intactness, <u>or</u> high-quality Aquatic Bird Habitat, which is equivalent to areas demonstrating high Watershed Quality and relatively high levels of aquatic resources (wetlands, lakes, and streams) per cell.

Caribou Value was modeled as a combination of Caribou Habitat Value and Caribou Occurrence (Figure 15). Caribou Occurrence (weighted by 10 in the model) was based on combining three different map sources to make sure the model was the most inclusive. These sources varied slightly from one another. Caribou Habitat Quality was mapped by <u>averaging</u> the Percent of Old Growth (>100 years; more being better) and Caribou Disturbance (less being better). Caribou Disturbance was based on <u>averaging</u> Cell Road Density, Cell Percent Disturbed, and Oil and Gas.

Fish Value was modeled as a combination of Watershed Quality and Species Occurrence (Figure 16). Species Occurrence is based on two species – Arctic Greyling and Bull Trout. Watershed Quality was the modeled as the <u>average</u> of Oil and Gas (based on Number of Wells and Pipeline Length), Road Density, Number of Road/Stream Intersections, Percent Forest, and Percent Disturbed. For all of the inputs other than Percent Forest, less was better than more in modeling Watershed Quality.

Forest Value was modeled as a combination Percent Old Growth (>150 years) and results from the Forest Fragmentation model (Figure 17). Forest Fragmentation was based on cell and neighborhood values for five different forest fragmentation metrics calculated using FRAGSTATS® (McGarigal and Marks 1995) based on a simple input theme of forest, non-forest, and water prepared from the most recent (2006) Landsat ETM+ satellite imagery. The five fragmentation metrics evaluated included: (1) Total Core Areas Index (calculates the percentage of core forest based on a 90m edge buffer distance), (2) Percent Forest, (3) Patch Number (total number of forest patches), (4) Mean Nearest Neighbor (mean distance in meters between the forest patches in a cell), and (5) Contagion (a measure of overall landscape permeability).

Grizzly Value was based on outputs of grizzly bear modelers from the ongoing Foothills Model Forest project. Grizzly Value was mapped as a combination (<u>union</u>) of Expanded Grizzly Bear Habitat and Grizzly Bear Habitat Security (Figure 18). Expanded Grizzly Bear Habitat is defined as mapped Grizzly Bear Connectivity <u>or</u> high Grizzly Bear Habitat Selection, which are based on grizzly bear population models for three seasons – spring, summer, and fall. Grizzly Bear Security is based on areas modeled with low Grizzly Bear Mortality <u>or</u> areas not identified as Grizzly Bear Sinks.

Heritage Value was based on areas with known Environmentally Significant Areas (ESAs) <u>or</u> high Heritage Scores (based on heritage program data since 1985 and weighted by level of rarity), <u>or</u> mapped important wildlife habitat by Alberta Sustainable Resource Development (Figure 19).

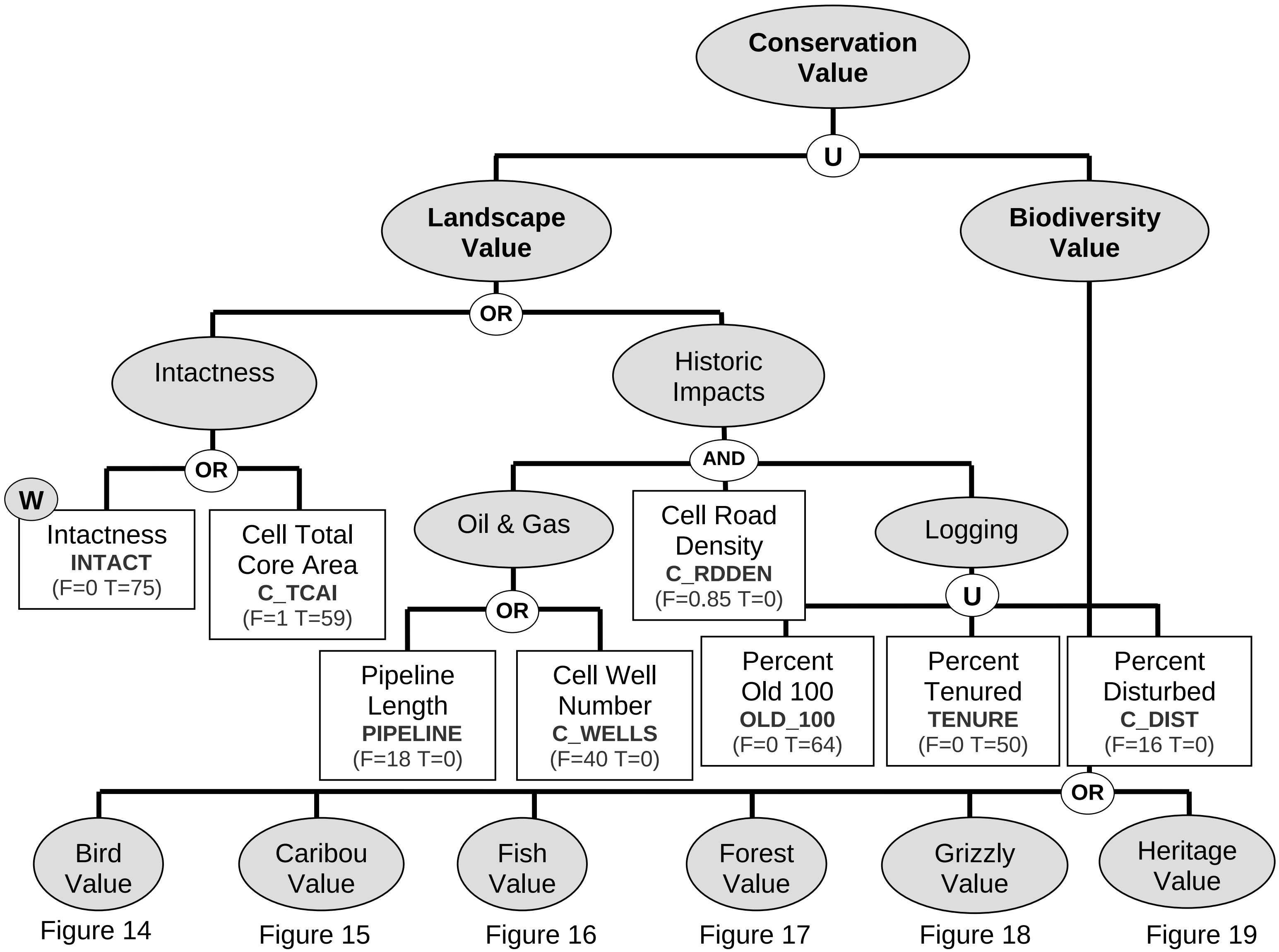

Figure 13. Higher level Netweaver® logic diagram for the Alberta Foothills decision support model.

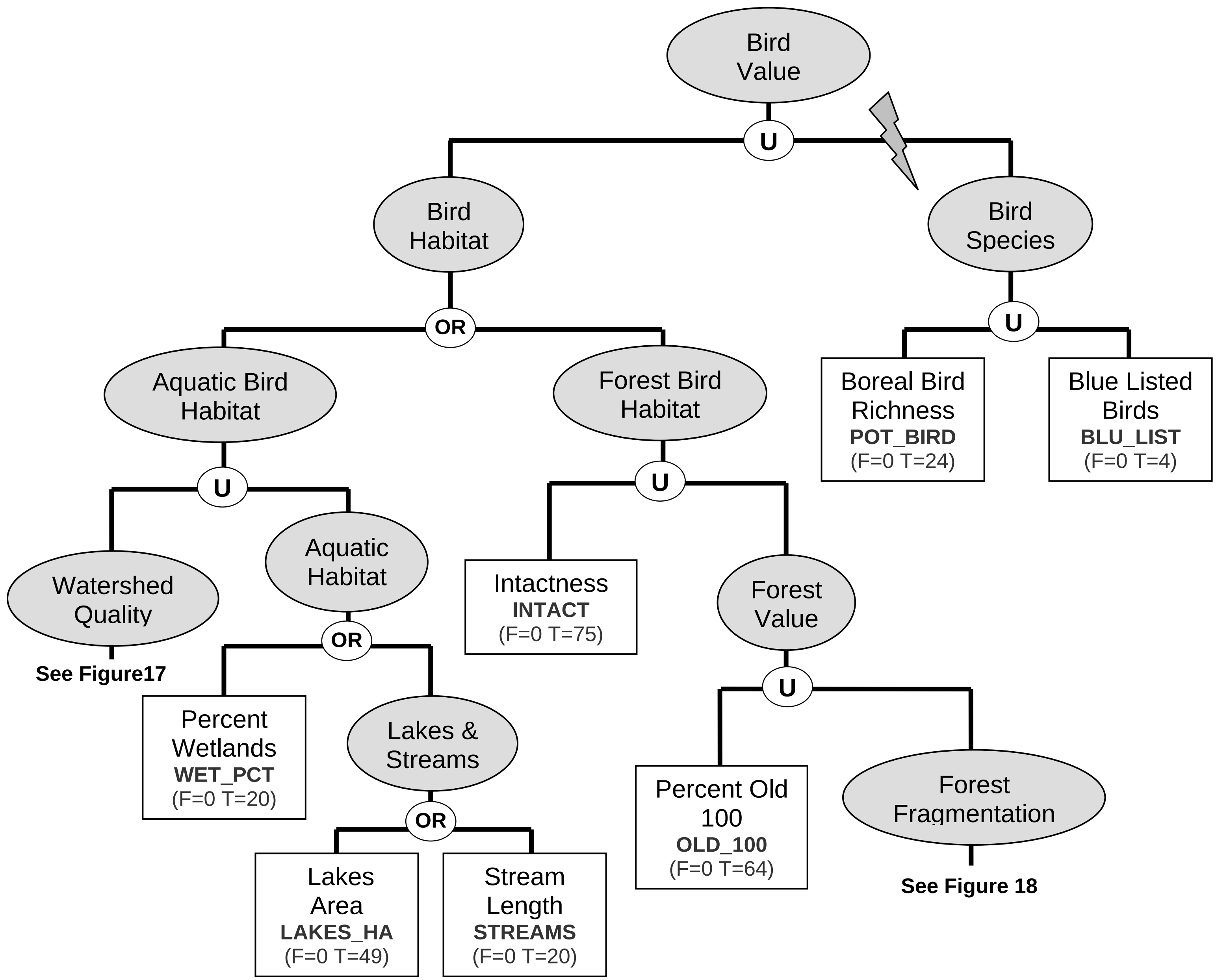

Figure 14. Bird Value Netweaver® logic diagram for the Alberta Foothills decision support model. Lightening bolt depicts a break in the logic diagram.

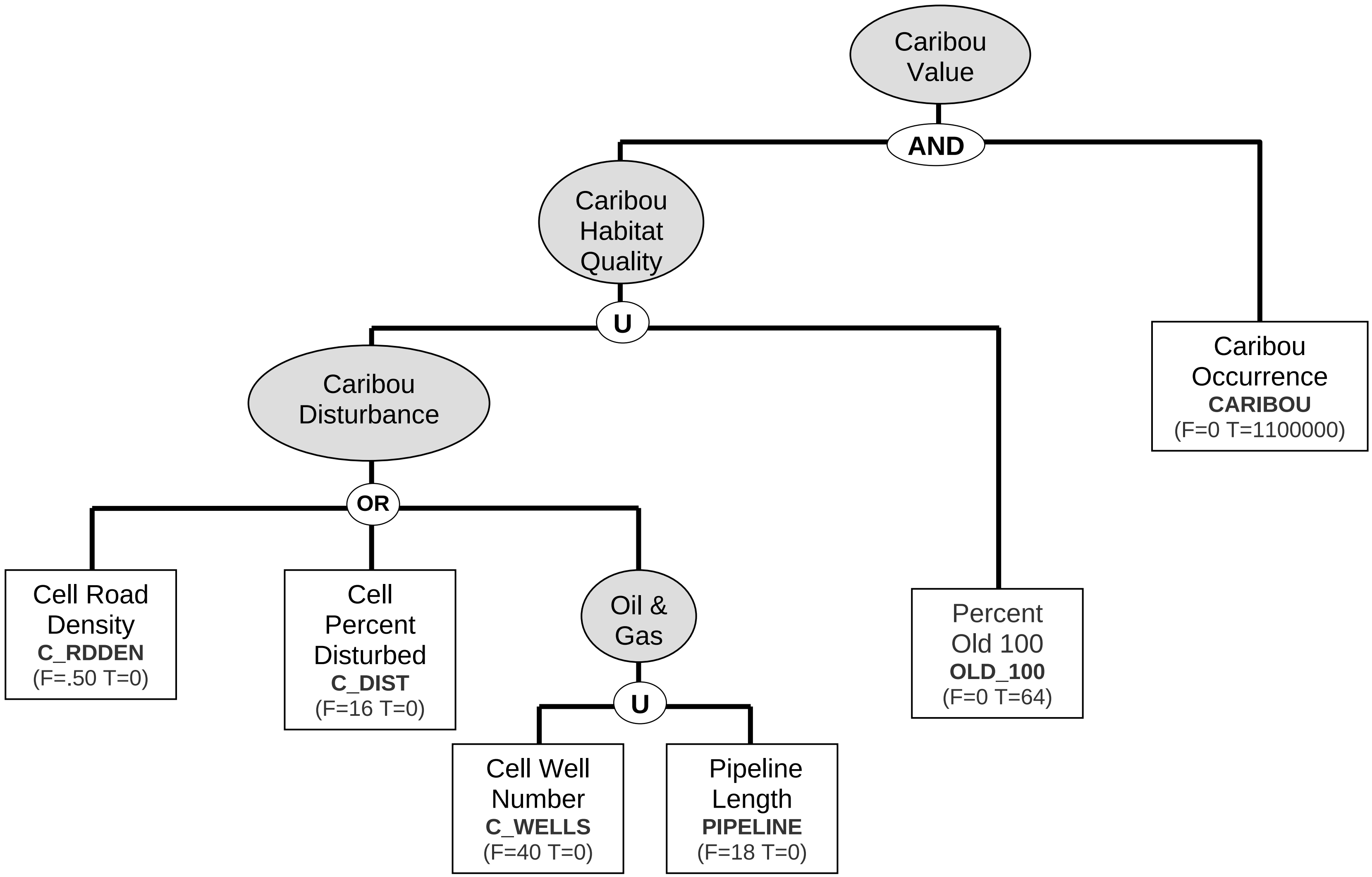

Figure 15. Caribou Value Netweaver® logic diagram for the Alberta Foothills decision support model.

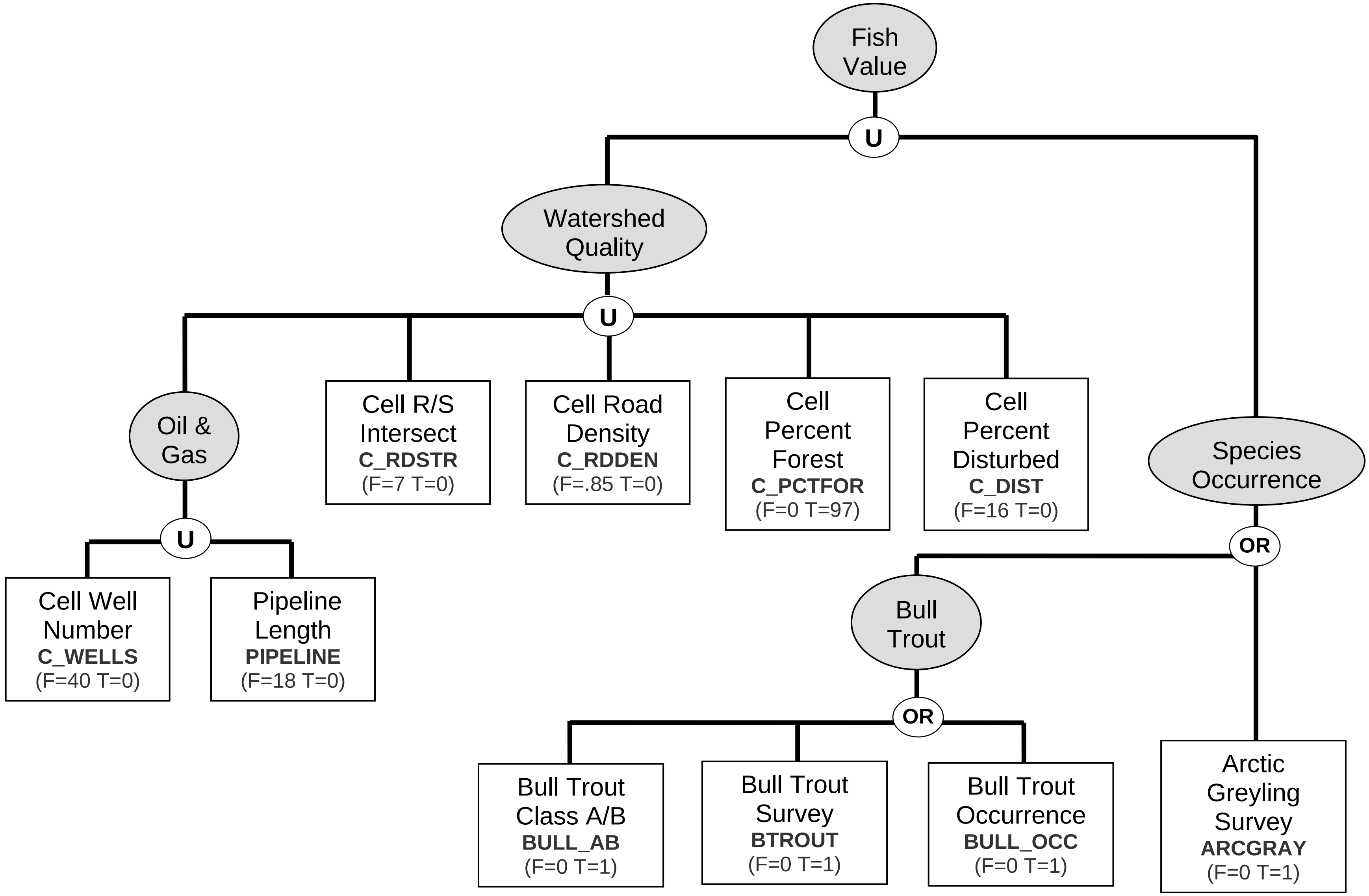

Figure 16. Fish Value Netweaver® logic diagram for the Alberta Foothills decision support model.

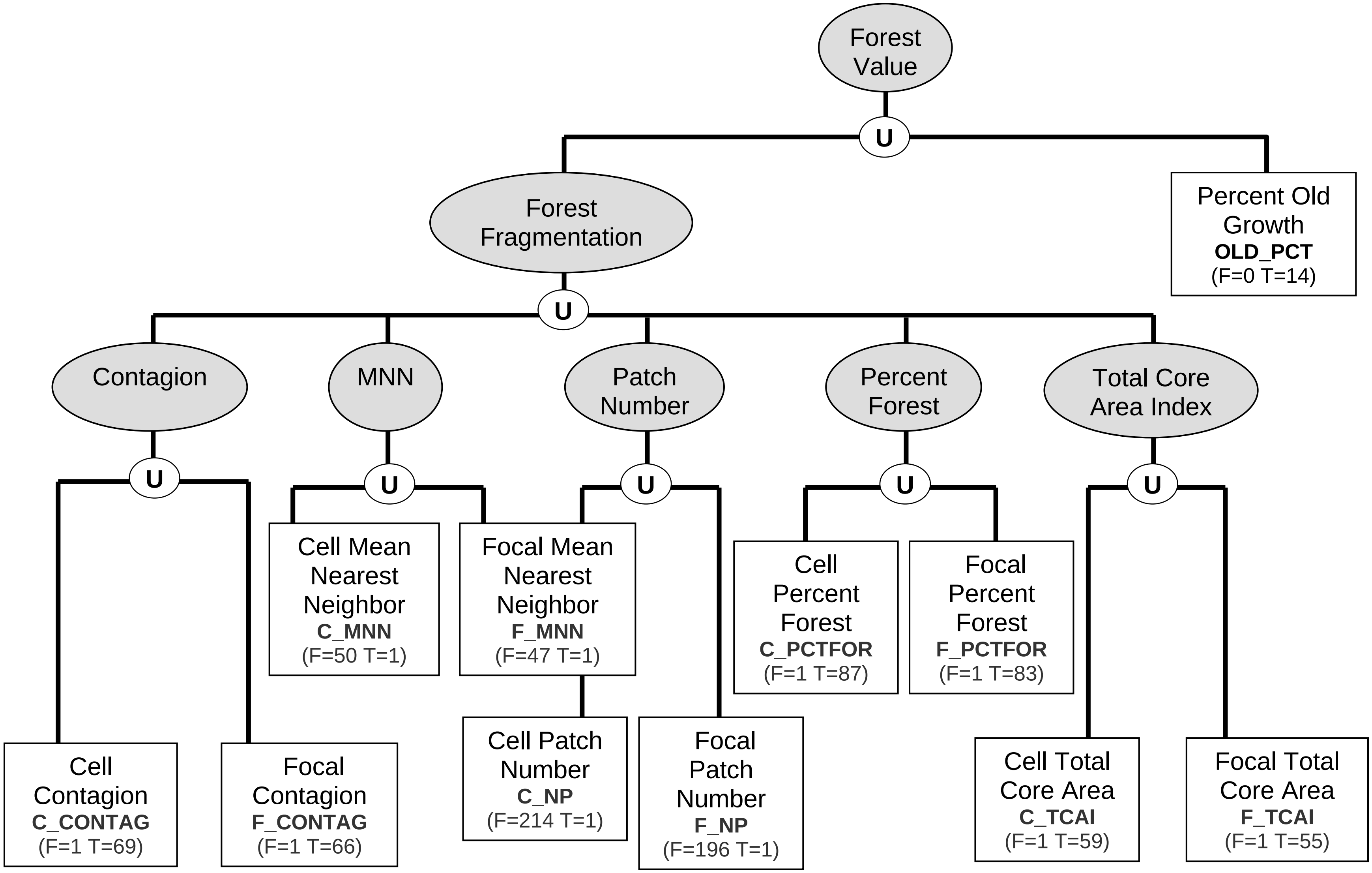

Figure 17. Forest Value Netweaver® logic diagram for the Alberta Foothills decision support model.

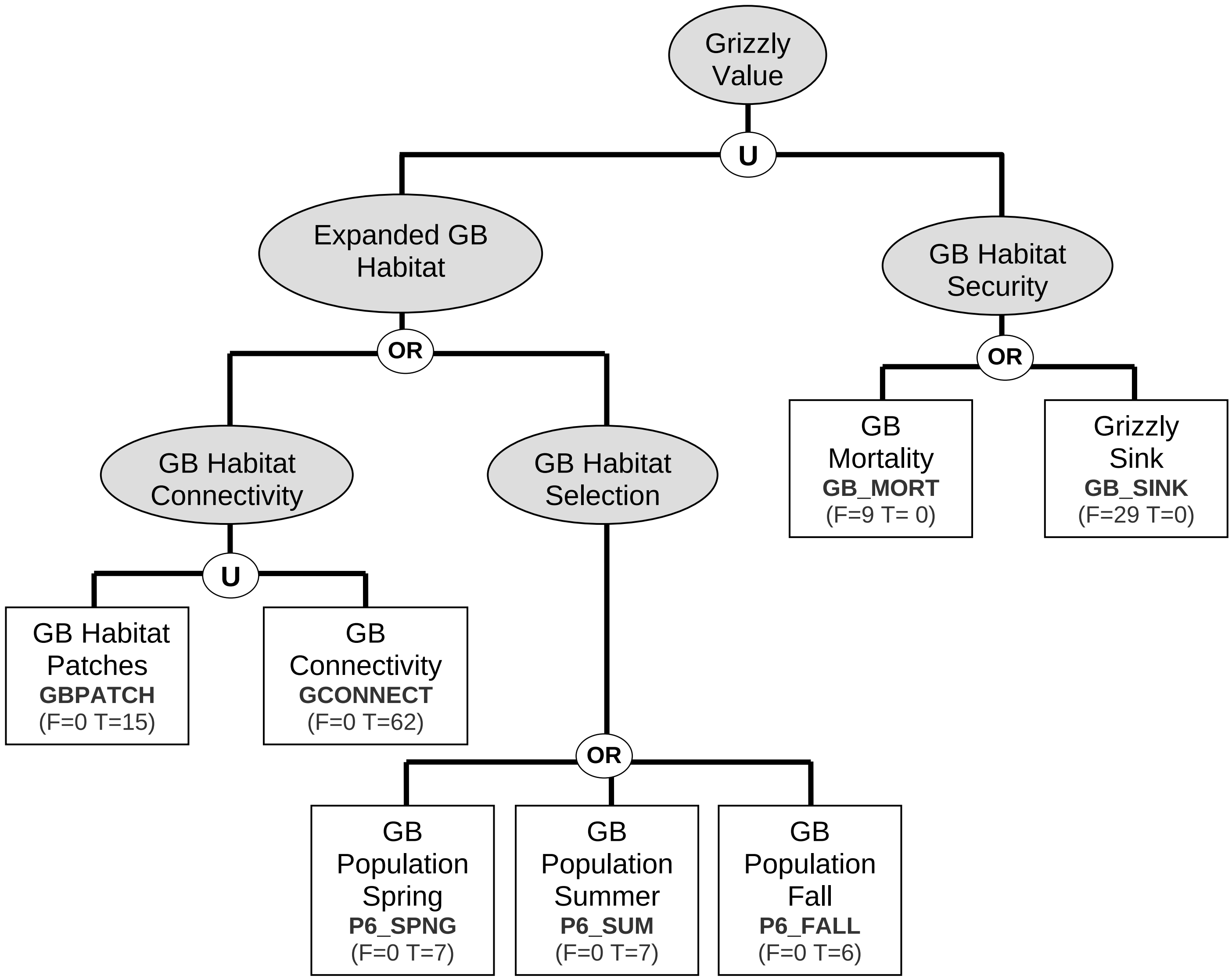

Figure 18. Grizzly Bear Value Netweaver® logic diagram for the Alberta Foothills decision support model.

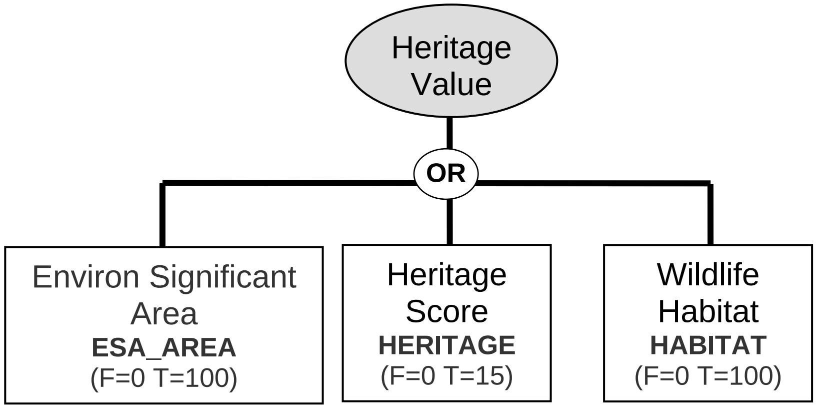

Figure 19. Heritage Value Netweaver® logic diagram for the Alberta Foothills decision support model.

Results & Discussion

As with all EMDS decision support models, mapped results are generated for every goal (represented as ovals in the logic diagrams). The logic diagram constructed for this study included over 30 goals. We have chosen to only present the higher level goal results with a discussion about what they mean and how they should be used to inform future land use decisions, particularly with regard to establishing new protected areas. And rather than starting with the apex goal called Conservation Value, we have elected to start with the 6 main goals under the Biodiversity Value heading – Bird Value, Caribou Value, Fish Value, Forest Value, Grizzly Value, and Heritage Value plus a handful of other insightful maps under these goal headings. Please remember that all of the mapped goals are tied directly to the logic diagrams presented in the previous section. Also, we have elected to standardize the maps by using the same color scheme (dark red to dark green with dark green being the highest scoring analytical units for each goal) and by portraying seven individual classes generated using natural breaks on the model outputs for each goal.

Bird Value is the average (or union) between Bird Habitat (emphasizing forest and aquatic habitat) and Bird Species (Figure 20). The Bird Species goal is based on two inputs – Boreal Bird Richness (maximum of 24 species) and the number of Blue Listed Species (maximum of four species). In both cases, species are located more in the northern extent of the ecoregion than other places, so in the overall Bird Value model result, the best 5km x 5km analytical units are skewed to the north. If one considers just Bird Habitat or Bird Habitat Quality (again based on only mature forest and aquatic habitats), the higher value units are more widely distributed throughout the entire ecoregion (Figure 21). Because of the very general nature of the bird species occurrence data, we elected to break the logic diagram and not use the Bird Species component in the final model output. Bird Value was exactly the same as Bird Habitat Quality in the final decision support model. However, the insight obtained by considering the Bird Species goal suggests that more boreal species will be contained in protected areas if they are concentrated in the northern portions of the ecoregion.

Caribou Value is the combination of two main goals (Caribou Occurrence and Caribou Habitat) using the AND operator, which means that the lowest scores of the two input layers dominates the results (Figure 22). This assures that the only suitable habitat is located where caribou still occupy the landscape (see Figure 10). Caribou Habitat Quality (Figure 23) shows more broadly distributed potential caribou habitat based on the level of human disturbance and amount of old forest >100 years. However, the potential caribou habitat is heavily fragmented and therefore not likely to support viable caribou populations. These model results show that the portion of the habitat for the Slave Lake caribou herd that falls inside our study area is of generally poor quality. Unless more favorable habitat is present outside our study area, this caribou herd is likely to be at serious risk of extirpation. The other boreal ecotype herd (Little Smoky) is almost completely surrounded by unsuitable habitat and the quality of the habitat is mixed within its current extent. This herd should also be at significant risk. Of the three mountain ecotypes, the A la Peche herd has the most favorable winter range within our study area. The habitat in the ecoregion for the Narraway herd is fair to good and habitat for the Redrock/Prairie Creek herd is good on the western portion of its range in the ecoregion and poor throughout its eastern half.

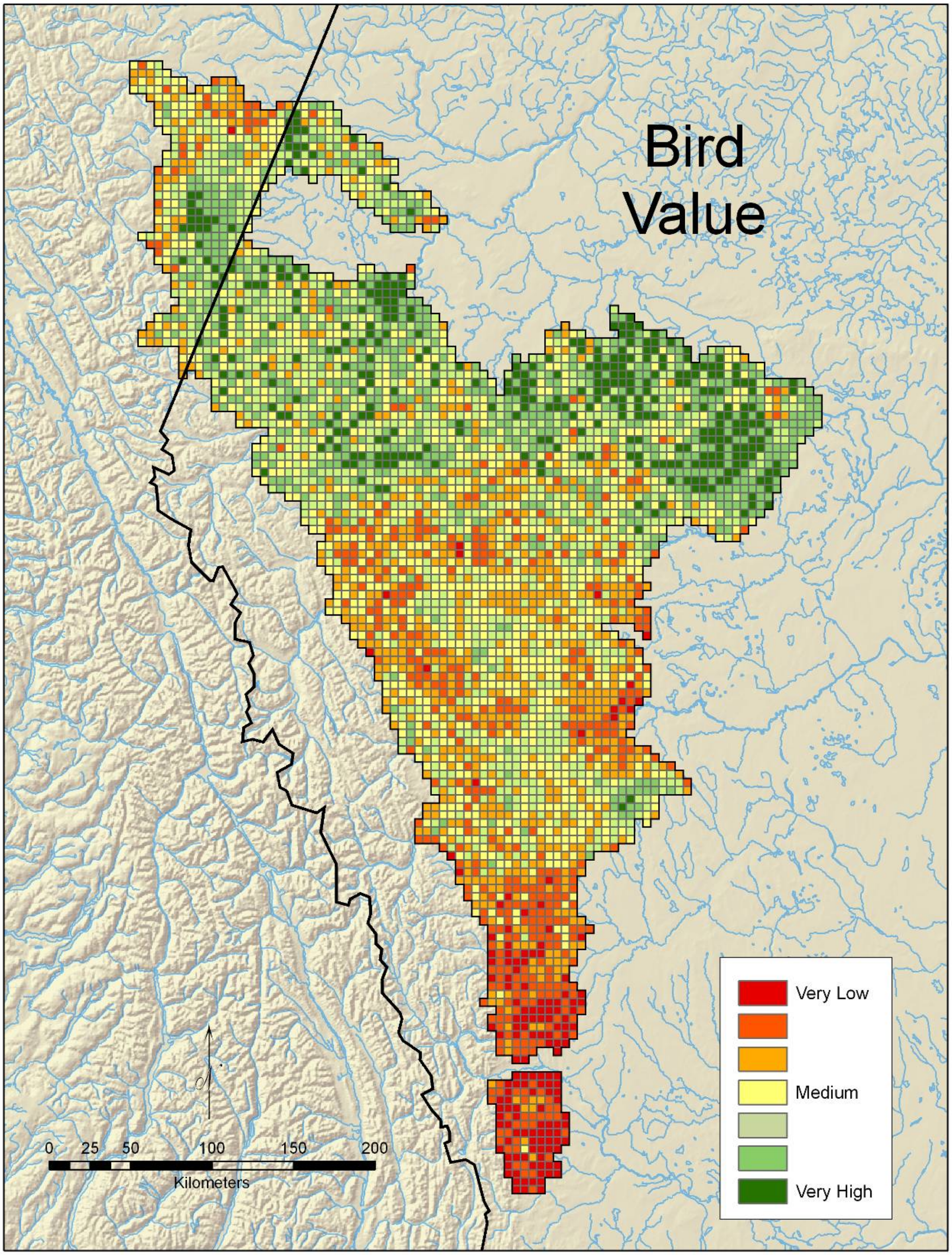

Figure 20. Bird Value results using natural breaks from the Alberta Foothills decision support model.

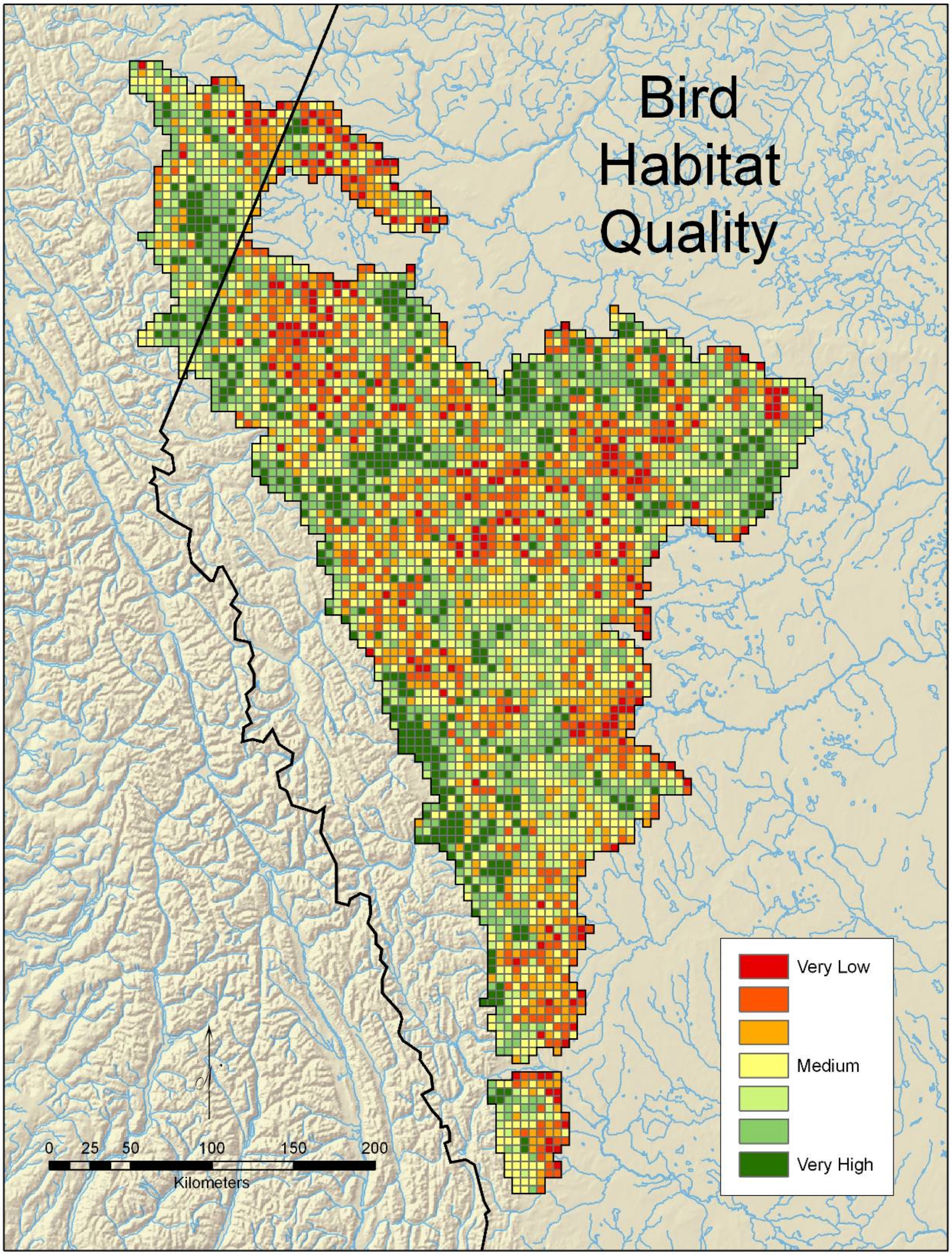

Figure 21. Bird Habitat Quality results using natural breaks from the Alberta Foothills decision support model.

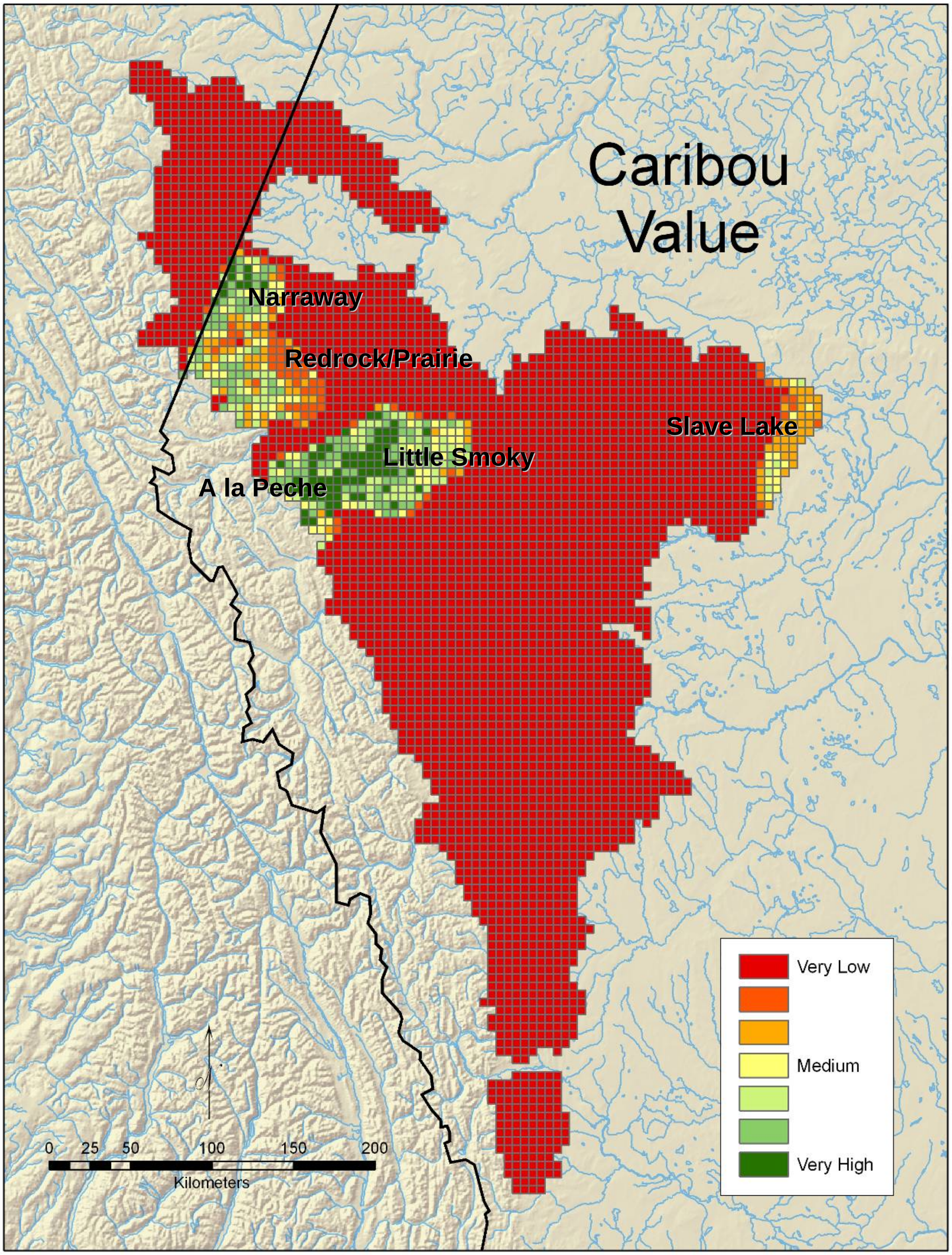

Figure 22. Caribou Value results using natural breaks from the Alberta Foothills decision support model.

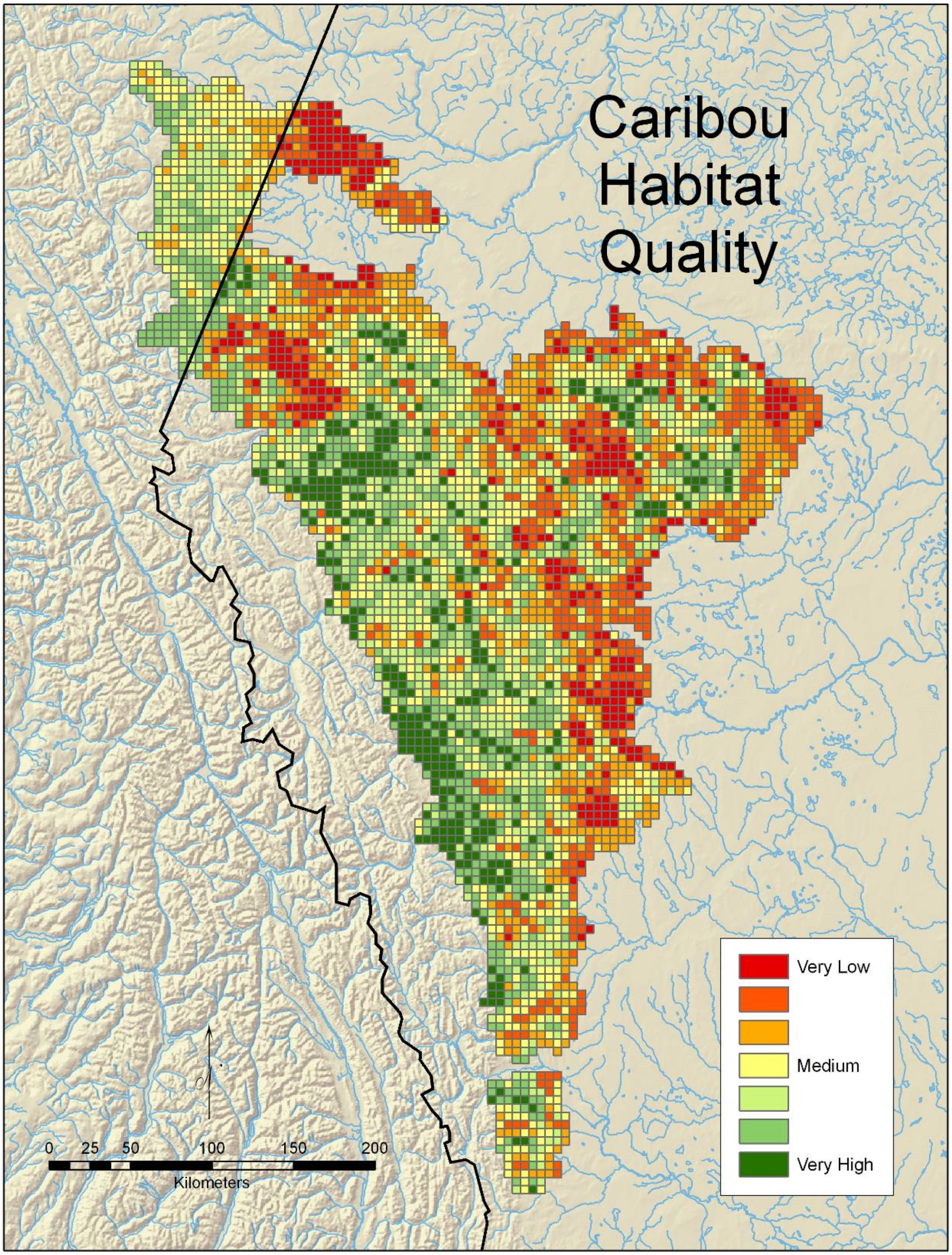

Figure 23. Caribou Habitat Quality results using natural breaks from the Alberta Foothills decision support model.

Fish Value is the combination of Watershed Quality and Species Occurrence (Figure 24). Species Occurrence is driven by two threatened species – bull trout and arctic greyling. Watershed Quality (Figure 25) is important in capturing other sites of relative high value whether they contain known occurrences of these two threatened species or not. An alternative approach would be to just use the Watershed Value goal results and by-pass the species data altogether like we did with the bird value. In this case, we elected to keep the species data, since it covered almost the entire study area and surveys were quite extensive. The only data missing was for the BC portion of the study area. Note the lower performance in BC with the final Fish Value results. Another way to adjust this would be to obtain equivalent species occurrence data for bull trout and arctic greyling in BC.

Forest Value is based on two main factors – amount of old growth (>150 years) and the level of overall forest fragmentation (Figure 26). As observed in other biodiversity goals, the lack of comparable data for the BC side of the ecoregion distorts the results in favor of the Alberta side. The lack of extensive areas of old growth constrains the results to a considerable degree. The Forest Fragmentation results (Figure 27) is based on a uniform dataset for the entire study area. This mapped goal shows the average results for five different FRAGSTATS metrics at both the cell scale and at a neighborhood scale, which included each cell and all immediately adjacent cells. The rationale for including the neighborhood function was to include the fragmentation context for each cell. Model results show that Forest Value is concentrated in particular areas throughout the ecoregion. Note that this portion of the model focused on forest cover rather than intact landscapes. Some relatively large wetland complexes were mapped as non-forest for this part of the logic tree even though they typically include scattered patches of tree cover or expanses of tree cover at low canopy cover.

Grizzly Value was based solely on data provided by the Foothills Model Forest and was confounded somewhat by the lack of uniform data across the entire study area. For figures 28-30, we highlight the areas with no data. In the logic models, all no data areas are given a value of 0, which falls exactly in the middle of the continuum between +1 and -1. Grizzly Value (Figure 28) is essentially Expanded Grizzly Bear Habitat (Figure 29) moderated by Grizzly Bear Habitat Security (Figure 30). Unfortunately, these two goals do not cover the exact same geographic extent. This causes some distortion in the Grizzly Value model (note the moderation over the areas which contain no data for the Grizzly Bear Habitat Security model), but overall the results are a very important biodiversity component. As updates to the grizzly monitoring program become available, it would be helpful to update this component of the decision support model. With the existing data, the highest quality grizzly bear habitat (areas that have bears and reasonable security for those bears) lies along the Rocky Mountains and several large patches in the northern section of the ecoregion.

Heritage Value (Figure 31) is a composite of three data inputs – Alberta Environmentally Significant Areas, Wildlife Habitat for the central portion of the ecoregion on the Alberta side, and Heritage Score, which includes data for Alberta and BC that are weighted by the global status – the more rare at the global and national scale, the higher the weight. The Alberta side was far more complete and that is reflected in the map for this goal with a full range of values from very poor to very high. Notice the BC portion of the ecoregion is centered on the middle classes. That is because “no data” gets represented with a zero along the +1,-1 continuum.

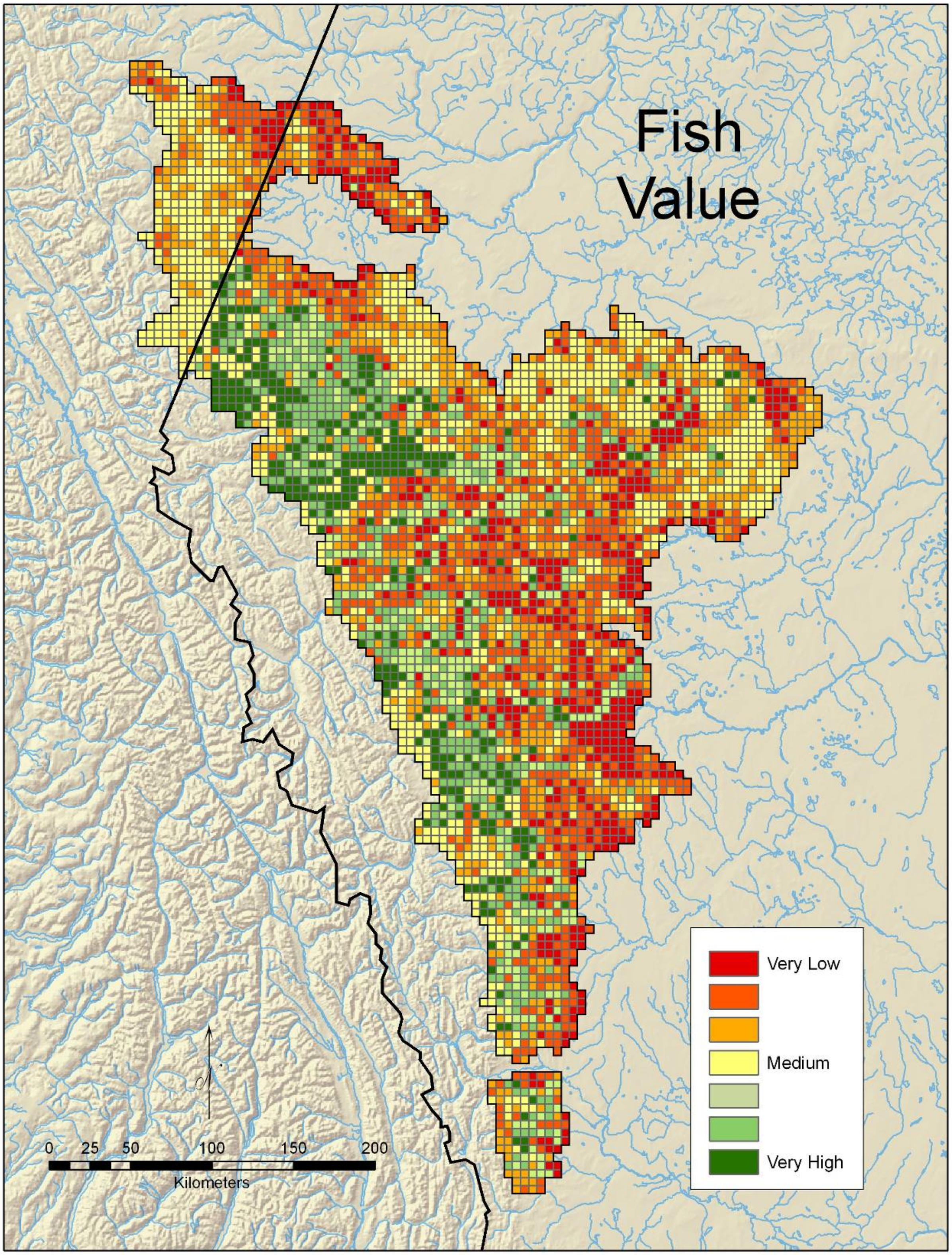

Figure 24. Fish Value results using natural breaks from the Alberta Foothills decision support model.

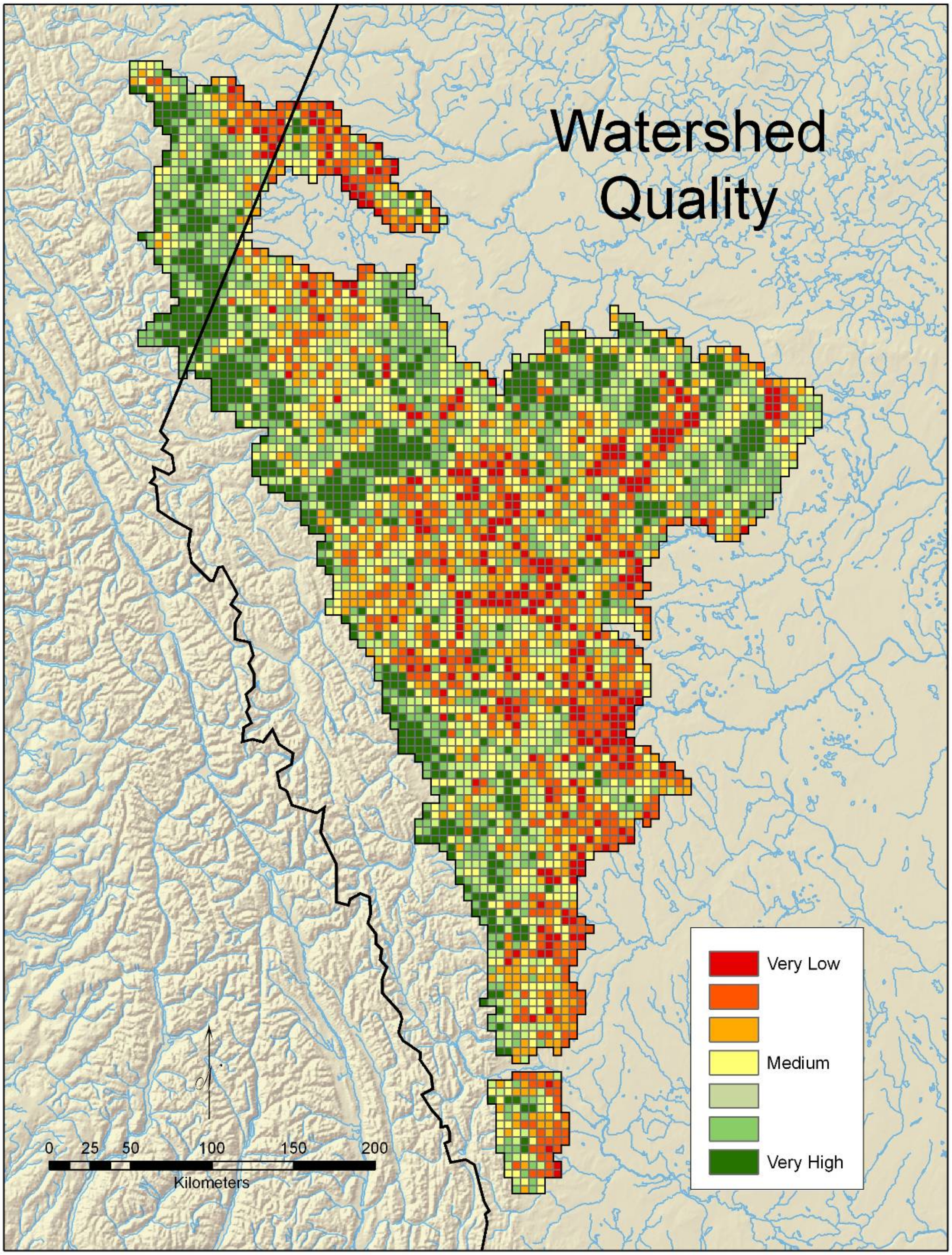

Figure 25. Watershed Quality results using natural breaks from the Alberta Foothills decision support model.

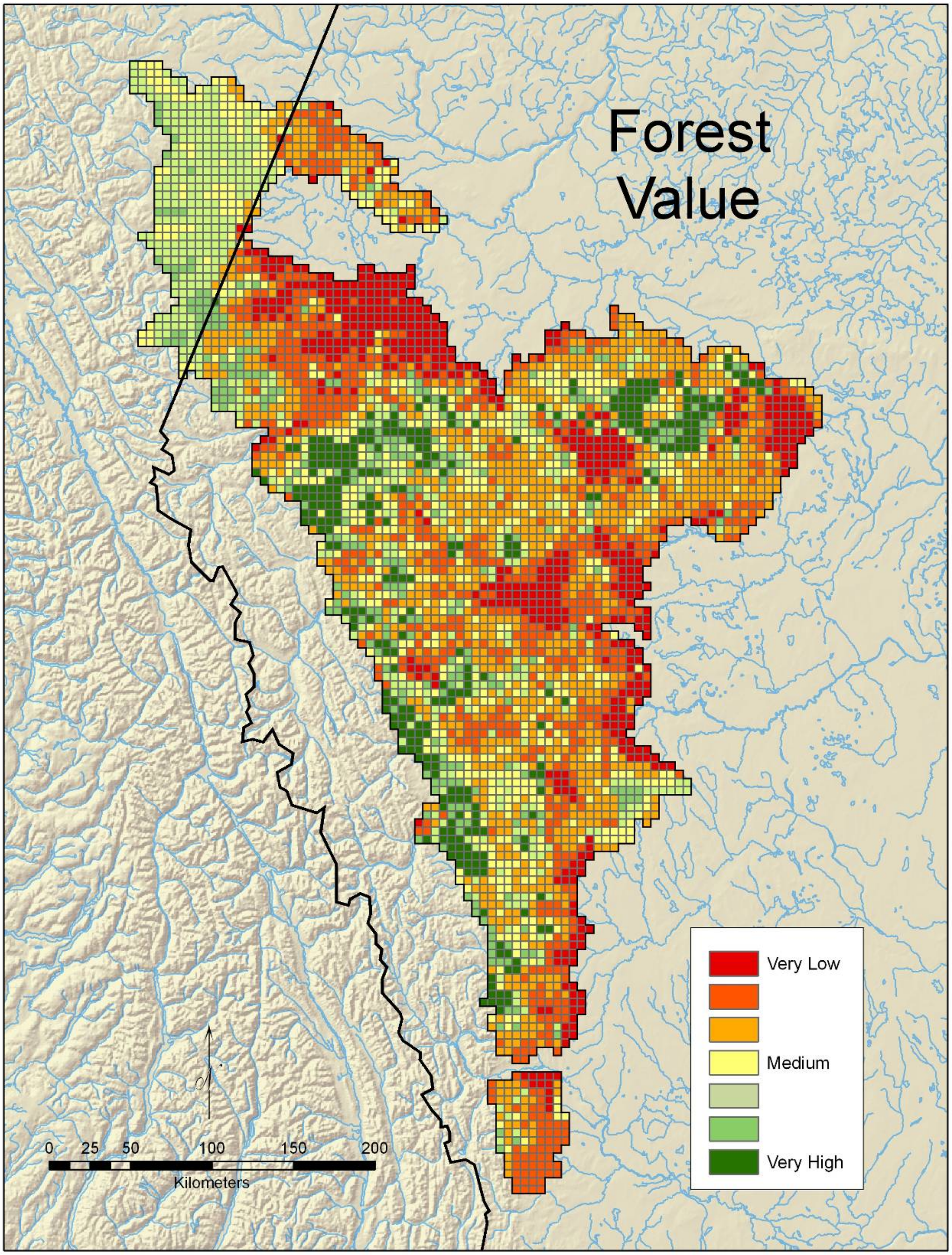

Figure 26. Forest Value results using natural breaks from the Alberta Foothills decision support model.

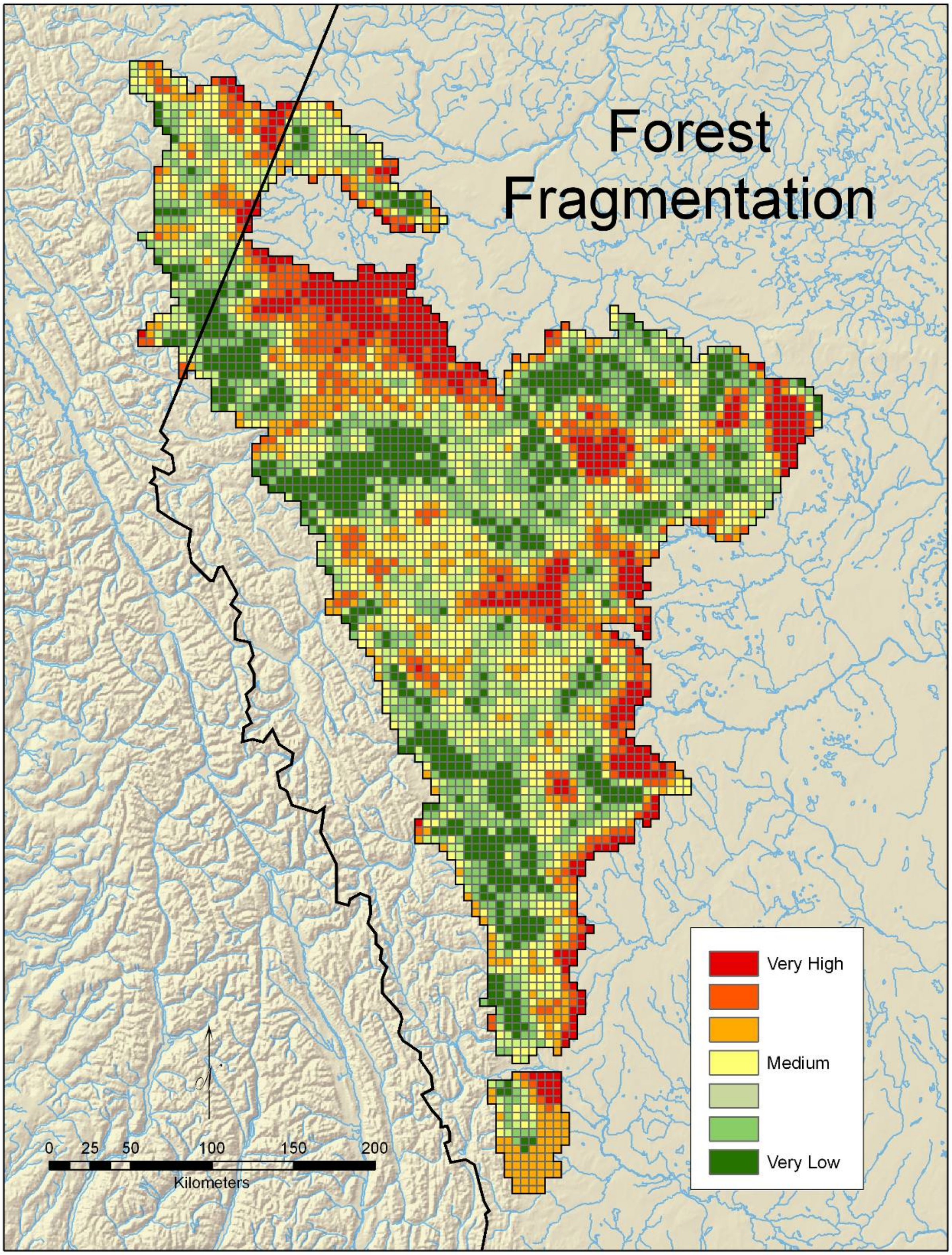

Figure 27. Forest Fragmentation results using natural breaks from the Alberta Foothills decision support model.

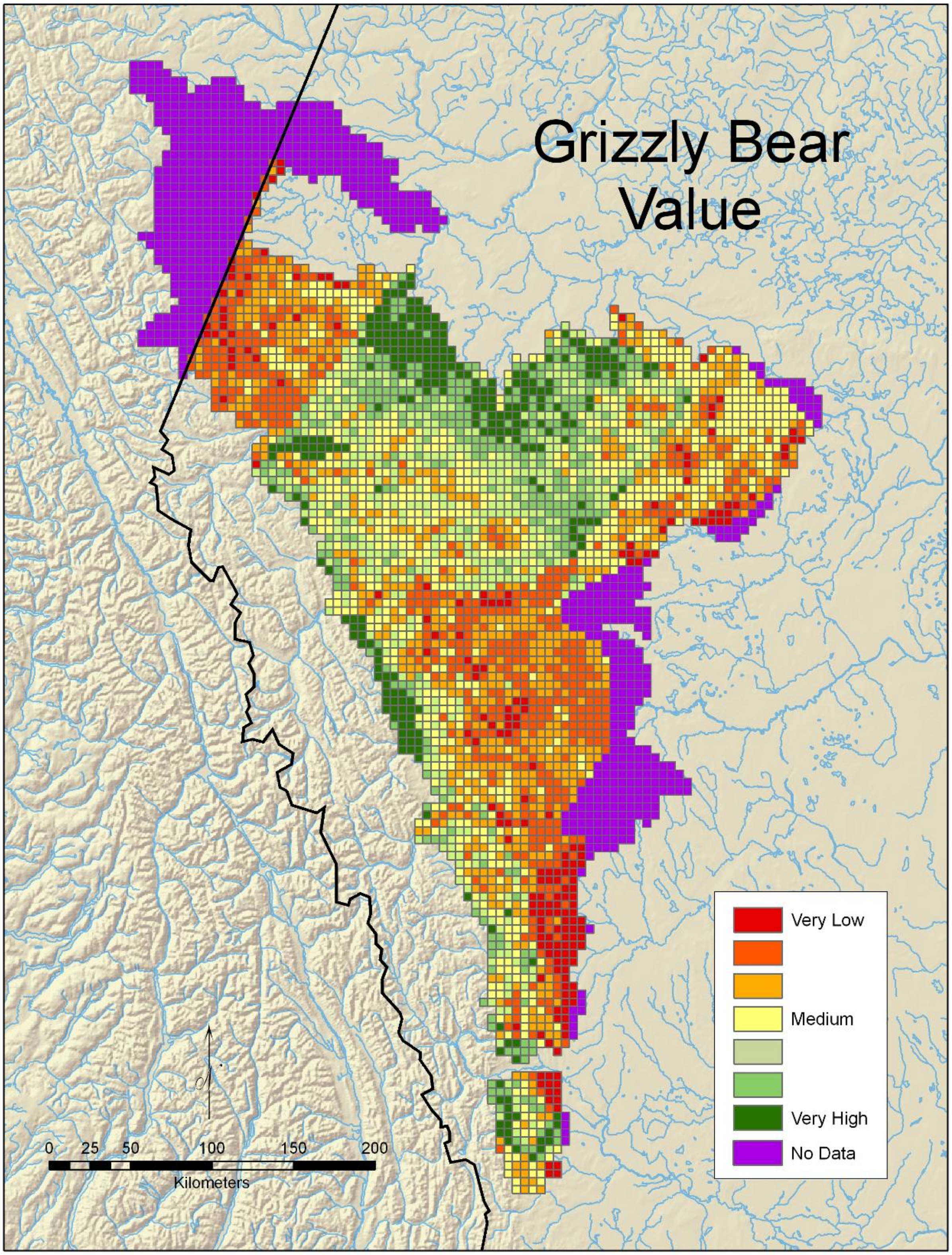

Figure 28. Grizzly Value results using natural breaks from the Alberta Foothills decision support model.

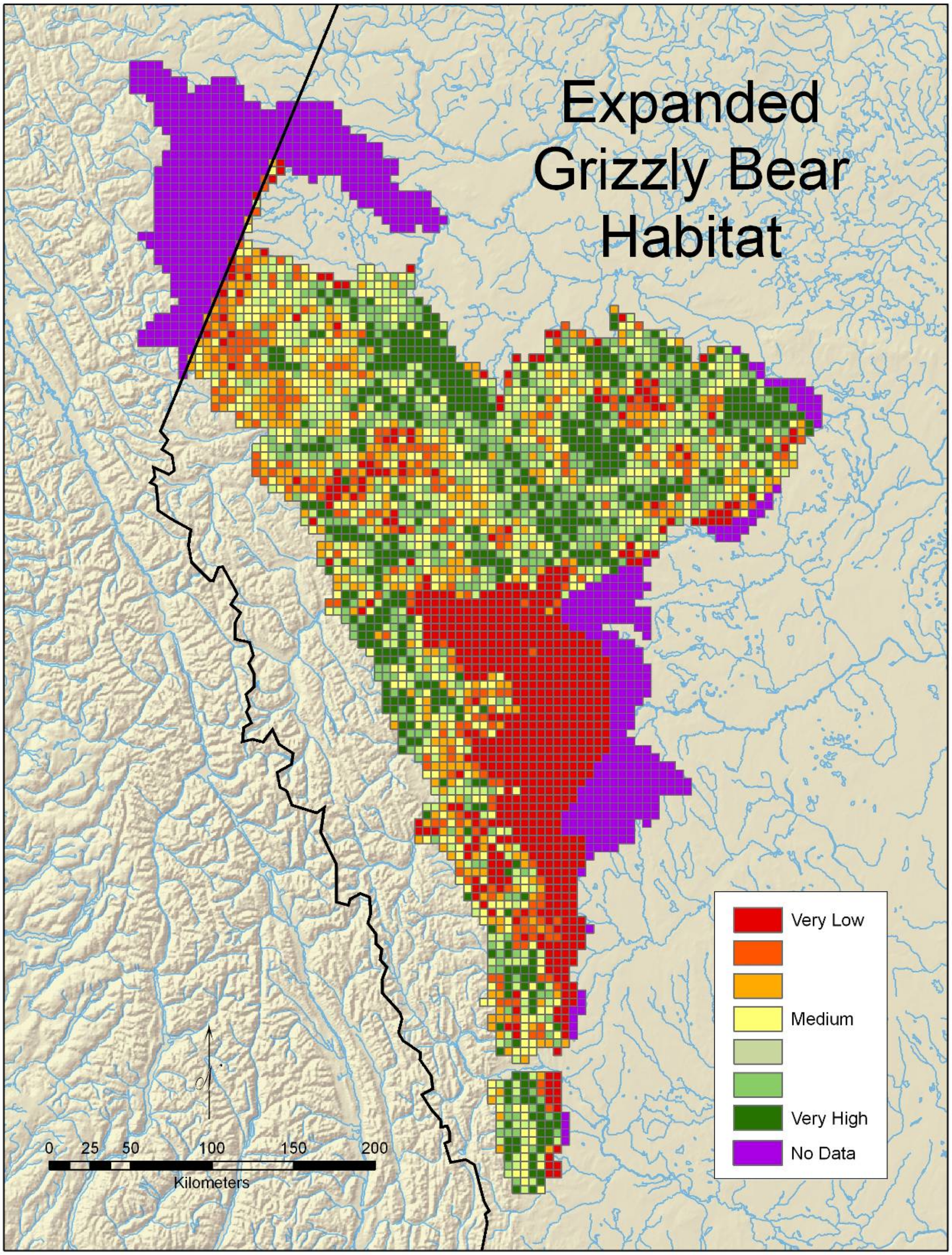

Figure 29. Expanded Grizzly Bear Habitat results using natural breaks from the Alberta Foothills decision support model.

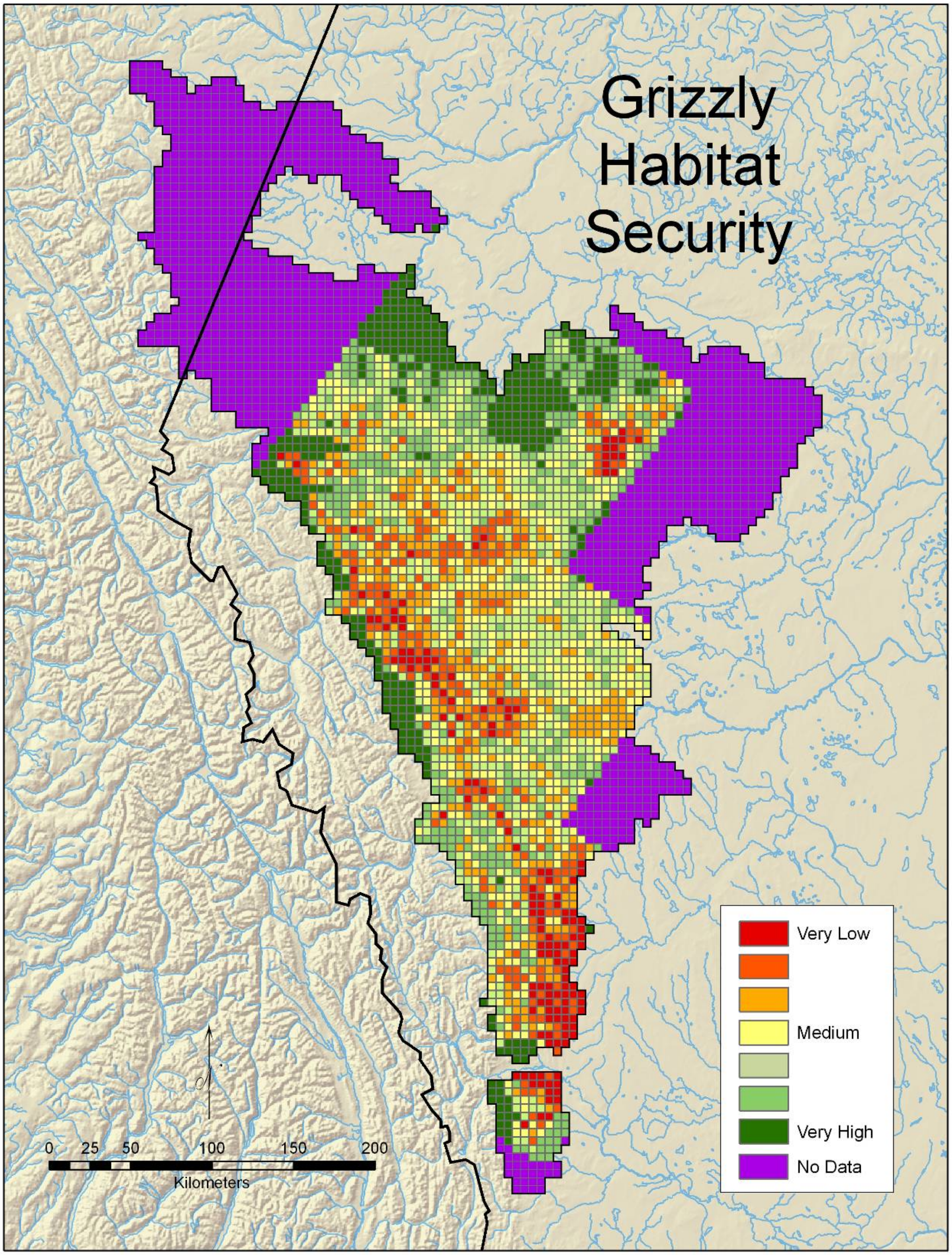

Figure 30. Grizzly Habitat Security results using natural breaks from the Alberta Foothills decision support model.

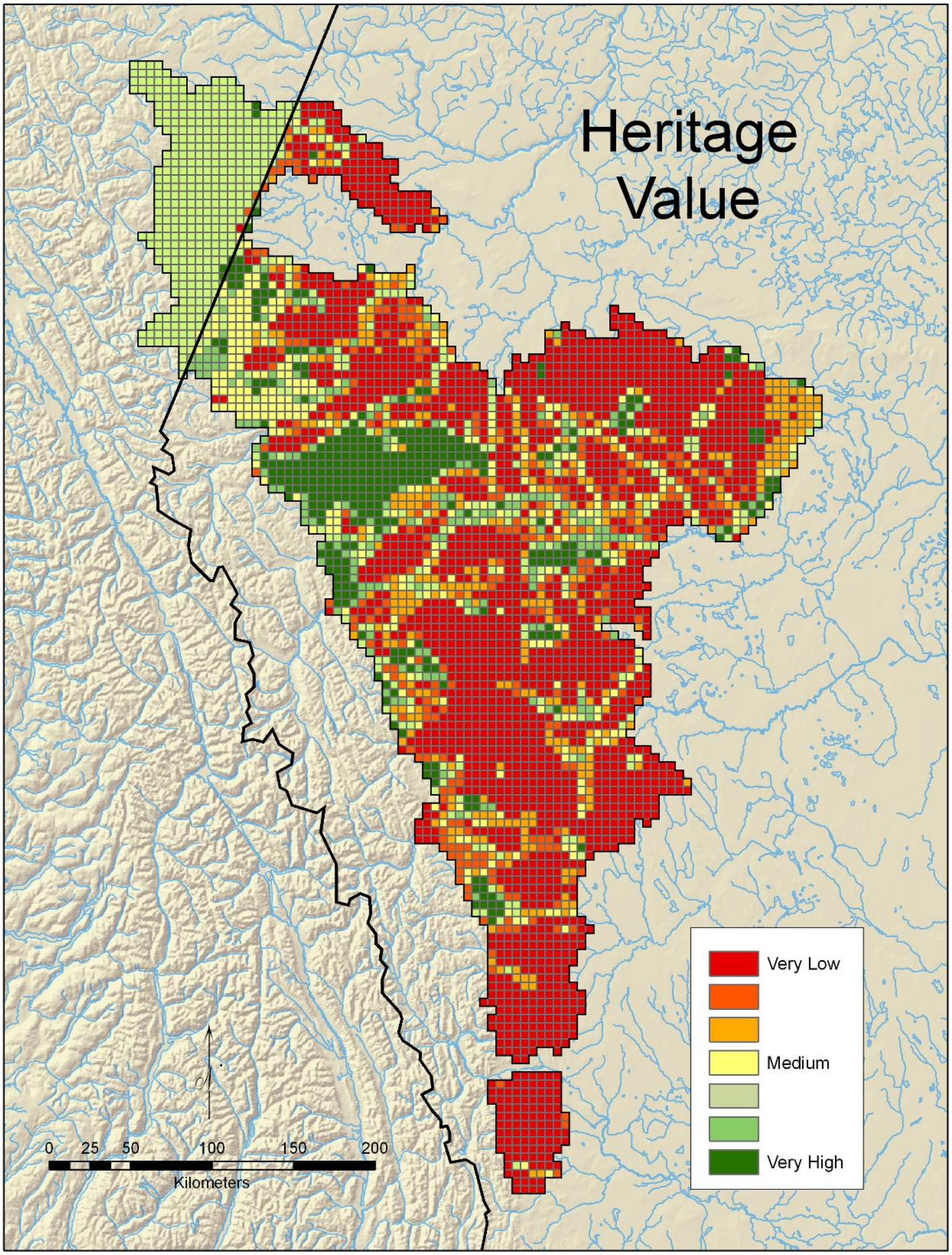

Figure 31. Heritage Value results using natural breaks from the Alberta Foothills decision support model.

The model results for Biodiversity Value is presented in Figure 32 and was generated by combining each biodiversity goal with an OR operator command. The OR operator was used to highlight any cell that contained a very high value for any of the biodiversity goals. An alternative way to assess Biodiversity Value would be to average (or UNION) the entire biodiversity goal inputs. That technique pushes the final results toward the middle of the +1,-1 continuum. We preferred to discriminate the cells more and to assure that any cell with a high value for any of the biodiversity goals would be highlighted. One additional feature of the EMDS® software is that it allows the analyst to query each cell and retrieve how it scored for each of the various goals. For example, if we zoom into the Biodiversity Value goal map and query cell 2375, which is of very high value, we can obtain the underlying information as to why it scored very high (Figure 33). Cell 2375 scored very high for Grizzly Value and Heritage Value and less well for the other values. Because we used an OR function in the logic, the cell is labeled as very high.

The Biodiversity goal map (Figure 32) highlights areas along the Rocky Mountains largely driven by grizzly bear, bird, and fish values (#1). The largest group of cells corresponds closely to high values for all of the biodiversity values examined except grizzly bear (#2). Caribou, birds, forest, heritage, and fish values explain the high scoring cells along the Alberta/BC border (#3), and the few large concentrations of high scoring cells found in the northern portion of the study area is due to high grizzly and bird value (#4). There are smaller high scoring clusters along some of the main rivers driven by fish, forest, and/or heritage values (#5). Using seven class natural breaks the number of cells within each value class is provided in Table 5.

Table 5. Natural breaks results for the Biodiversity Value logic goal for the Alberta Foothills ecoregion.

Class	Biodiversity Value Scores	Number of Cells
1	-0.139 – 0.200	200
2	0.201 – 0.383	420
3	0.384 – 0.519	37
4	0.520 – 0.642	653
5	0.643 – 0.764	748
6	0.765 – 0.899	683
7	0.900 – 1.000	703
Total		**4,044**

The Landscape Value goal map loosely corresponds to the Biodiversity Value goal map with some important differences (Figure 34). For example, many of the large clusters of very high biodiversity value cells are modified (in this case eroded) by the different levels of landscape integrity found at these locations. This is extremely valuable in establishing new protected areas because it is desirable to maximize the biodiversity values at locations with the highest levels of landscape integrity to maximize your chances of maintaining those values over time. Using seven class natural breaks the number of cells within each value class is provided in Table 6.

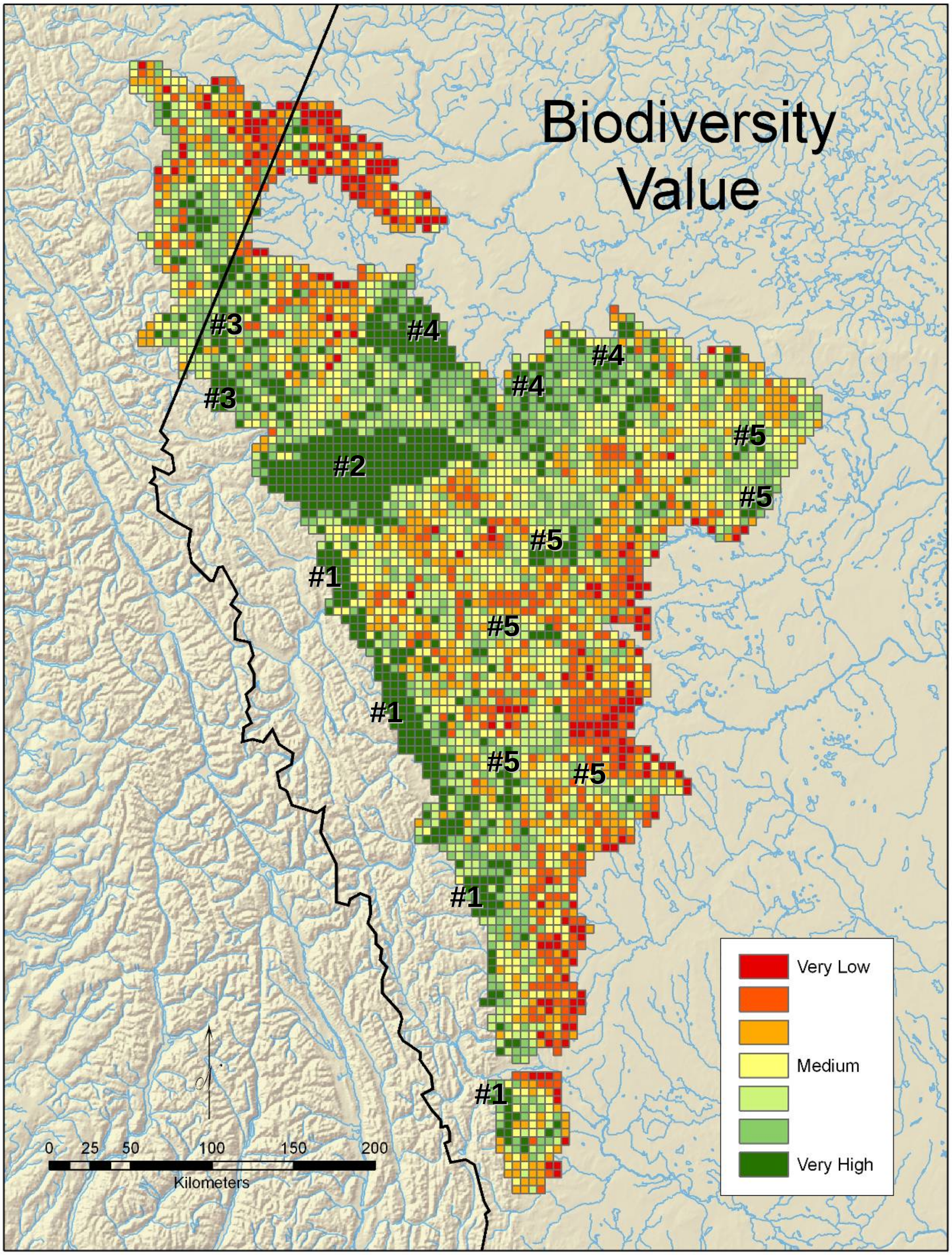

Figure 32. Biodiversity Value results using natural breaks from the Alberta Foothills decision support model. Labels correspond to descriptions in the text.

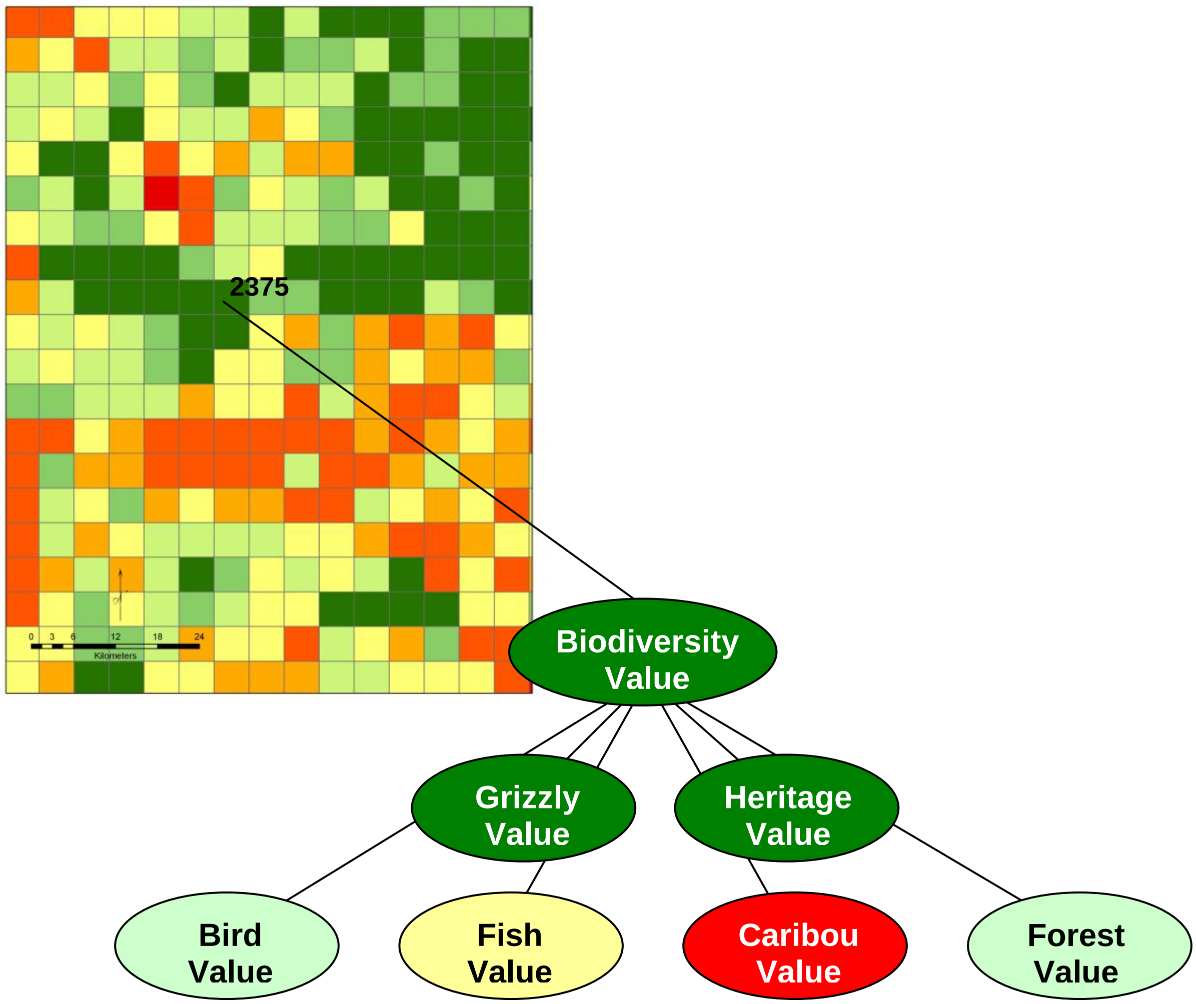

Figure 33. Example hotlink query of the Biodiversity Value results for cell 2375 showing model results for each underlying goal.

Table 6. Natural breaks results for the Landscape Value logic goal for the Alberta Foothills ecoregion.

Class	Biodiversity Value Scores	Number of Cells
1	-0.999 – -0.444	466
2	-0.443 – -0.111	756
3	-0.110 – 0.167	408
4	0.168 – 0.407	636
5	0.408 – 0.630	651
6	0.631 – 0.860	756
7	0.861 – 1.000	367
Total		**4,044**

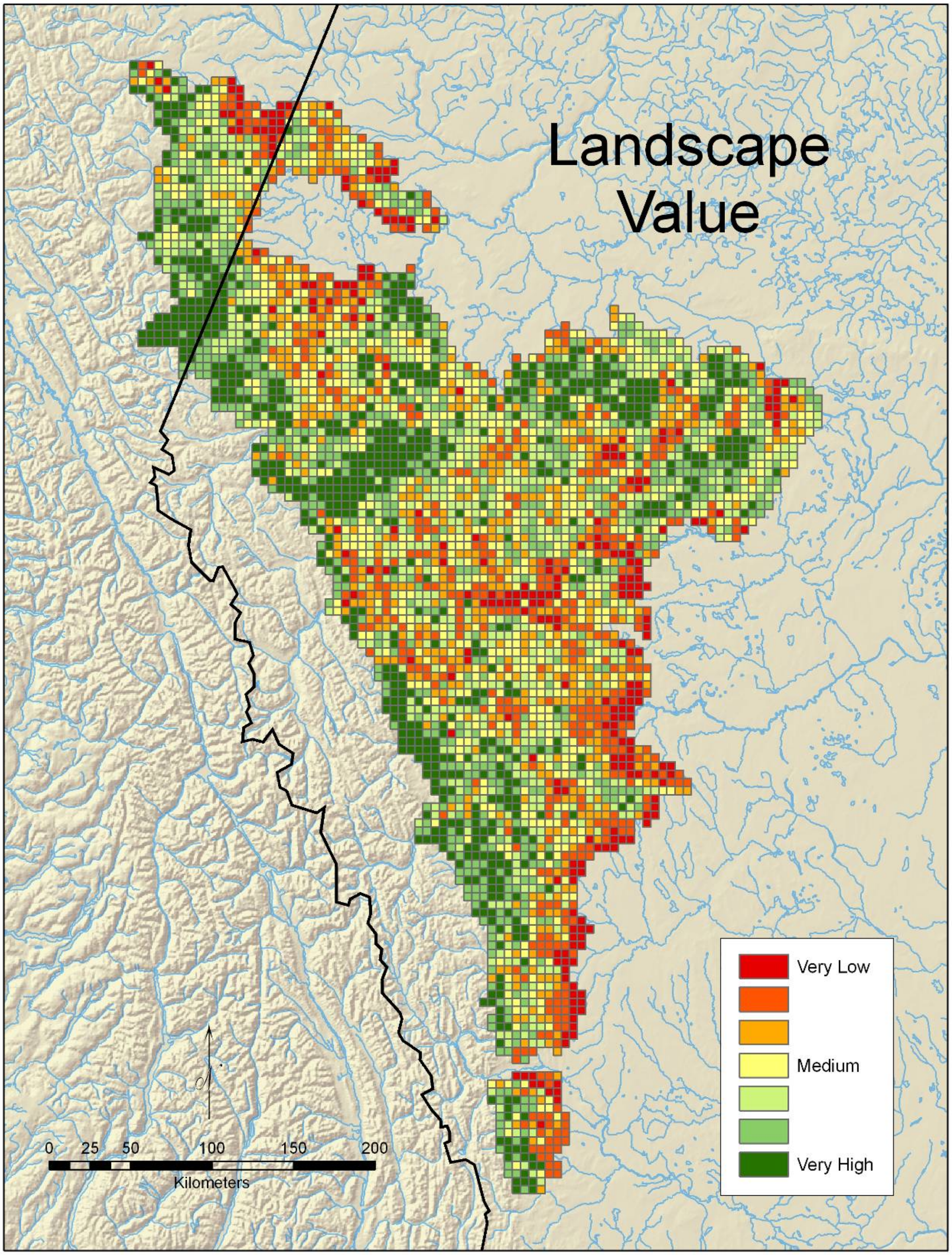

Figure 34. Landscape Value results using natural breaks from the Alberta Foothills decision support model.

The interaction (or UNION) between Biodiversity Value and Landscape Value is expressed in the highest level logic goal – Conservation Value (Figure 35). The cells highlighted in dark green are those cells that possess the highest biodiversity values and highest landscape values. Using natural breaks, approximately 16 percent of the ecoregion scored in the highest class (Table 7).

Table 7. Natural breaks results for the Conservation Value logic goal for the Alberta Foothills ecoregion.

Class	Biodiversity Value Scores	Number of Cells
1	-0.493 – -0.124	246
2	-0.123 – 0.098	357
3	0.099 – 0.296	508
4	0.297 – 0.472	690
5	0.473 – 0.642	817
6	0.643 – 0.811	772
7	0.812 – 1.000	654
Total		**4,044**

If we constrain the model output and query the top 10 percent of the ecoregion (the highest scoring 404 cells), we generate the map shown in Figure 36. If we expand to the top 30 percent of all cells, we generate a map shown in Figure 37. These alternative maps are presented to demonstrate the versatility of the model outputs and to show an example of how they can be used to develop solutions. With the logic diagrams and initial model results in-hand, one can easily test different logic ideas or assumptions and include new data and information as those spatial themes become available. One could take our results and use them like any other report, but the primary goal of this project was to develop a spatially explicit tool that would take what is known about the Alberta Foothills with regard to conservation value and create a scientifically defensible approach to maintaining these values. Thus, the more useful and powerful way to use the work done here would be to use the logic and subsequent model outputs in future discussions regarding conservation of the Alberta Foothills. Aspects of the model can be run on-the-fly during meetings if necessary or results plugged directly into other planning software such as SPOT® or MARXAN®, which were developed to optimize solutions in an iterative fashion.

Based on the information provided in the Ecological Setting section of this report, there is poor protection for the existing conservation values in the Alberta Foothills and resource development pressure remains high. The question is not whether or not more protection is needed; the question is how to achieve it. Establishing new designated protected areas is one way and this study has identified the sites where the greatest biodiversity values occur and where they are most likely to persist through time (highest landscape value – dark green). The highest scoring cells make up the candidate sites from which new protected areas could be established. That is not to say all of these cells or only these cells should be thought of in terms of new protected areas. Rather, these cells show where native species and ecological processes would benefit the most from new protected areas.

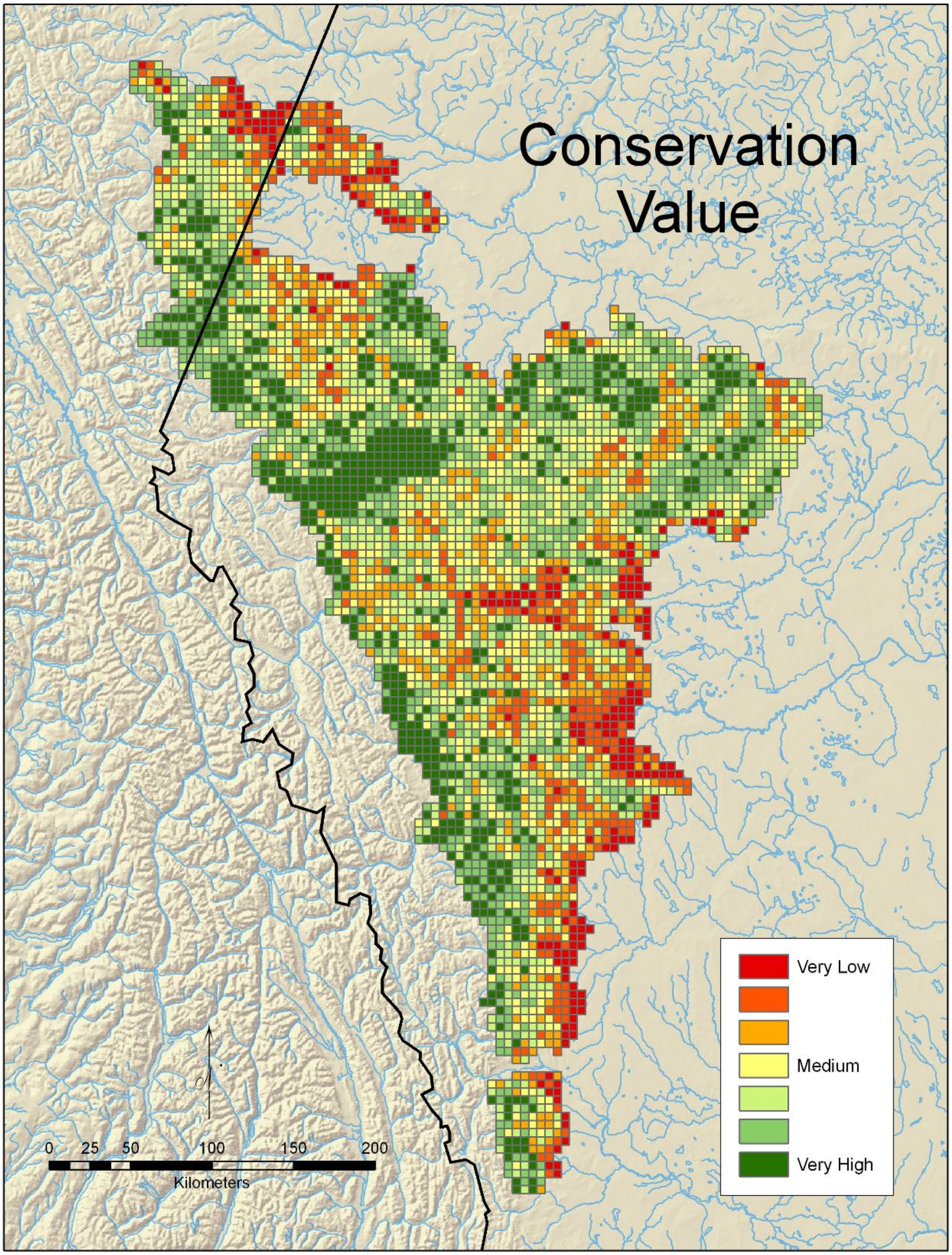

Figure 35. Conservation Value results using natural breaks from the Alberta Foothills decision support model. Top tier includes approximately16 percent of the ecoregion.

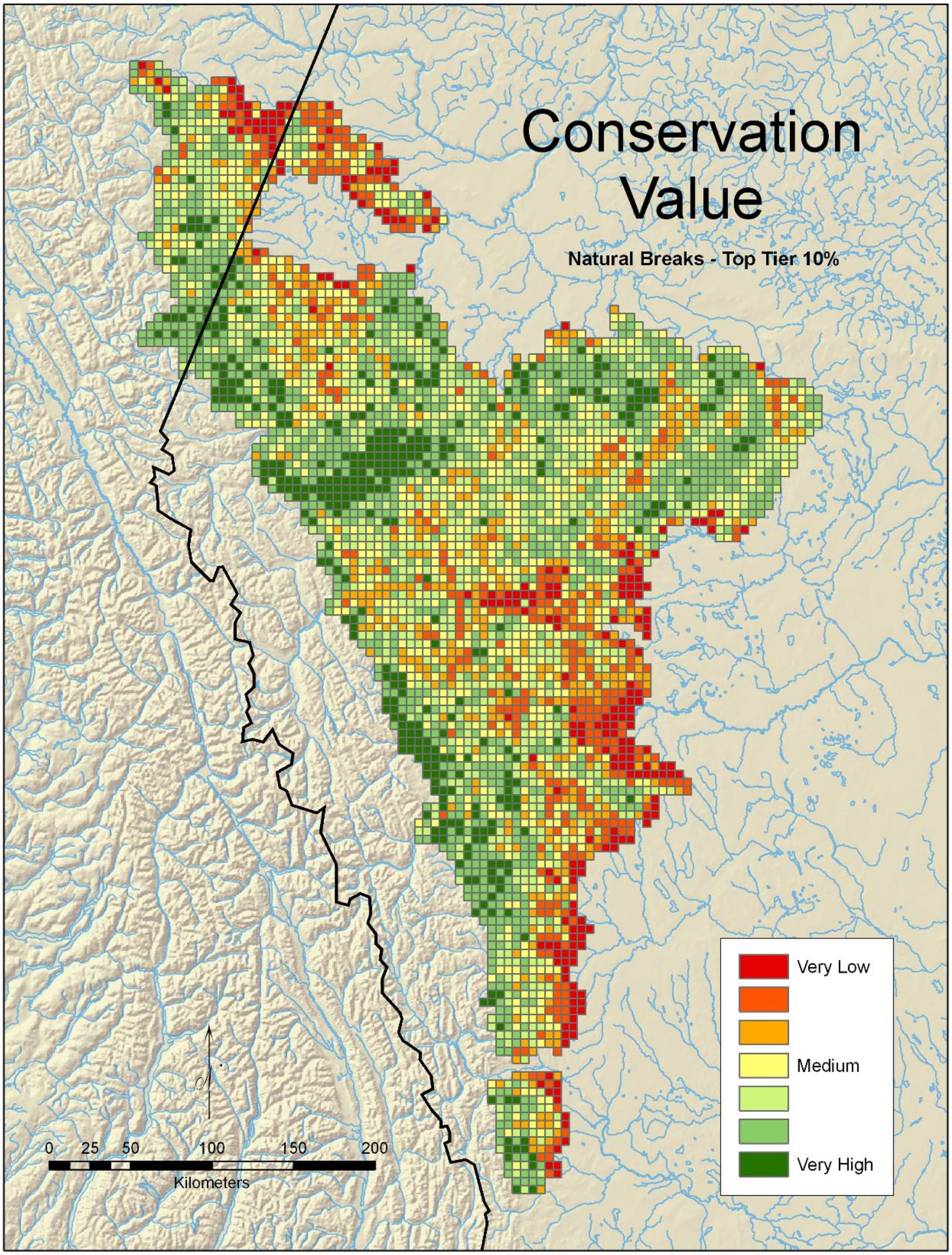

Figure 36. Conservation Value results using natural breaks from the Alberta Foothills decision support model forcing the top tier to include 10 percent of the ecoregion.

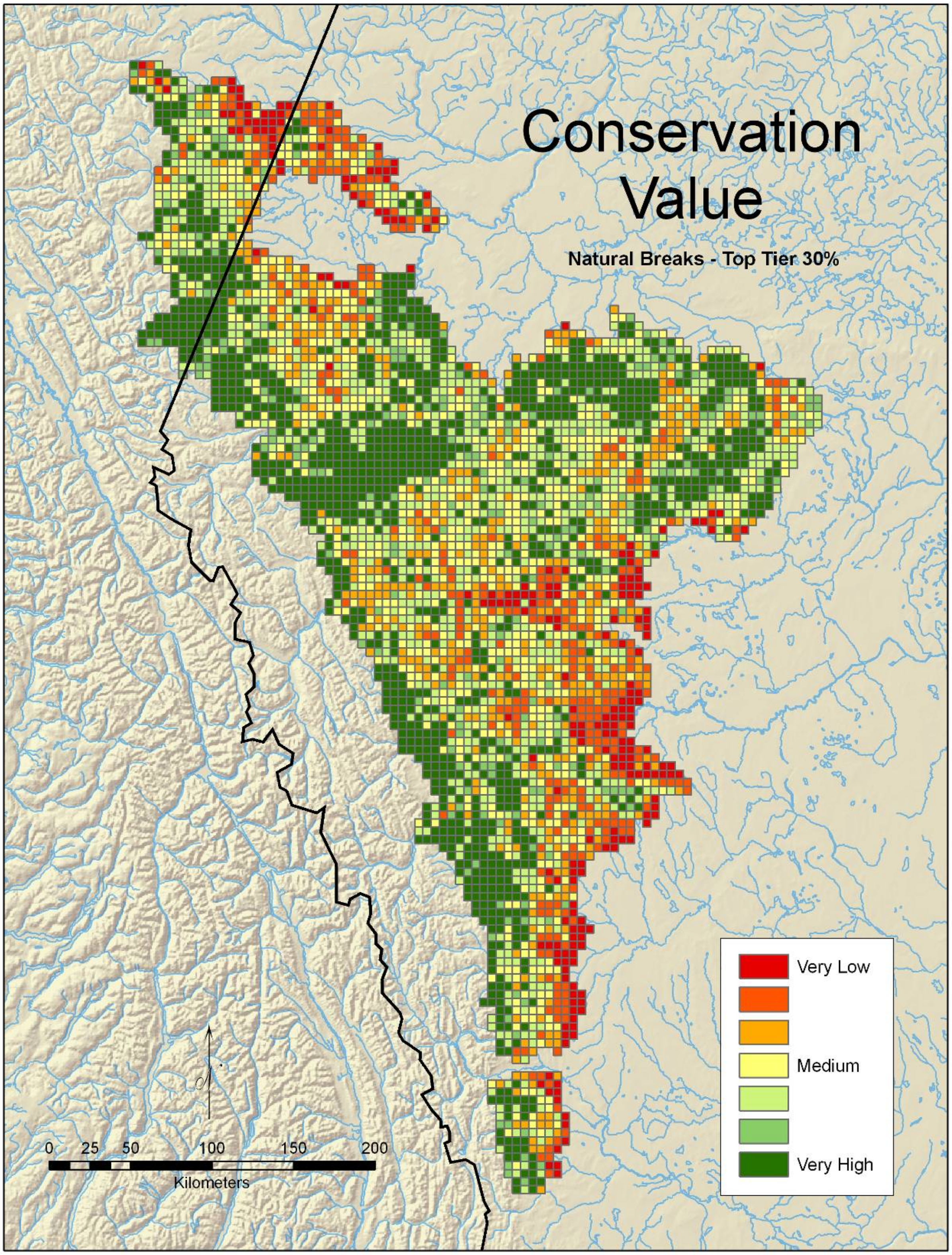

Figure 37. Conservation Value results using natural breaks from the Alberta Foothills decision support model forcing the top tier to include 30 percent of the ecoregion.

In all likelihood, the dark green cells would form the nucleus for any new protected areas in the region, but more spatially detailed site assessments would be necessary to establish the actual boundaries. These site-level assessments might actually include portions of grid cells that did not perform particularly well at the coarser scale.

The dark green cells depicted in Figures 35-37 differ only by raising or lowering the "high value" threshold. So where do we draw the line between those cells that should be protected (Endangered Forests) from those that could maintain their conservation values through special management? The answer to this question remains illusive because in every locality we are dealing with unique conservation values that differ widely in their tolerance of human disturbance. While a single threshold might be desirable from a policy standpoint (e.g., the top 16% of the highest scoring cells are the Endangered Forests), it is not possible to establish such a universal threshold that is scientifically defensible. The better approach would be to examine the results carefully from the perspective of each noted value (the hotlink tool in EMDS contains that function) and assign relative importance based to a large extent on their tolerance to human disturbance. For example, based on the contextual information for the Alberta Foothills, cells scoring high for woodland caribou should not be developed. Caribou numbers are declining and scientific research has shown high levels of sensitivity to human disturbance (Cameron et al. 1992, Vistnes and Nellemann 2001, and Schaefer and Mahoney 2006). Therefore, the highest priority for new protected areas should focus on protecting any remaining woodland caribou habitat.

Taking all of the values into consideration, the starting place for establishing new protected areas in the Alberta Foothills should be the original natural breaks model output, which placed approximately 16 percent of the ecoregion in the highest value category. Figure 38 shows this model output and highlights the possible locations for new protected area sites as generalized ovals. There are a handful of sites that include relatively large areas (area in the heart of the remaining woodland caribou habitat and along the Rocky Mountain front) as well as some that are moderate or small in size. Compared to other protected areas in the ecoregion, they would all be considered quite large, but compared to parks in the neighboring Rocky Mountains, they would be considered moderate or even small in size. Note that the ovals depict general location; more detailed site assessments would delineate actual protected area boundaries. Figure 38 also shows high-priority riparian corridors in the region that require close attention. Functionally connecting existing and new protected areas is an important consideration in this ecoregion and the main river segments highlighted offer an important opportunity to do that both from the standpoint of aquatic and terrestrial conservation values. These linear corridors do not necessarily mean they require their own protected area designation, but they should be viewed and treated as important landscape connectivity features on the landscape. A handful of the larger ones are highlighted (thick medium blue lines), but others are also present. There are also numerous protected area opportunities along the neighboring Rocky Mountains, which are largely protected by a series of established parks. Many species of concern (e.g., mountain woodland caribou and grizzly bear) seasonally move between these parks and the Alberta Foothills and so this interregional connectivity is also an important consideration. Assuming a series of protected areas are established along a west-east orientation starting with the largest oval on the map, connectivity between these new protected areas should be considered (dashed purple line).

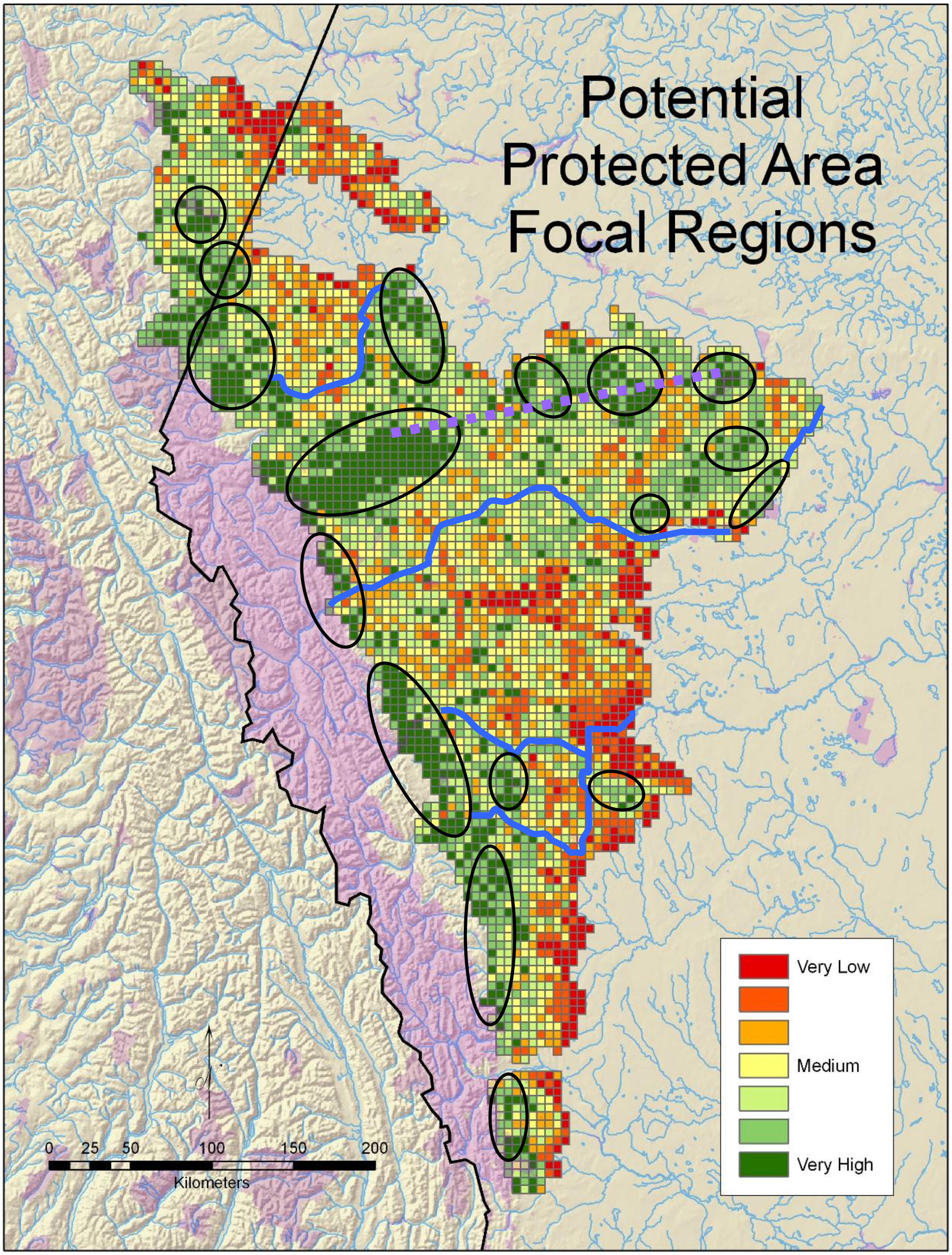

Figure 38. Potential protected area focal regions (black ovals) for the Alberta Foothills ecoregion and high-priority riparian corridors (thick medium blue lines) and terrestrial linkage corridors (purple dashed line). Background is the 16 percent Conservation Value results. Light purple depicts existing protected areas.

The dashed line depicts the general orientation of the connection, but this would need to be mapped at a finer spatial scale and would likely include multiple physical connections and/or highly permeable landscapes for target species. For example, grizzly bears would not necessarily require continuous forest cover, but would require secure pathways to travel between the new protected areas.

It is difficult to predict how much of the ecoregion could be placed into new protected areas via the existing political process. With over 86 percent of the ecoregion already allocated in logging tenures and with oil and gas development widespread, it is going to be difficult to establish many new protected areas even though the science strongly argues for much more land placed under protection status. The province may not be willing to establish many new protected areas, but that does not preclude industry from setting aside some lands from development. In fact, some areas will need to remain undeveloped in order to obtain FSC certification. Nor does it preclude industry from establishing alternative management strategies in junction with existing and new protected areas that helps maintain the important biodiversity values in the region. Specific guidelines could be established and implemented based upon the values present and the spatial database and logic model makes that a simple task.

The optimal solution for the Alberta Foothills will be the interaction of existing and new protected areas with special management over relatively large areas and even some strategic areas targeted for restoration (e.g., reduction of linear disturbances, reforestation, and .culvert improvement). One generalized vision of a combined protected area/special management strategy is presented in Figure 39.

Using the 10 percent target level for the highest scoring cells, the focus for new protected areas appears as dark green with fewer potential protected area sites highlighted (black ovals). The riparian and terrestrial connectivity vectors remain the same from the previous figure, but an extensive area identified as special management is shown in cyan, which includes areas that scored the highest in the conservation value model behind the top category (~20% of the ecoregion).

As pointed out earlier, there is an important relationship between the amount of land protected and the amount of land in special management. In general, the greater the area protected the less area needed in special management, so further investigation into this question is required to properly balance these two complimentary strategies. While this strategy may look more development friendly, the development restrictions placed on roughly a third of the ecoregion will have to be quite high for this approach to be effective. The most effective conservation plan for the Alberta Foothills that still allows for considerable resource development will be some combination of these last two maps and will require an iterative approach. With each new protected area or comparable site established, the question of representation will need to be revisited as will other factors such as regional connectivity, biodiversity values included, etc. In addition to establishing new protected areas, appropriate management goals and prescriptions will need to be developed. One good example for why this is important is the potential pine beetle impacts over the next decades. How should pine beetle infestation be managed within and adjacent to existing and newly established protected areas? Answers to this and other questions will need to be factored into the final decisions about the overall conservation strategy for the region.

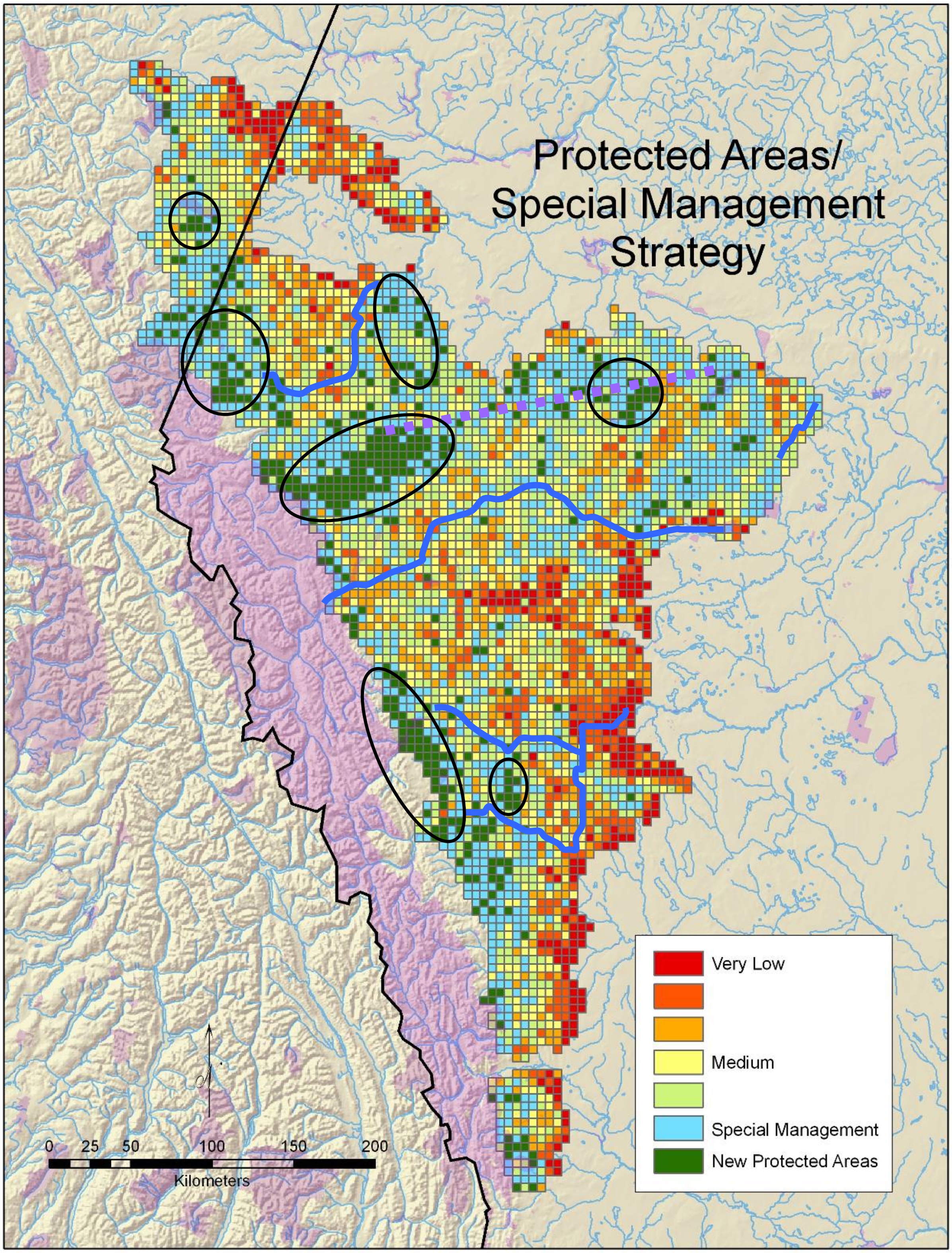

Figure 39. Potential protected area focal regions (black ovals) and special management areas (cyan) for the Alberta Foothills ecoregion and high-priority riparian corridors (thick medium blue lines). Background is the 10 percent Conservation Value results. Light purple depicts existing protected areas.

Conclusion

The Alberta Foothills contains many important conservation values, including woodland caribou, grizzly bear, boreal songbirds, old-growth forests, intact fragments, and aquatic communities. The Alberta Foothills is also poorly protected and these values are under considerable threat from ongoing resource development. Considerable investment in more protection (via more designated protected areas and special management) is need if these important values are to be maintained over time. Using available spatial data and integrated computer software (Netweaver®, EMDS®, and ArcMap®), we developed a decision support tool for identifying and mapping the areas of the highest conservation value in the Alberta Foothills (High Conservation value and Endangered Forests). The results highlight areas within the ecoregion that contain the highest value from a landscape and biodiversity perspective, which should be used to form the foundation for an expanded protected areas network and help guide special management. Failure to act will result in numerous species extirpations and significant loss of overall ecological integrity, including the degradation of several important ecosystem services.

The science-based logic model developed for this case study, which remains transparent and easy to interact with, could easily be used in future assessments, discussions, and negotiations regarding land use decisions in the region. Although not demonstrated in this report, the decision support tool developed forms the analytical foundation for iterative conservation planning in the region. The findings could also be incorporated into any FSC certification efforts within the ecoregion as our study directly addressed the biological aspects of High Conservation Value Forests (Principle 9). This case study can also serve as a template for similar High Conservation Value and Endangered Forest assessments in other parts of the world.

Literature Cited

Brewin, P.A. and M.K. Brewin. 1997. Distribution maps for bull trout in Alberta. Pp. 209-216 in Friends of the Bull Trout Conference Proceedings (Mackay, W.C., M.K. Brewin, and M. Monita, eds.). Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Cameron, R.D., D.J. Reed, J.R. Dau, and W.t. Smith. 1992. Re-distribution of calving caribou in response to oil field development on the Arctic Slope of Alaska. Arctic 45: 338-342.

CBD (Convention on Biological Diversity). 2004 . "Programme of Work on Protected Areas. Annex to Decision VII/28: Protected areas." Decisions Adopted by the Conference of the Parties to the Convention on Biological Diversity at its Seventh Meeting. UNEP/CBD/COP/7/21. <http://www.biodiv.org/doc/decisions/COP-07-dec-en.pdf>. (December 2005).

FAO (Food and Agriculture Organization of the United Nations). 2001. State of the World's Forests 2001. Rome, Italy. Available at: http://www.fao.org/forestry/index.jsp (April 2005).

ForestEthics, Greenpeace, Natural Resources Defense Council, and Rainforest Action Network. 2006. Ecological Components of Endangered Forests. Available at: http://forestethics.org/downloads/EFDefinitions_April_2006_2.pdf (April 2007).

Gordon, S.N., K.N. Johnson, K.M. Reynolds, P. Crist, and N. Brown. 2004. Decision support systems for forest biodiversity: Evaluation of current systems and future needs. Final Report – Project A10 National Commission on Science and Sustainable Forestry. Available at www.ncssf.org (April 2007).

Hockings, M., S. Stolton, and N. Dudley. "Evaluating effectiveness: A framework for assessing the management of protected areas." Best Practice Guidelines 6 (2000):x + 121 IUCN, Gland, Switzerland and Cambridge, UK.<http://iucn.org/dbtw-wpd/edocs/PAG-006.pdf>. (December 2005).

Hummel, M. 1995. Protecting Canada's Endangered Spaces. Key Porter Books. Toronto, Canada. 251 pp.

Jennings, S., et al. 2004. The High Conservation Value Forest Toolkit. Edition 1, 2003. Proforest. Available at: www.fscoax.org/principal.htm (April 2004).

Lee P. 2007. Recent Anthropogenic Changes within the Boreal Forests of Ontario and Their Potential Impacts on Woodland Caribou (A Global Forest Watch Canada Report). Edmonton, Alberta: Global Forest Watch Canada. 51 pp.

Lindenmayer, D.B. and J.F. Franklin. 2002. Conserving Forest Biodiversity: A Comprehensive Multiscaled Approach. Island Press, Washington, D.C.

McGarigal, K. and B.J. Marks. 1995. FRGASTATS: spatial pattern analysis program for quantifying landscape structure. Gen. Tech. Rep. PNW-GTR-351. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 122 p.

Ricketts T.H., et al. 1999. Terrestrial Ecoregions of North America: A Conservation Assessment. Island Press, Washington, D.C. 485 pp.

Ryti, R.T. 1992. Effect of local taxon on the selection of nature reserves. Ecological Applications 2: 404-410.

Schaefer, J.A. and S. P. Mahoney. 2006. Effects of progressive clearcut logging in Newfoundland caribou. Journal of Wildlife Management. In Review.

Scott, J.M., et al. 2001. Nature reserves: Do they capture the full range of America's biological diversity? Ecological Applications 11(4): 999-1007.

Shands, W.E. and R.G. Healy. 1977. The lands nobody wanted. The Conservation Foundation, Washington, D.C.

Soulé, M.E. and M.A. Sanjayan. 1998. Conservation targets: Do they help? Science 279: 2060-2061.

Stanojevic Z, Lee P, and JD Gysbers. 2006. Recent Anthropogenic Changes within the Northern Boreal, Southern Taiga, and Hudson Plains Ecozones of Québec (A Global Forest Watch Canada Report). Edmonton, Alberta: Global Forest Watch Canada. 63 pp. Available at: http://www.globalforestwatch.ca/change_analysis/downloadQC.htm

Stanojevic Z, Lee P, and JD Gysbers. 2006. Recent Anthropogenic Changes within the Boreal Plains Ecozone of Saskatchewan and Manitoba: Interim Report (A Global Forest Watch Canada Report). Edmonton, Alberta: Global Forest Watch Canada. 44 pp. Available at http://www.globalforestwatch.ca/change_analysis/downloadSKMB.htm

The Millennium Assessment. 2005. Millennium Ecosystem Assessment Synthesis Report. Available at: www.millenniumassessment.org/en/index.aspx (April 2005).

United Nations Environment Program. 2005. Available at: www.unep-wcmc.org/forest/data/cdrom2/world.htm (April 2005).

Vistnes, I. and C. Nellemann. 2001. Avoidance of cabins, roads, and power lines by reindeer during calving. Journal of Wildlife Management 65: 915-925.

World Commission on Environment and Development. 1987. Our Common Future. Oxford University Press, New York. 383 pp.

APPENDIX A. Primary data themes used to supply background information or in the decision support modeling

Theme	Source	Data Type	Scale/Resolution
Analysis Units	Conservation Biology Institute	Polygon	5km grid cells
Arctic Greyling Occurrence	Alberta Forestry, Lands and Wildlife	Point	1:100,000
Average Site Quality	Canadian Forest Inventory	Polygon	based on 10km grid cell array
Blue Listed Species	NatureServe	Polygon	1:1,000,000
Boreal Bird Richness	NatureServe	Polygon	1:1,000,000
Bull Trout Class AB Streams	Alberta Sustainable Resource Development	Line	1:100,000
Bull Trout Occurrence	Alberta Forestry, Lands and Wildlife	Point	1:100,000
Bull Trout Habitat	Berwin and Berwin 1997	Line	1:100,000
Canadian Large Fire Database	Natural Resources Canada, Canadian Forest Service	Point	?
Caribou Occurrence	Alberta Natural Heritage Information Centre	Polygon	1:100,000
Cumulative Impacts	World Wildlife Fund Canada	Grid	1km
Digital Elevation Model	Natural Resources Canada - Geogratis	Grid	80m
Dominant Forest Genus	Canadian Forest Inventory	Polygon	based on 10km grid cell array
Enduring Features	World Wildlife Fund Canada	Polygon	1:1,000,000
Enduring Features Representation	Conservation Biology Institute	Polygon	1:1,000,000
Environmentally Significant Areas	Alberta Natural Heritage Information Centre	Polygon	1:100,000
First Nation Lands	Department of Indian and Northern Affairs	Point	1:2,000,000
Forest Age (Old Growth)	Foothills Model Forest	Grid	30m
Forest Contagion	FRAGSTATS - Conservation Biology Institute	Polygon	15m data summarized by 5km grid cell array
Forest Intactness	Global Forest Watch Canada - Conservation Biology Institute	Polygon	based on 30m imagery
Forest Patch Mean Nearest Neighbor	FRAGSTATS - Conservation Biology Institute	Polygon	15m data summarized by 5km grid cell array
Forest Patch Number	FRAGSTATS - Conservation Biology Institute	Polygon	15m data summarized by 5km grid cell array
Forest Production Mills	Global Forest Watch Canada	Point	?
Forestry Footprint	World Wildlife Fund Canada	Grid	1km
Grizzly Corridors	Foothills Model Forest	Grid	30m
Grizzly Population Sinks and Mortality	Foothills Model Forest	Grid	30m
Grizzly Resource Selection Areas (~6 themes)	Foothills Model Forest	Grid	30m
Heritage	Alberta Natural Heritage and BC Conservation Data Centre	Point/Polygon	mixed
Hydrography	Derived from DEMs by Conservation Biology Institute	Line/Polygon	1:100,000

Important Bird Areas	Bird Studies Canada and Canadian Nature Federation	Polygon	1:50,000
Intact Forest Landscapes	Global Forest Watch Canada/Conservation Biology Institute	Polygon	based on 30m imagery
Landsat ETM+ Imagery	NASA - Conservation Biology Institute	Imagery	15m
Landscape Disturbance 1990 - 2006	Global Forest Watch Canada	Polygon	based on 30m imagery
Logging Tenures	Global Forest Watch Canada	Polygon	1:1,000,000
Mining Footprint	World Wildlife Fund Canada	Grid	1km
Native Communities	Department of Indian and Northern Affairs	Point	1:2,000,000
Number of Forest Species	Canadian Forest Inventory	Polygon	based on 10km grid cell array
Oil and Gas Footprint	World Wildlife Fund Canada	Grid	1km
Percent Conifer Forest	Foothills Model Forest	Grid	30m
Percent Forest	FRAGSTATS - Conservation Biology Institute	Polygon	15m data summarized by 5km grid cell array
Pipeline Length	Foothills Model Forest	Grid	30m
Populated Places	Natural Resources Canada	Point	1:2,000,000
Protected Areas	Environment Canada, Canada Council on Ecological Areas	Polygon	1:50,000
Road /Stream Intersections	Conservation Biology Institute	Point	1:100,000
Road Density	Conservation Biology Institute	Polygon	1:100,000
Roads	Natural Resources Canada	Line/Polygon	1:100,000
Roads and Linear Disturbances	Natural Resources Canada, DMTI, Global Forest Watch Canada	Line/Polygon	1:100,000
Small Forest Blocks	Conservation Biology Institute	Polygon	based on 15m imagery
Soil Organic Carbon	Agriculture and Agri-Food Canada	Polygon	1:1,000,000
Surficial Geology	Natural Resources Canada, Geological Survey of Canada	Polygon	1:5,000,000
Timber Volume	Canadian Forest Inventory	Polygon	based on 10km grid cell array
Total Forest Core Area	FRAGSTATS - Conservation Biology Institute	Polygon	15m data summarized by 5km grid cell array
Well Sites	Global Forest Watch Canada	Point	?
Wetlands-Peatlands	Geological Survey of Canada	Polygon	1:2,000,000
Wildlife Habitat	Alberta Sustainable Resource Development	Polygon	1:100,000