Foothills Model Forest Grizzly Bear Research Project
Habitat Mapping and RSF Modeling Component
In Participation with the Habitat Stewardship Program for Species at Risk

Final Report
For the period ending March 31/04.

1. Project Name:	Foothills Model Forest Grizzly Bear Research Project: Habitat Mapping and RSF Modeling Component
2. Recipient Organization:	Foothills Model Forest, Hinton, Alberta.
3. Contact Information:	Gordon Stenhouse FMF Grizzly Bear Project Leader and Provincial Grizzly Bear Specialist Box 6330 Hinton, Alberta. T7V 1X6. (780) 865-8388. Gordon_Stenhouse@gov.ab.ca.
4. Reporting Date:	For the period April 1 2003 – March 31 2004
5. Reporting Period:	Final Program Report
6. Signature:	___________________________________

Part C—Final Report

1) Target Species and Habitat

a) Target species for the Project

Species Name [latin and common]	Current COSEWIC Status
(Ursus arctos) Grizzly Bears	May be at risk

b) Target habitats

Ecoregion of Canada	Habitat/Ecosystem Type	Specific Location (nearest populated centre)
Montane Cordillera Ecozone	Eastern slopes, Upper and lower foothills of Alberta	Hinton, Alberta

2) Financial Information and Partners

a) Indicate actual financial and/or in-kind contributions and expenditures that have been provided to and spent for each project, as per the tables below.

Contributors	**Contribution (projected)**			**Contribution (actual)**		
	Cash	**In-kind**	**Total**	**Cash**	**In-kind**	**Total**
Environment Canada (HSP)	60,000		60,000	60,000		60,000
Foothills Model Forest	22,000		22,000	22,000		22,000
Ainsworth Lumber	10,000		10,000	10,000		10,000
Petro Canada	10,000		10,000	10,000		10,000
Talisman Energy	10,000		10,000	10,000		10,000
Blueridge Lumber	15,000		15,000	15,000		15,000
Canfor	15,000		15,000	15,000		15,000
Conoco	10,000		10,000	10,000		10,000
Millar Western	5,000		5,000	5,000		5,000
Sundance Forest Products	15,000		15,000	15,000		15,000
Weldwood of Canada	10,000		10,000	10,000		10,000
Total Credits	**182,000**		**182,000**	**182,000**		**182,000**

DEBITS

		Projected Amount			**Actual Amount**		
Expenditure Type	**Paid To**	**Cash**	**In-kind**	**Total**	**Cash**	**In-kind**	**Total**
Image purchase & processing	University of Calgary	29,000		29,000	29,000		29,000
Subtotal	**First Quarter**	**29,000**		**29,000**	**29,000**		**29,000**
Image classification	University of Calgary	40,000		40,000	30,000		30,000

Ground truthing costs (these costs have not been invoiced)	University of Calgary	42,000		42,000	19,061		19,061
Field crew salaries		10,000		10,000	10,000		10,000
Food , fuel and truck rental	FMF Contractors	6,000		6,000	5,283		5,283
	FMF Staff & various suppliers						
Subtotal	**Second Quarter**	**98,000**		**98,000**	**64,344**		**64,344**
Image classification	FMF Staff				10,000		10,000
*Ground truthing costs	FMF Staff				22,939		22,939
Rental	Various suppliers				425		425
*RSF Mapping	University of Alberta	15,000		15,000			
*Graph Theory Modelling	University of Western Ontario	15,000		15,000			
Subtotal	**Third Quarter**	**30,000**		**30,000**	**33,364**		**33,364**
Rental	Various suppliers				415		415
RSF Mapping	University of Alberta				15,000		15,000
Graph Theory Modelling	Wilfred Laurier University				15,000		15,000
GIS support for map production	FMF Staff	3,000		3,000	2,877		2,877
Image purchase	University of SK	6,000		6,000	6,000		6,000
Admin costs	FMF	16,000		16,000	16,000		16,000
Subtotal	**Fourth Quarter**	**25,000**		**25,000**	**55,292**		**55,292**
TOTAL DEBITS		**182,000**	**0**	**182,000**	**182,000**	**0**	**182,000**

b) Total Program/Project Budget (for this year): $182,000_(no change from budget)

Total amount supplied by the Habitat Stewardship Program:__$60,000
Total amount supplied by other federal programs:___(_none_)
Total amount of non-federal financial match secured: ____$122,000
Total estimated amount of non-federal in-kind match secured:____(n/a)___________

c) Please list any other partners involved in this project that are not named above, and their role(s). *This project benefited from having grizzly bear location data (GPS) to allow the testing and validation of existing RSF models. The costs of capturing and collaring bears, and collecting this data was paid for by other program sponsors of the Foothills Model Forest Grizzly Bear Research Program. Most importantly were the Alberta Conservation Association and the FRIAA open fund of the Alberta Forest Products Association. Overall the costs of gathering this test data is estimated to be $250,000.00*

3) Project summary

This HSP supported program is the first major attempt to use remote sensing techniques to map large land areas for grizzly bear habitat mapping in North America and as such marks a significant step for grizzly bear conservation efforts in Alberta, and Canada. Our team of scientists wanted to use these new map products to help in predicting the probability of grizzly bears on the landscape and understand where high quality habitat if found. The remote sensing team utilized the knowledge and experience from 5 years of previous research in a smaller area (10,000 km2) within the larger mapping area. The 100,000 km2 mapping effort was successfully completed and provided to the resource selection function (habitat use) modelling team for analysis. This team used the base remote sensing landcover map and applied previously developed mathematical coefficients to produce probability of grizzly bear occurrence maps. (RSF). These maps were tested with newly acquired grizzly bear GPS location data and were found to work well in predicting female grizzly bear occurrence on the landscape. Models to predict where adult male bears would be expected on the landscape did not perform as well, which may be a result of limited test data or biological parameters. The program team plans to continue this work mapping and providing predictive models for all currently defined grizzly bear range in Alberta.

4) Project Activities and Accomplishments

a) In relation to each activity listed in Appendix B of the Contribution Agreement, use the table format provided below to describe the final project outcomes and accomplishments in terms of the associated performance indicator(s). Where accomplishments cannot be accurately measured, estimates are acceptable, but should be noted as such.

Specific Activity (from Workplan)	**Anticipated Results and Deliverables** (from Workplan)	**Activity Status**	**Performance Indicators** (from Workplan)	**Final Project Accomplishments**
Create a seamless integrated grizzly bear habitat map to cover and area of 30,000 km2 along the east slopes of Alberta	Final Habitat Map	Completed	This mapping effort was expanded to cover an area of 100,00 km2, or 3 times the original mapping boundary	This mapping effort is considered complete, however our remote sensing team is continuing work on the final product to add increased value to the grizzly bear landcover map
Using existing RSF models create landscape level RSF maps for 2 seasons	Final RSF maps for 2 seasons for 30,000 km2	Completed with some ongoing work	This RSF map work was expanded to cover an area of 100,000 km2. The maps have been completed for a 20,000 km2 area at present.	The RSF models have been provided in digital form to HSP for the 20,000 km2 area. The models were further expanded to provide models for 3 seasons and for 2 sex cohorts of bears. Further these models were tested and validated using new GPS bear location data. Final models are being run for the expanded area using additional GIS data and these will be completed and provided in June 2004.
With completed habitat and RSF maps run current graph theory models for the study area	Final Graph Theory Movement Models	Runs are currently being completed at Wilfred Laurier	Successful completion of Graph Theory Models for the study area.	Due to the size of the expanded mapping area and the size of the GIS files involved additional computer resources have been required to do these runs. These runs are now taking place and final models will be available (after testing and validation) in May 2004.

		University		
Workshops to provide project tools and models to land and resource managers	Completion of workshop sessions	First series planned for May 2004 in Hinton and 2 set for fall 2004	Completion of workshop sessions and delivery of products to land users.	Due to the size and complexity of the expanded mapping effort ity has taken our team longer than anticipated to deliver final products and tools. In the interim we have communicated with many resource and land managers concerning the new tools that we will deliver this year. Scheduling workshops with industry groups has indicated that the fall of 2004 will result in higher attendance.

b) Describe any problems or unexpected difficulties (e.g. due to weather/seasonal delays, limited budget, equipment failure, etc.) that may have altered the original project workplan or accomplishment of objectives specified in the Contribution Agreement.
There was one significant change to this program in that we expanded the mapping effort from 30,000 km2 to 100,000 km2 which is a three fold increase in the size of the land area mapped. This change was accomplished by working with other collaborators to gather the necessary training data. This large mapping work resulted in some slight delays in getting the maps needed to the RSF team and in turn since the graph theory work was dependent on the RSF output layers the graph theory products were delayed. All the work is now either completed or in the final stages of completion. Program partners are aware of the products and workshop sessions are planned. In our view however, the accomplishments of this program have exceeded our expectations and we now have maps and models for approximately one-third of the grizzly bear range in Alberta. The mapping and modelling work has not only be shown to be possible but validation work proves this.

c) Provide a complete list of species occurrence data (species, number, age, sex, location, etc.) collected during the project whether it was collected as part of project activities or as incidental observations by project staff unless the release of this data is restricted by existing agreements.
Species occurrence data on grizzly bears from this project is available to HSP in hard copy map format, but use and release of this data is restricted under data sharing agreements with Alberta Sustainable Resource Development. Further information on data access can be obtained from the author.

NOTE: all information on locations of improvement and restoration projects, species at risk, etc. will be kept strictly confidential by the Minister unless authorized by the Recipient. In presenting, reporting or displaying this information, the data will be blurred such that it will not be possible to determine exact locations or to tie specific data to a specific location.

Specific requirements for data display purposes…please contact the author for maps or figures required.

5) Program Delivery Results

Please identify the most appropriate Activity Types for your project from the List. **Many projects may have only one or two Activity Types**. In the Result column, please provide the requested results for the applicable Activity Type. Quantitative measures are preferred, and where outcomes cannot be accurately measured, estimates can be provided. Please also select the most appropriate Result Type from the three provided in the table heading, and provide the percentage of project funding that went towards the Activity Type (percentages in table are for all funds combined and should add to 100%).

Activity Type List	**Result** Provide number / info where applicable	**Result Type** Choose most applicable: Habitat Protection Habitat Improvement Mitigating Human Impact	**Percentage Funds Spent on Activity Type** (Rough Estimate)
Acquire land by donation of title	# properties acquired: # hectares secured: SAR that will benefit:		
Secure land by donated conservation easement	# properties involved: # hectares secured: SAR that will benefit		
Acquire land by purchase of title	# properties acquired: # hectares secured: SAR that will benefit:		
Secure land by purchased conservation easement	# properties involved: # hectares secured: SAR that will benefit:		
Secure land by written agreement	# properties involved: # hectares secured: SAR that will benefit:		
Secure land by verbal agreement	# properties involved: # hectares secured: SAR that will benefit:		

Activity Type List	**Result** Provide number / info where applicable	**Result Type** Choose most applicable: Habitat Protection Habitat Improvement Mitigating Human Impact	**Percentage Funds Spent on Activity Type** (Rough Estimate)
Develop guidelines, plans, strategies, apply/promote Best Practices	This project has mapped 100,000 km2 of grizzly bear habitat in Alberta. The models from these maps will be used to develop best management practices for land use planning in grizzly bear habitat in the mapped area. Training workshops to deliver these new products are scheduled.		**95%**
Deliver SAR education/awareness to general public	# people reached by recipient: # who demonstrate interest in further action:		
Deliver SAR education/awareness to a specific audience	type of audience: # people reached by recipient: # who demonstrate interest in further action:		
Deliver SAR education/awareness to youth	# people reached by recipient:		
Train individuals in stewardship practices	Training workshops to deliver these new products are scheduled. Enrolment in the May workshop is 150 as of March 31/04 and we expect that an additional 300 people will attend the fall 04 workshops	**Habitat Protection**	**10%**

Activity Type List	**Result** Provide number / info where applicable	**Result Type** Choose most applicable: Habitat Protection Habitat Improvement Mitigating Human Impact	**Percentage Funds Spent on Activity Type** (Rough Estimate)
Conduct habitat/species surveys, community monitoring	This project has mapped 100,000 km2 of grizzly bear habitat in Alberta. The models from these maps will be used to develop best management practices for land use planning in grizzly bear habitat in the mapped area.	**Habitat Protection**	**90%**
Evaluate program/project outcomes	main results from data: describe link to future on-the-ground stewardship activities:		
Restore habitat from an altered site	# sites: # hectares (or other unit) affected: SAR that will benefit:		
Improve habitat quality (e.g. providing residences, build passages, fencing)	# sites: # hectares (or other unit) affected: SAR affected (estimated # SAR saved/year if possible):		
Apply modified or new technology to prevent accidental harm	# sites or units: estimated # SAR saved/year:		
Protect and rescue SAR (eg disentanglement, nest relocation)	estimated # SAR saved/year:		

Achievement of Project Objectives

a) For each of the Project Objectives listed in Appendix B of the Contribution Agreement, use the table format provided below to indicate whether or not the objective has been achieved, and provide a brief explanation. Accomplishments listed above may offer assistance.

Project Objectives	**Objective Achieved** (yes/no)	**Details** (include how project evaluated and evaluation results)
Create seamless grizzly bear habitat map using new remote sensing techniques	*Yes*	*Evaluation provided in detail report below*
Using new grizzly bear habitat maps create RSF maps for 2 seasons	*Yes*	*Our team has created maps for 3 seasons for two separate sex classes of bears (see full details in report below). In addition we have tested and evaluated these maps with new GPS location data to prove their validity and utility. This work has focused on a 20,000 km2 area and as an outcome of this testing results, the remaining area is now being completed.*
Using the new RSF maps create graph theory maps showing grizzly bear travel corridors	*(No) Partly*	*With delays in completing the mapping and RSF modelling due to the expanded study area the graph theory computer runs are still in progress at this time and will be completed in the near future.*
Deliver these tool, models and maps to land and resource managers	*(Yes) Partly*	*Although our first major workshop is scheduled with Alberta PLFD staff in May 2004, our tools and maps are being used by Weldwood of Canada, Elk Valley Coal and Petro-Canada in relation to road and resource extraction planning. Additional presentations on current results have been made to senior department staff of Alberta SRD. Full workshops for the Forestry and Energy sectors are scheduled for fall 2004.*

b) Indicate whether the overall species and habitat priorities outlined in this agreement have been addressed, with respect to the explanations provided above?
In my view (G. Stenhouse) the species and habitat priorities outlined in the agreement have been met. We have far exceeded the originally proposed mapping area and now have 1/3 of the grizzly bear habitat in Alberta mapped. The remote sensing team continues to work on improving this map product as a result of detailed analysis (see below). The RSF mapping work, although not completed for the entire 100,000 km2 area, has not only been tested and validated with new data but we have constructed models for 3 seasons and two sex cohorts which shows important major differences in model performance. The graph theory work continues using the newly developed and proven RSF layers. Many efforts have been made to have this information used and available and workshops are being held in May and the fall of 2004.

7) Recommendations for Future Stewardship/Conservation Activities

a) Specify outstanding activities that could be undertaken where problems, described in 3) b) above, prevented or modified the original plan for each activity (and suggest how these problems might be overcome in future);
Work continues to improve the landscape level habitat map to include other variables that may be important for grizzly bear habitat selection. The team has the needed data for this work and these value added efforts are continuing. The RSF models have now been shown to be applicable to areas outside where they were originally developed and testing confirms there utility. Ongoing work will complete these models for the study area, however testing in new ecosystems is critical for broad acceptance and use of these tools. With completed RSF layers the movement corridor work can now proceed as planned. Since all program elements were tied to the delivery of the final map products delays encountered due to the expansion forced the start dates back on both RSF and Graph Theory work.

b) Please provide recommendations for other future stewardship and conservation efforts that would expand the scope of the original project and further contribute to the goals of the Habitat Stewardship Program.
This program is now planning a further expansion to extend our maps and products south of the Clearwater River down to the Montana border in the 2004 field season. When this is complete in the spring of 2005 we will have mapped approximately 63% of the grizzly bear habitat in Alberta. Our long-term goal is to continue this work until we have seamless grizzly bear habitat maps and models for all grizzly bear habitat in Alberta. No other jurisdiction in North America has undertaken such a significant habitat conservation initiative for grizzly bears. Having test data to validate the maps and models we produce is a vital part of our program.

Please list any other reports that have been prepared for the project and attach a copy if the report(s) provide additional information on the project. *The program team has a number of scientific papers in press at this time and these will be provided to HSP on acceptance.*

A LANDCOVER/VEGETATION INFORMATION SYSTEM TO SUPPORT GRIZZLY BEAR CONSERVATION ACTIVITIES IN ALBERTA

1.0 Introduction and Objectives

Effective ecosystem management requires high-quality inventory and regular monitoring of natural landscapes at fine spatial scales. In Alberta, managers often rely on the Alberta Vegetation Inventory within the operational green area, and the Biophysical Land Classification within the protected areas of the mountain parks to meet these needs. However, as environmental issues become more complex, the ability of these traditional data sources to serve them becomes limited. Issues such as wildlife management, biodiversity conservation, and long-term productivity transcend political and land use boundaries, and often require the use of multiple information sources.

Remote sensing has emerged as a viable, complementary source of environmental information capable of supporting the diverse information needs of modern ecosystem management. However, the optimal strategies for extracting ecologically-significant information from satellite imagery have not yet been identified, and we continue to struggle with the production of consistent, high-quality maps over very large areas.

Remote sensing activities in the Foothills Model Forest Grizzly Bear Project have evolved throughout the six-year history of the program to meet the demands of this growing and challenging conservation initiative. We have continued to build on the 'IDTA' methodology developed in earlier phases, and the progressive move towards larger areas and regular monitoring. The current work represents an ambitious step towards a more holistic approach to land system characterization that we hope will form the next generation of remote sensing information products.

1.1 Objectives

We set out to develop a landcover/vegetation information system capable of supporting the full range conservation activities within the Grizzly Bear Project. In doing so, we set forth the following objectives:

1. A flexible information base that preserves the diversity of information and is capable of supporting multiple objectives. Users of remote sensing map products often have unique information needs, including the general attributes of interest and – within those attributes – specific definitions regarding class boundaries (Cohen *et al.*, 2001). It is unreasonable to expect a single, categorical map to serve the multiple information needs that exist even within a single project. As a result, we chose to produce a series of products that maintained maximum flexibility, rather than a single map that could not be substantially altered.

2. A series of seamless products that display no meaningful edge effects across image boundaries. In addition to developing an information source that maintains

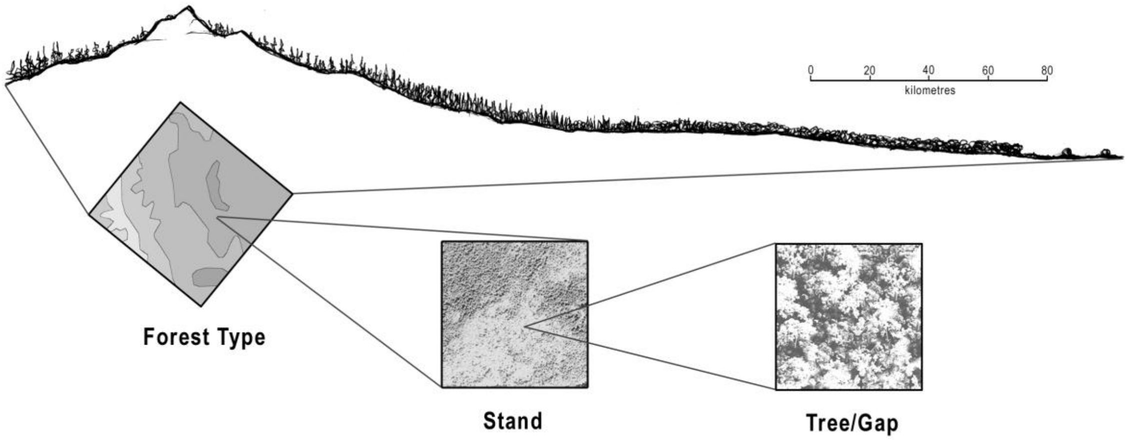
consistency across jurisdictional boundaries, we wanted a system that reduced or eliminated seam lines in a multi-image mosaic. While seam lines do not necessarily affect overall map accuracy, they detract from other elements of map quality, including consistency (Worboys, 1998), and reduce end users' ultimate confidence in the product.

3. A cost-effective production standard that can be expanded to map the entire province, if needed. Given the demand for spatially-detailed landscape information and the high cost of field work, it is necessary to develop cost-efficient procedures for map production that are scalable and limit the need for expensive field data. The Grizzly Bear has a stated goal of mapping the bear range over the entire province, and there is ultimately a need for landscape information on national and continental scales.

2.0 Methods

Unfortunately, many remote sensing products can be criticized for presenting an overly simplistic representation of landcover and vegetation, perhaps contributed to by historical limitations of satellite data and the ubiquitous use of classification as an information extraction technique. However, both of these factors have undergone recent change, with the growing number and availability of commercial and non-commercial satellites acquiring data with ever-increasing spatial, spectral, and temporal dimensions (Phinn, 1998).

Natural landscapes are complex phenomena that vary across both space and time (Hay *et al.*, 2002), and require a well-thought-out strategy for information extraction (Phinn *et al.*, 2003). In order to govern this process, we adopted a hierarchical system similar to that described by Woodcock and Harward (1992) that nests landscape attributes on the basis of scale (Figure 1). The system is composed of three categories in ascending order: tree/gap, stand, and forest type. In addition to providing a logical and convenient means of organizing the various information attributes we are interested in, the system formalizes the relationship between remote sensing pixel size and the multi-scale objects of information, providing a foundation upon which subsequent mapping and modelling activities can be based. We used image segmentation and classification techniques to produce categorical maps in cases where the image objects were substantially larger than the remote sensing pixel size (landcover, forest type), and empirical models to produce continuous parameter estimates when the objects of interest were smaller than individual pixels (crown closure, species composition, LAI). The strategy represents a sophisticated approach to mapping that matches the scale of information to the most appropriate image processing techniques.



	Landscape Attribute	Extraction Technique	Product
Tree/Gap	Crown closure, species composition, LAI	Empirical modelling	Per-pixel models; continuous
Stand	Landcover	Classification	Ten-class map; categorical
Forest Type	Natural subregion	Classification	Four-class map; categorical

Figure 1: Hierarchical information system used for characterizing landscape attributes for habitat mapping in western Alberta.

2.1 Study Area

The current Grizzly Bear Project study area covers more than 100,000 km^2 of rugged terrain in western Alberta, extending along the Rocky Mountains, foothills, and adjacent regions of the province (Figure 2). The area is physigraphically diverse, ranging in elevation from approximately 450 to 3500 metres and covering portions of four natural regions – rocky mountains, foothills, boreal forest, and parkland – and ten natural subregions (Achuff, 1994). The area hosts a tremendous variety of land use activities, including commercial timber harvesting, oil and gas, mining, and agriculture. In addition to intensive resource extraction activities, the study area also contains some of the most ecologically and recreationally significant portions of the province, including Banff and Jasper National Parks, the Willmore Wilderness Area, Kananaskis Country, and a number of other protected areas. It is also home to the core range of grizzly bears (*Ursus arctos*) in Alberta, containing more than 60% of the province's current population of wild bears, in addition to the significant numbers of moose (*Alces alces*), big horned sheep (*Ovis canadensis*), woodland caribou (*Rangifer tarandus*), elk (*Cervus elaphus*), mountain lion (*Felis concolour*), wolf (*Canis lupus*), wolverine (*Gulo gulo*), and black bear (*Ursus americanus*).

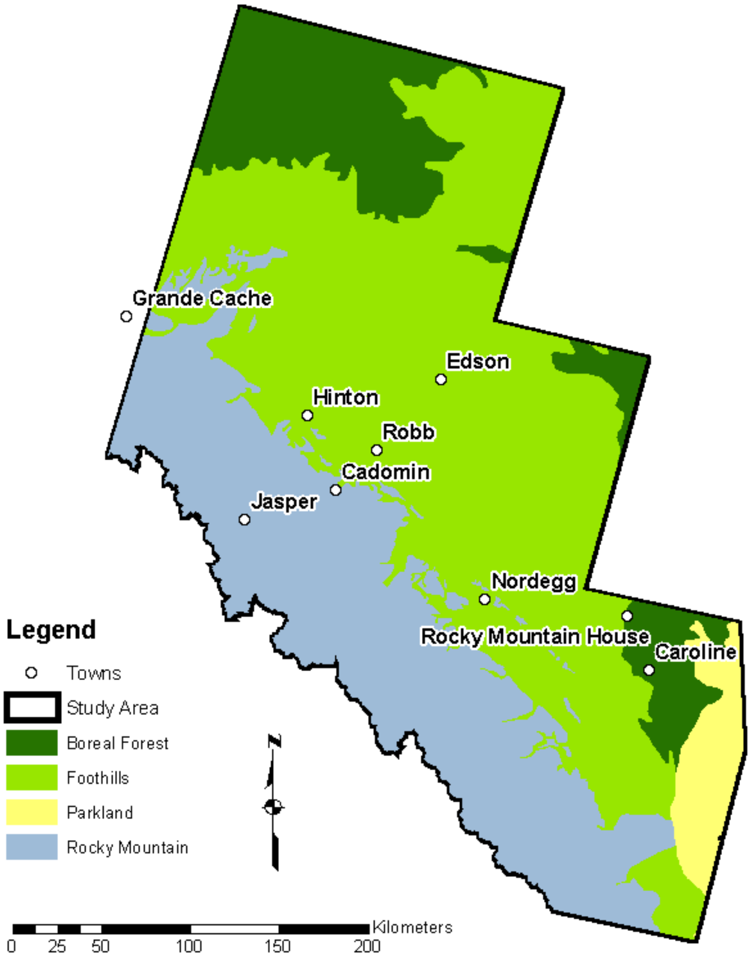


Figure 2: Study area, located in western Alberta.

2.2 Field Sampling

Field sampling in support of remote sensing activities has taken place across portions of the study area each summer from 1999 through 2003. The initial campaigns (1999-2001) were concerned primarily with mapping landcover across the early phases of the study area (Franklin *et al.*, 2001), while later field efforts (2002-2003) expanded the focus to include the characterization of vegetation structure and phenology.

While the specific field sampling methods have evolved somewhat over time, they have been consistently designed to capture elements of the ground target that could be used to explain the link between physical habitat structure and the digital measurements obtained by remote sensing. At each location, a 30x30 metre plot was established and oriented along a north bearing transect. A prism sweep was conducted from the centre of the plot, with each tree labelled, identified for species, and measured for DBH. A random sample of three trees was measured for height, height to live crown, and crown diameter. Cores were taken and measured for age and sapwood depth. During recent field seasons (2002-2003), we also established five sub plots located at the centre and corners of the 30-metre plot and used these as the basis for a series of additional measurements, including crown closure (spherical densiometer) leaf area index (AccuPAR ceptometer), and canopy structure (hemispherical photography). Additional information describing slope, aspect, elevation, topography, disturbance, and animal use was also recorded at each location.

While the four years of field work have yielded more than 850 data points, the sample distribution is heavily skewed towards the original core study area around Robb. The outlying areas north of Highway 16 and south of the Brazeau River were not sampled until the summer of 2003. As a result, we made concerted attempts to coordinate with active field programs in outlying portions of the study area such as the Jasper Woodland Caribou study and the Alberta Ground Cover Characterization project. As a result of these efforts, we were able to obtain several hundred additional sites outside of our own data. While differences in field protocols reduced the utility of these additional points, they were still a welcome addition to the field data set.

2.3 Image Acquisition and Pre-processing

We used imagery from both the Thematic Mapper (TM) instrument on Landsat 5 and the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on board the Terra satellite to create the various elements of the landcover/vegetation information base developed in this study. The characteristics of TM data are well-known, and these imagery continue to form our core data set for ongoing mapping work. The current study area is covered by five WRS scenes from paths 43, 44, and 45. Where possible, we used imagery acquired during the summer of 2003; however, cloud cover and specific temporal targets required the use of additional imagery from 2001 and 2002. A summary of all the imagery used in this study is shown in Table 1.

Table 1: Remote sensing imagery used to create the landcover/vegetation information base developed in this study.

LANDSAT		MODIS	
Image Source	Acquisition Date(s)	Image Source	Acquisition Dates
Path 43 Row 24	June 17, 2003	MOD13Q1.004	June 8-14, 2003; Aug 31-Sep 2, 2003; Oct 19-25, 2003
Path 44 Row 23	June 13, 2002; July 10, 2003		
Path 44 Row 24	July 10, 2003		
Path 45 Row 22	September 3, 2003		
Path 45 Row 23	August 23, 2002; September 3, 2003		

While the good spectral and spatial resolution of Landsat TM makes this imagery well-suited for most medium-scale mapping and modelling work, the 16-day revisit period of Landsat limits the ability of these data to characterize certain ‘temporally specific’ attributes. The difficulty (and cost) of obtaining cloud-free mosaics over large areas at specific time periods precludes the use of these data for many time-sensitive initiatives. For these reasons, we turned to MODIS to address our needs for a high-temporal-resolution sensor for exploring seasonal patterns in LAI.

The MODIS sensor acquires 36 bands of imagery with spatial resolutions from 250 to 1000 metres in the 620 to 2155 nanometre wavelengths. The instrument's most attractive qualities for our purposes include the temporal resolution: daily for individual scenes, swath width: 2330 km, and price: free! Of particular interest to us are the 250-metre vegetation indice (VI) products derived from weekly cloud-free mosaic composites. The VIs involve transformations of the red (620-670 nm), near-infrared (841-876 nm), and blue (459-479nm) bands designed to enhance the 'vegetation signal' and allow for precise inter-comparisons of spatial and temporal variations in terrestrial photosynthetic activity. The VI products consist of two indices, the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI). Each MOD13Q1 product includes VI quality information in addition to composited surface reflectance bands 1-3 and 7 (red, NIR, blue, and MIR (2105-2155nm)). The NDVI output represents a 'continuity index' for existing AVHRR-derived NDVI, while the EVI is MODIS-specific measure that offers improved sensitivity in high biomass regions, improved vegetation monitoring through a de-coupling of the canopy background signal, and a reduction in atmospheric influences. We used MODIS VI products from three different time periods (early summer, late summer, and leaf off) to track the basic phenological patterns across the study area.

Image pre-processing for the Landsat TM imagery consisted of both geometric and radiometric correction routines designed to produce a clean, five-scene orthorectified mosaic suitable for generating accurate and seamless map products (Figure 3). Geometric correction was performed using satellite orbital modelling within the software package Geomatica OrthoEngine. We collected 60-80 ground control points per scene co-located on both the uncorrected raw imagery and orthorectified master scenes, and achieved RMS values below 0.5 pixel in each case. Elevation data were extracted from a DMTI Spatial digital elevation model (DEM) acquired under an academic licensing agreement through the University of Calgary. The DMTI DEM was created through interpolation of the National Topographic Database 1:50,000 scale digital mapping standards on a 30-meter grid. We judged this product to be of a slightly higher quality than the 100-meter Alberta provincial DEM that was also available for the study area.

Radiometric processing of the seven Landsat scenes used in the analysis was conducted with a relative calibration

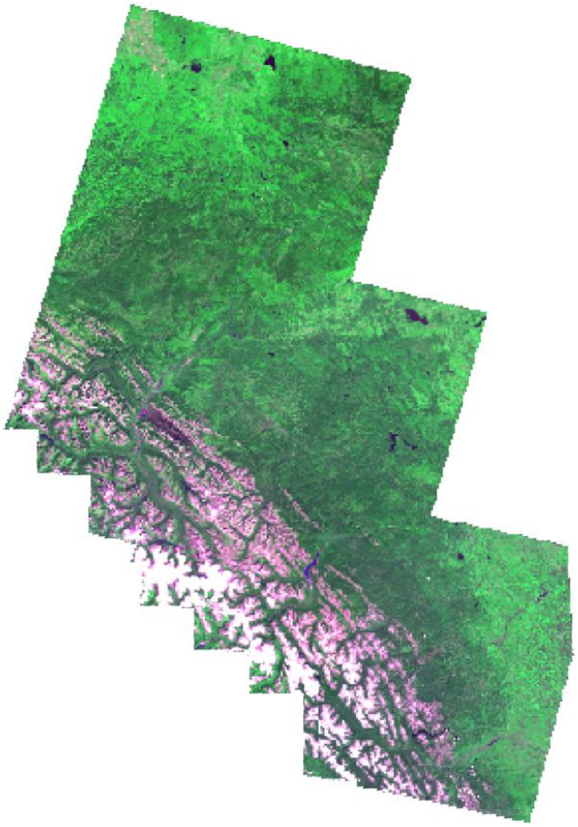


Figure 3: Landsat TM orthomosaic of the study area.

procedure that matched the seven ‘slave’ TM images to a single, high-quality ‘master’ scene (path 45, row 23; September 10, 2003). The procedure involved first transforming each image to top-of-atmosphere reflectance in order to remove illumination differences due to solar geometry, then performing a linear transformation derived using samples selected from ‘pseudo-invariant targets’ located on the overlapping portions of adjacent images; similar to the technique described by Hall *et al.* (1991). The method is different than most common radiometric processing routines in that it does not attempt to remove the effects of the atmosphere, but rather transforms the slave imagery appear as though they were acquired through the same atmospheric conditions as the master. Our experience is that this technique is more reliable for producing high-quality, radiometrically-consistent mosaics.

The pre-processing routine adopted for the MODIS imagery was much simpler, since the data are distributed at a high processing level that includes orthorectification and radiometric transformation to surface reflectance. The only procedures that were required involved image mosaicking and transformation from sinusoidal to the Universal Transverse Mercator projection used throughout this project.

2.4 Landcover Classification

Landcover classification was performed using object-oriented image processing techniques implemented within the software package eCognition (Baatz *et al.*, 2003). The procedure involved performing a multi-resolution segmentation of the five-scene study area to identify a nested hierarchy of image object primitives: homogeneous groups of pixels that form the basis of all subsequent processing. The segmentation algorithm uses a bottom-up, region-merging technique that starts with single pixels and creates subsequently larger objects through a clustering process based on weighted heterogeneity (Baatz and Schape, 1999). The size of the resulting objects is controlled by scale and shape parameters, enabling the user to create a multi-resolution network of nested objects for various classification tasks. For this project, we started with a two-tiered object hierarchy: composed of small objects for stand-based classification of landcover nested within large objects for forest type representation of natural region. The larger objects were used to create a broad, four-area classification approximating the natural region designation of Achuff, 1994. We used the resulting polygons to segment the five-scene mosaic for more detailed stand-based classification.

In order to facilitate the accurate representation of stand-based landcover, we created a classification hierarchy composed of four levels of detail (Table 2). Beginning with the most general level, we performed an iterative process of training, classification, and refinement until we arrive at an acceptable level of accuracy. Once achieved, we performed a classification-based segmentation to merge the original object primitives into new objects appropriate for that level of classification. In this way, we created an object-based hierarchy that ‘drilled down’ towards the most detailed classification represented by level IV.

Table 2: Class hierarchy used in landcover classification.

Level I	Level II	Level III	Level IV
Vegetation	Trees	Coniferous Trees	Upland Coniferous
			Wetland Coniferous
		Broadleaf Trees	Broadleaf Trees
		Mixed Trees	Mixed Trees
	Herbs	Herbs	Upland Herbs
			Wetland Herbs
	Shrubs	Shrubs	Shrubs
No Vegetation	Water	Water	Water
	Barren Land	Barren Land	Barren Land
	Snow/Ice	Snow/Ice	Snow/Ice
	Cloud	Cloud	Cloud
	Shadow	Shadow	Shadow

Ecognition uses a supervised, fuzzy classification system based on nearest neighbour analysis. The nearest neighbour technique is a powerful decision rule for handling the broad, spectrally-diverse classes commonly encountered in rugged terrain and over large areas, since there are no assumptions concerning statistical normality. Nearest neighbour classifies image objects in a given feature space based on a training sample of the classes concerned. In the classification phase, unknown objects are assigned to the class represented by the closes sample object. The quality of the classification is determined jointly by the explanatory variables that compose the feature space and the object samples that make up the training sites. In performing this process, we divided the 1125 sample sites that made up the field data set and into two groups: 844 for training, and 281 for testing.

2.5 Crown Closure and Species Composition

Vegetation attributes that vary at the tree/gap level are not well-suited to classification procedures using Landsat data, since the objects of interest occur over areas that are smaller than individual pixels. In addition, there is an incentive to produce models that maintain higher-order data than the ordinal values produced by most categorical classification procedures. As a result, we used logistic regression to produce ‘continuous variable’ models of crown closure and species composition – defined here in the most general sense as %broadleaf and %conifer – within each pixel of the 30-meter raster data set. The explanatory variables were composed of a variety of spectral measures from the TM data (the tasseled cap variables brightness, greenness, and wetness) and topographic measures from the DEM (elevation, slope, and incidence). Each variable was examined for collinearity, and determined to be independent at the $r<0.6$ level.

We used bionomial family generalized linear models in S-PLUS with the log-linear link to conduct the logistic regression analysis (Crawley, 2002). Count values from densiometer data and prism sweeps were used to derive the failure/success data necessary to construct the two-vector response variable. We used a stepwise procedure based on

Akaike's Information Criterion (AIC) to select the best-fitting model with the fewest number of predictor variables, following the principle of parsimony, and verified the results through F-tests and analyses of variance.

Initially, we derived and applied models of crown closure and species composition across the entire unsegmented mosaic, but discovered unwanted seam lines on the boundaries of adjacent scenes. In spite of our best efforts at radiometric normalization, the changing ground conditions observed across the summer growing season combined with the sensitivity of continuous-variable parameter estimates lead to unacceptable variability. To overcome these issues, we retreated back to the five individual scenes that made the Landsat mosaic and performed modelling on a per-scene basis. In two cases (path 44, row 23 and path 45, row 23) there was enough field data to enable the models to be both trained and tested, but in the remaining three scenes there was not. In these cases, we used the applied radiometric normalization procedure described by Cohen *et al.* (2001) to extend model predictions from the two source images to the three adjacent destination scenes. The technique involves using model predictions from the source image to train new models with explanatory measures obtained from the overlapping portion of the destination image. The resulting model parameters for the destination scene were slightly different, accounting for the differences in ground condition and eliminating the unwanted seams. Any field data that existed in the destination imagery was used for model verification and testing.

2.6 Leaf Area Index and LAI Productivity

Leaf area index (LAI) is defined as ½ the total leaf area per unit ground area, and is related to forest productivity, biomass, and a variety of other key ecological parameters (Chen and Black, 1992). However, since LAI changes rapidly across the growing season, it is important to develop models that match field data with time-coincident remote sensing measures. In 2002, we conducted two intensive field campaigns designed to measure LAI across a sample of sites during two distinct time periods: the pre-berry period of early summer (June 19 to July 8), and the post-berry period of late summer (August 14 to September 2). We used a 'corrected' version of the Normalized Difference Vegetation Index (NDVIc) from two coincident Landsat scenes (path 44, row 23 and path 45, row 23) to model LAI across broad contiguous portions of the study area. NDVI is calculated as

$$NDVI = \frac{TM4 - TM3}{TM4 + TM3}$$

and is perhaps the most widely-used of the common VIs. It operates on the principal that healthy green vegetation absorbs photosynthetically-active radiation in the visible portion of the spectrum (TM3) while reflecting the bulk of near-infrared radiation (TM4) (Frankin, 2001). The corrected version – NDVIc – incorporates a mid-infrared correction factor into the index, calculated as

$$NDVIc = NDVI * \left(1 - \frac{TM5 - TM5_{\min}}{TM5_{\max} - TM5_{\min}}\right)$$

The correction is designed to act as a 'greenness factor' that accounts for the contribution of the background or understory (Nemani *et al.,* 1993), and has been shown to provide a better estimate of effective LAI than NDVI, particularly in conifer forests in complex terrain (Pocewicz *et al.*, 2004).

While the TM-derived LAI estimates produced interesting snapshots of vegetation phenology at two key periods of the summer, the coverage was limited to the time and area recorded by the two specific Landsat scenes. The second phase of the process involved using MODIS data to expand our estimates over the entire study area and across additional time frames. Lacking the field measurements required to characterize LAI over a 250-metre pixel, we used the TM-based model to 'scale up' our estimates to the resolution of MODIS. This was accomplished by re-sampling the Landsat-derived estimates of LAI to a 250-metre grid using bilinear interpolation, then regressing the modelled values of LAI against the MODIS VI products. In addition to the pre- and post-berry estimates measured by Landsat, we also produced a 'leaf off' LAI product from the middle of October, under the assumption that the model parameters derived over the summer imagery could be applied to surface reflectance imagery of the same area, but different times of the year.

3.0 Results and Summary

The various mapping and modelling efforts described in the previous section resulted in the creation of a suite of seamless, contiguous, and spatially-explicit map products describing various elements of the landscape over the rugged, 100,000 km^2 study area. Together, they constitute the makings of a landcover/vegetation information system that provides a flexible foundation for mapping grizzly bear foods and habitat across the core of their Alberta range. The products currently exist in an advanced beta stage with preliminary or unspecified levels of accuracy (Table 3). We anticipate completion of the final version 1.0 database by the end of April, 2004. The figures and brief examples that follow are illustrations using the preliminary products.

Table 3: Current status and preliminary quality indicators of layers composing the forthcoming landcover/vegetation information system.

Product	Status	Preliminary Quality
Landcover Level I	Complete	>95% accuracy
Landcover Level II	Complete	90% accuracy
Landcover Level III	Complete	80% accuracy
Landcover Level IV	Beta	N/A
Crown Closure	Beta	N/A
Species Composition	Beta	N/A
Pre-Berry LAI	Complete	$R^2=0.67$
Post-Berry LAI	Complete	$R^2=0.63$
Leaf-Off LAI	Beta	N/A

The layers that make up the information base can be used either individually, or in concert. In most cases, it will be desirable to re-classify the tree/gap-level layers to a more generalized (and more accurate) series of categorical classes. The original intention of producing ‘continuous variable’ estimates was to maintain flexibility with regards to class decision boundaries; the layers suggest false levels precision well outside the accuracy of the models.

Figure 4 is an example of a composite map that was created by combining Level III landcover with re-classed versions of crown closure and species composition. The information content of these products can be further enhanced by incorporating additional GIS layers such as fire scars, clear cuts, roads, or other cultural features. Forthcoming tests with food and bear location data will help us gauge the utility of the database and provide guidance for the development of future iterations. Additional research will focus on a variety of fronts, including developing additional data layers (e.g. maturity, tree species, biomass, and a more sophisticated characterization of phenology), exploring the impact of topographic normalization, and assessing the role of new sensor technologies.

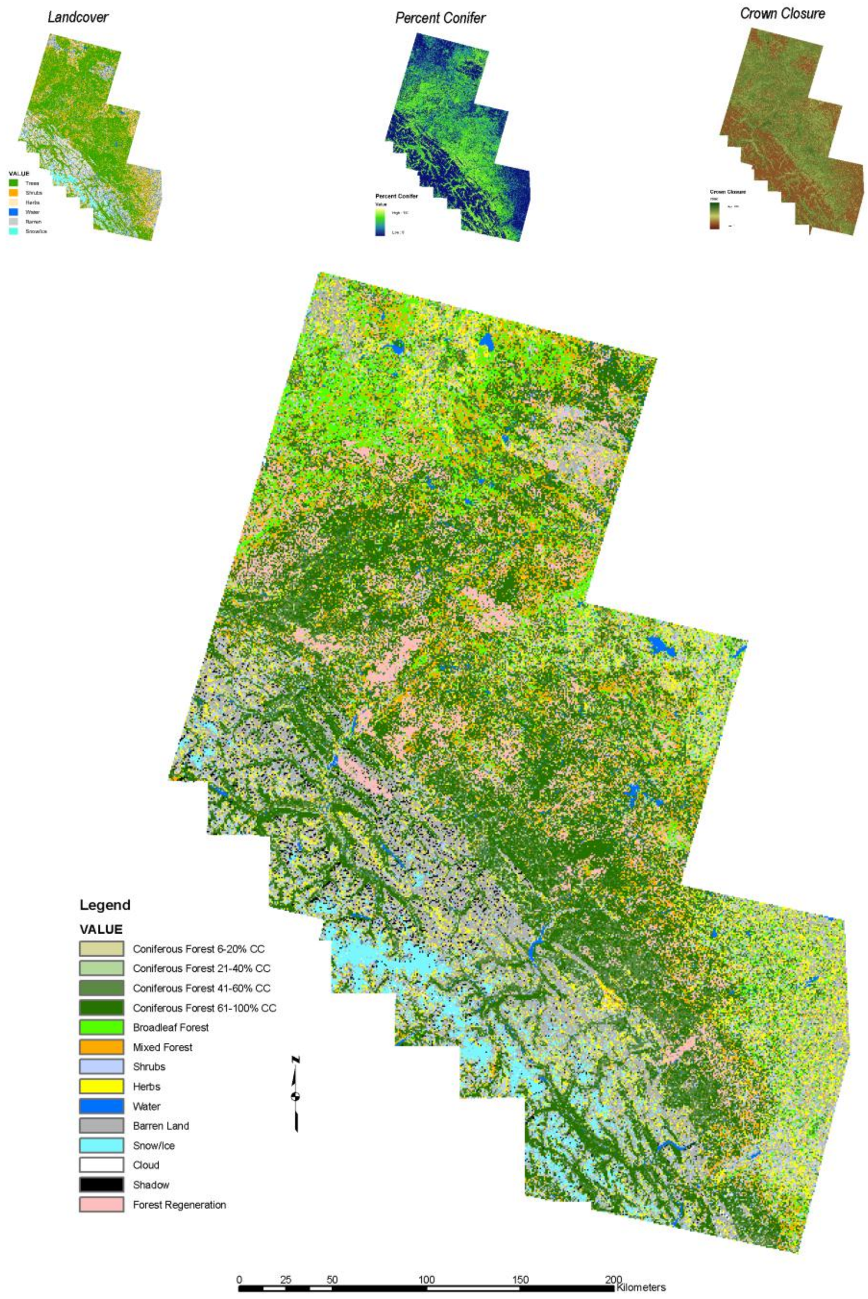


Figure 4: A sample merged product created by combining elements of level III landcover, crown closure (re-classed to four categories), species composition (re-classed to three categories) and forest regeneration (cut blocks and recent burns) from a GIS.

4.0 References

Achuff, P.L., 1994: *Natural Regions, Subregions and Natural History Themes of Alberta: A Classification for Protected Areas Management*. Alberta Environmental Protection.

Baatz, M. and A. Schape, 1999: Object-oriented and multi-scale image analysis in semantic networks. In *Proceedings of the 2nd International Symposium on Optimization of Remote Sensing,* Enschede, Netherlands.

Chen, J. M. and T. A. Black, 1992: Defining leaf area index for non-flat leaves. *Plant, Cell, and Environment*, 15, 421-429.

Cohen, W. B., T. K. Maiersperger, T. A. Spies, and D. R. Otter, 2001: Modelling forest cover attributes as continuous variables in a regional context with Thematic Mapper data. *International Journal of Remote Sensing*, 22:12, 2279-2310.

Crawley, M. J., 2002: *Statistical Computing: An Introduction to Data Analysis Using S-Plus*. John Wiley and Sons, West Sussex, England.

Baatz, M, U. Benz, S. Dehghani, M. Heynen, A. Holtje, P. Hofmann, I. Liginfelder, M. Mimler, M. Sohlbach, M. Weber, and G. Willhauch, 2003: *eCognition Object-Oriented Image Analysis User Guide 3*. Definiens Imaging Corporation, Munchen, Germany.

Franklin, S. E., 2001: *Remote Sensing for Sustainable Forest Management*. Lewis Publishers, New York.

Hall, F. G., D. E. Strebel, J. E. Nickeson, and S. J. Goetz, 1991: Radiometric rectification: Toward a common radiometric response among multidate, multisensor images. *Remote Sensing of Environment*, 35, 11-27.

Hay, G. J., P. Dube, A. Bouchard, and D. J. Marceau, 2002: A scale-space primer for exploring and quantifying complex landscapes. *Ecological Modelling*, 153, 27-49.

Nemani, R., L. Pierce, S. Running, and L. Band, 1993: Forest ecosystem processes at the watershed scale: sensitivity to remotely-sensed leaf area index estimates. *International Journal of Remote Sensing*, 14, 2519-2534.

Phinn, S. R., 1998: A framework for selecting appropriate remotely sensed data dimensions for environmental monitoring and management. *International Journal of Remote Sensing*, 19:17, 3457-3463.

Phinn, S. R., D. A. Stow, J. Franklin, L. A. K. Mertes, and J. Michaelsen, 2003: Remote sensed data for ecosystem analyses: combining hierarchy theory and scene models. *Environmental Management*, 31:3, 429-441.

Pocewicz, A. L., P. Gessler, and A. P. Robinson, 2004: The relationship between effective plant area index and Landsat spectral response across elevation, solar insolation, and spatial scales in a northern Idaho forest. *Canadian Journal of Forest Research*, 34, 465-480.

Plummer, S. E., 2000: Perspectives on combining ecological process models and remotely sensed data. *Ecological Modelling*, 129, 169-186.

Worboys, M., 1998: Imprecision in finite resolution spatial data. *GeoInformatica*, 2, 257-279.

Grizzly bear habitat modeling for the 2004 expanded study area

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Objectives and Introduction-

Grizzly bears have been considered an umbrella (large area requirements), flagship (majestic and charismatic), and/or focal species (surrogate species for regional planning) for regional conservation planning (Noss *et al*. 1996; Carroll *et al*. 2001; Bowen-Jones and Entwistle 2002). As such, habitat modeling for grizzly bears has received much attention (Waller & Mace 1997; Mace et al. 1999; McLellan & Hovey 2001; Nielsen *et al*. 2002, 2003). Here, we describe the results of work recently undertaken to predict grizzly bear habitats in an expanded study region of west-central Alberta, Canada. This area, corresponding to grizzly bear management areas 3B and 4B covered a 16,000-km^2 area that was bordered by Highway 11 and the North Saskatchewan River in the south, the Athabasca River and the Yellowhead Highway in the north, the National Park boundaries in the west, and the lower foothills in the east. We describe, in detail, the methods and results of this expanded habitat-mapping program for grizzly bears.

Grizzly bear data and RSF mapping methods (the 2001 reference area)-

We used standard resource selection function (RSF) methods (Manly *et al*. 1993; 2002) to describe the relative probability of occurrence of grizzly bears within the original 2001 Foothills Model Forest (FMF) study area (Nielsen 2004; Figure 1). It was within this reference area that the information necessary to identify grizzly bear-habitat relationships and resulting habitat models were made. To develop habitat models, we used 28,227 global positioning system (GPS) radiotelemetry locations from 32 grizzly bears acquired from 1999 through 2002. We divided these data into 3 separate seasons to account for variation in habitat use through time (Schooley 1994; Nielsen *et al*. 2003). Seasons were defined from food habits and selection patterns for the region (Pearson and Nolan 1976; Hamer & Herrero 1987, 1991; Hamer *et al*. 1991; Nielsen *et al*. 2003). The first season, hypophagia, was defined as that occurring between 1 May and 15 June. During this spring period, bears readily fed on roots of *Hedysarum* spp., carrion or ungulate calves, and early green herbaceous material, such as clover (*Trifolium* spp.) and horsetails (*Equisetum arvense*). The second season, early hyperphagia, was defined as the period occurring between 16 June and 15 August. During this season, bears normally fed on green herbaceous material including cow-parsnip (*Heracleum lanatum*), graminoids, sedges, and horsetails, and in some cases ants and ungulate calves. And finally the third season, late hyperphagia, was defined as the period from 16 August to 15 October. During this season, bears normally sought out berries from Canada buffaloberry (*Shepherdia canadensis*), blueberries and huckleberries (*Vaccinium* spp.), followed by late season digging for *Hedysarum* spp. We did not stratify animal locations within season by year due to limitations in sample size. Although annual differences in habitat selection are bound to occur, pooling years provided an average estimate of seasonal habitat use. The resulting seasonal models will thereby be in line with conservation mapping and land use planning needs that will not likely address annual variations in habitat use, since future projections are not possible without a mechanism to predict that change.

Beyond temporal differences in habitat use, individual level variation among animals can also be important. Animals often form, for instance, distinct groups such as gender, age, social status, and/or body size (Ulfstrand *et al*. 1981; Aebischer *et al*. 1993; Zharikov & Skilleter 2002). For grizzly bears, sex-age composition can be an especially important consideration in understanding habitat use. Adult females may avoid habitats used by adult males to reduce potential encounters with sexually motivated nonsire males where risk of infanticide is greatest (Wielgus and Bunnell 1994, 1995; Swenson *et al*. 1997). Sexually dimorphic differences in grizzly bear size and home range requirements would further suggest the need for partitioning of habitat resources due to energetic demands (Rode *et al*. 2001; Dahle and Swenson 2003). To account for potential differences in habitat use between sex-age groups, we stratified animals into one of the following three groups: (1) adult female; (2) adult male; and (3) sub-adult animals. Adult animals were defined as those averaging 5-years of age or older during radio tracking, while sub-adult animals averaged between 2 and 4 years of age. Given the above-defined season and sex-age strata, a total of 9 sex-age combinations were present.

We evaluated third-order (Johnson 1980) habitat selection for each sex-age strata using a 'design III' approach, where the individual identity of the animal was maintained throughout the analysis (Thomas and Taylor 1990). Remote sensing and GIS data were used as environmental covariates. In order to characterize habitat selection, however, we also required an assessment of habitat availability. Availability of resources was characterized for individual animals by sampling within minimum convex polygons (MCP). MCP's were based on animal locations from 1999 through 2002. Within each animal MCP, we generated a random sample (5 locations/km^2) of locations to characterize resource availability. Using these use (1) and available (0) location data by each strata we estimated an RSF using the following form from Manly *et al*. (1993, 2002):

$$w(\boldsymbol{x}) = \exp(\beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k) \qquad \text{[eqn. 1]},$$

where $w(\boldsymbol{x})$ is the resource selection function for a vector of predictor variables, x_i, and β_i's are the corresponding selection coefficients estimated with logistic regression. Stata (2001) was used for all logistic regression modeling. A total of 9 models were estimated, one for each sex-age and season strata. Linear predictor variables (Table 1) were assessed for collinearity prior to model building through assessments of Pearson correlations (r) and variance inflator function (VIF) diagnostics. All variables with correlations (r) >|0.6|, individual VIF scores >10, or the mean of all VIF scores considerably larger than 1 (Chatterjee *et al*. 2000) were assumed to be collinear. No evidence of collinearity was evident for map predictor variables. We accounted for autocorrelation between observations by assuming the unit of replication to be the individual and estimating robust variances around coefficients using a Huber-White sandwich estimator that clusters on individual bears (White 1980, Nielsen *et al*. 2002). We further corrected for habitat and terrain-induced GPS-collar bias (Obbard *et al*. 1998; Dussault *et al*. 1999; Johnson *et al*. 2002) by using probability sample weights for each

GPS location (Frair *et al*. 2004). Probability sample weights were based on local models predicting GPS fix acquisition as a function of terrain and land cover characteristics (Frair *et al*. 2004). Coefficients, standard errors, and significance levels were thereby modified to recognize bias in GPS data and the unit of replication to be the animal, not the radiotelemetry observation.

GIS and remote sensing predictor variables (the reference area)-

Predictor variables were derived from satellite, terrain, and land history data (Table 1). To characterize land cover, we used an Integrated Decision Tree Approach (IDTA) classification generated for the study area using Landsat TM satellite imagery (1999-2002), a 30 metre digital elevation model (DEM), GIS vegetation inventory data, and ground-truth field training sites (Franklin *et al*. 2001, 2002a, 2002b). Twenty-three land cover categories with a grain of 30 m were identified, having an overall classification accuracy of 83% (Franklin *et al*. 2001). We combined similar land cover classes into 10 major habitat classes that included 6 forest habitat classes (closed conifer, open conifer, mixed, deciduous, treed bog, and regenerating forest), 3 open habitat classes (alpine/herbaceous, non-vegetated, and open bog-shrub), and finally a single anthropogenic habitat class (Table 1). Using the above land cover categories, we reclassified the land cover grid into a single forest cover class to estimate our second variable, edge distance. We assumed that young regenerating clearcuts (0-2 yrs old and 3-12 yrs old) were still open and did not provide hiding cover and as such, we included these pixels as open habitats. The forest cover grid was converted to a polyline and used to calculate straight-line distance to polyline edge using the Spatial Analyst extension in ArcGIS 8.3 (ESRI 2002). The resulting edge distance metric (converted to 100 m intervals) represented the distance from either an interior location within a forest to a nearby open edge or the distance from a location within an opening to a nearby forest edge. Previous grizzly bear research in the area has shown strong selection for edge habitats (Theberge 2002; Nielsen *et al*. 2004a).

Forest age was estimated for closed conifer, deciduous, mixed, open conifer, and treed bog pixels using Alberta Vegetation Inventory (AVI) data and fire history GIS maps from Foothills Model Forest (FMF), Hinton, Alberta. Likewise, we used GIS forest harvest polygon data from forestry stakeholders to associate ages of regenerating clearcuts. All ages were simplified into an age class index that ranged from 1 to 15 (a value of 0 was given to all non-forested land cover pixels). Each age class in the index represented a 10-year period of succession following disturbance (e.g., age class 1 would be a 0 to 10-yr old forest or clearcut stand). We capped the age index for all forest stands ≥ 140 years of age to an age class of 15 to represent 'old growth' conditions. This simplified the distribution of forest ages, as some rare stands were quite old (i.e., 300-yrs of age), but not common enough to model habitat-relationships with any accuracy. Unknown forest ages were assigned a mean age class of 10.

Three terrain-derived variables were generated using a 30 m DEM. These 3 variables were: (1) a soil wetness index called compound topographic index (CTI); (2) a terrain ruggedness index (TRI); and (3) global radiation for the mid-month day's of June, July, and August (Table 1). CTI has been shown to correlate with several soil attributes including soil moisture, horizon depth, silt percentage, organic matter, and phosphorous (Moore *et al*. 1993; Gessler *et al*. 1995). Relating specifically to wildlife, CTI has previously been used to characterize habitat selection of clearcuts by grizzly bears, as well as the occurrence of important grizzly bear foods (Nielsen *et al*. 2004a, 2004b). To estimate TRI, we modified an existing equation of TRI from Nellemann and Cameron (1996), as described in detail in Nielsen *et al*. (2004c). TRI has been shown to be useful for describing habitat relationships for grizzly bears (Theberge 2002) and risk of human-caused mortality for grizzly bears (Nielsen *et al*. 2004c). Finally, we calculated short wave and diffuse radiation for 3 summer days: (1) June 15; (2) July 15; and (3) August 15. Both short wave and diffuse radiation were summed across all 3 days to estimate an index of summer global radiation (Table 1). Solar radiation and more generally, slope-aspect relationships correlated with solar radiation, have proven important predictors of grizzly bear habitat (Nielsen *et al*. 2002, 2003, 2004a, Theberge 2002). We assessed global radiation, however, for only 3 of the 10 land cover classes; classes which we expected to be variable (some classes were rather invariant due to their close association with flat terrain) and important *a priori*. These included closed conifer, regenerating forest, and alpine/herbaceous classes (Table 1). Each was treated as an interaction term between the categorical land cover class and global radiation estimates for each pixel in that class. As well, we hypothesized that interactions between CTI and age class, as well as CTI and edge distance, would be important descriptors of grizzly bear habitat (Table 1). We suspected that areas further from an edge were likely to be used more if the area was wet (e.g., high CTI values), while we also expected use of old growth stands to be greater if the area was wet. Finally, we fit quadratic terms for CTI, TRI, and age class variables allowing for non-linear responses (Vaughan and Ormerod 2003) that we hypothesized *a priori*.

Deriving RSF maps and model validation-

For the 2001 reference area, we report the resulting coefficients, standard errors and significance levels in Tables 2, 3, and 4 (corresponding to each season). Based on these coefficients, we estimated RSF maps in a GIS for each sex-age class using eqn. 1. RSF values were transformed, again in a GIS, using the following equation,

$$Tw(x) = \frac{w(x)}{\left(1 + w(x)\right)} \qquad \text{[eqn. 2]},$$

where $w(\boldsymbol{x})$ is the RSF prediction from eqn. 1 and $Tw(\boldsymbol{x})$ the transformed RSF value. The transformation arranged RSF values into a near normal distribution from an initially skewed distribution. Next, transformed RSF maps were binned, using a quantile classification, into 10 ordinal habitat values ranging from a low of 1 (low relative probability of occurrence) to a high of 10 (high relative probability of occurrence). Given the large number of interaction terms in the RSF models, interpretation of individual variables proved difficult. We therefore summarize some basic characteristics (mean and standard deviation) of each sex-age class (average seasonal models) in Figure 2. Overall we found that alpine/herbaceous and open conifer land cover types were consistently selected across all seasons for adult female and sub-adult animals. For adult males, however, the use of alpine and open conifer tended to vary throughout the year with treed-bog habitats often selected more than either alpine/herbaceous or open conifer. All sex-age groups tended to avoid non-vegetated and closed conifer classes. It is important to note, however, that substantial variation in RSF scores were observed within each of the land cover classes. This variation reflected micro-site characteristics associated with the additional environmental covariates in the model. Thus, land cover alone was not necessarily the most important factor determining habitat selection in grizzly bears. Instead, it was the combination of environmental factors within each land cover class that proved to be the important determinant of local habitat use. Regardless, certain land cover types on a whole tended to be either more commonly selected or avoided than others.

We evaluated the predictive performance of each reference area map (sex-age and season) by comparing the area-adjusted frequency of animal observations within each habitat bin and the corresponding rank of that bin using a Spearman rank correlation (r_s) and Somer's *D* statistic (Boyce *et al*. 2002). Area-adjusted frequency values for each bin, season, and sex-age class were calculated as,

$$f_i = \left(\frac{0.1}{a_i} \right) \times u_i \qquad \text{[eqn. 3],}$$

where f_i is the area-adjusted frequency of animal locations in bin *i*, u_i the proportion of use observations within bin *i*, and a_i the proportion of available study pixels in bin *i*. By dividing a_i by the expected frequency of available pixels for that bin (e.g., 1 out of 10 bins = 0.1), an area-based correction factor was applied to the frequency of observed use (u_i) observations for each bin. Without adjusting for area, we might for instance, find fewer use observations within certain bins that were rare on the landscape, despite having more observations per unit area. Two sets of validation data for each sex-age group were assessed. First, we assessed the relationship between map predictions and animal locations used for model training (radiotelemetry data from 1999 through 2002). This represented a within-sample test or more precisely an assessment of model fit and was therefore considered a liberal estimate of model performance. Second, we assessed the relationship between map predictions and an independent sample (out-of-sample) of animal locations collected from 2003 and not used for model building. This was considered an out-of-sample model validation and therefore more representative as an assessment of model predictive performance. We found models to fit and predict well overall, although out-of-sample data for adult males suggested the need for further improvement of that sex-age group (Table 5).

Applying RSF models to the 2004 expanded study area-

We generated the necessary GIS variables (Table 1) for the 2004 study area using a 30 m DEM and an East Slopes land cover map provided by the University of Alberta (UofA) Remote Sensing Laboratory of Dr. Arturo Sanchez in Earth and Atmospheric Sciences. This land cover map, however, did not provide differentiation of open and closed conifer stands. Given the importance of open conifer habitats for local grizzly bear populations (Figure 3), we used a canopy model from Greg McDermid (University of Calgary, Department of Geography) to separate open and closed conifer stands. A second limitation of the UofA land cover map was the lack of anthropogenic habitats. We therefore were forced to assume that for the 2004 expanded study area such habitats were not present. Finally, Jerome Cranston from the Foothills Model Forest (FMF) provided forest and clearcut age information extracted from Alberta Vegetation Inventory

(AVI) and GIS forestry management databases. Using these data products, the final study extent related to that matching the minimum data extent, which in this case was the forest and clearcut age data. These data corresponded to a 16,000-km^2-study area representing grizzly bear management areas 3B and 4B and bordered by Highway 11 and the North Saskatchewan River in the south, the Athabasca River and the Yellowhead Highway in the north, the National Park boundaries in the west, and the lower foothills in the east (Figure 3).

Using these GIS data for the expanded study region, we applied seasonal RSF models for each of the 3 sex-age classes using the reference models described in the above section (Tables 2-4) and in Nielsen (2004). This included the reclassification of $Tw(\boldsymbol{x})$ scores (transformed $w(\boldsymbol{x})$ values) to 'habitat' bins using eqn. 2. To assess the predictive performance of resulting expanded study area RSF maps, we used 6,564 radiotelemetry locations from 20 grizzly bears acquired within the expanded study region during 2003 (Table 6). We used eqn. 3 to derive frequency of occurrence within habitat bins for the expanded study region maps using each sex-age and season strata. A Somer's *D* statistic was used to compare the bin number with observed frequency (area-adjusted) of occurrence (Table 7). We found the adult female (Figure 4) and sub-adult (Figure 6) maps to be quite predictive overall, while the adult male map (Figure 5) showed signs of poor fit (Table 7). The poor fit of the adult male model may partially be explained by the small sample of 2003 radiotelemetry locations used for validation. Alternatively, adult males may simply be difficult to model, as their movement rates and corresponding large home ranges result in rather broad-scale use of most habitat resources. We have provided to the FMF 9 GIS maps that describe the relative probability of grizzly bear occurrence, by season and sex-age strata, using the above described ordinal bin scales from 1 (low relative probability of occurrence) to 10 (high relative probability of occurrence). Previous work has shown that such bins cannot be assumed to be monotonically linear (Nielsen 2004), so caution should be used when interpreting differences in 'habitat quality' between bin values (i.e., the difference between bin value 1 and 2 is typically not the same as between 9 and 10). Moreover, our confidence in the predictive capacity of the adult male maps is low and therefore we suggest caution in any further use of these sex-age class maps. Finally, we have depicted average seasonal RSF maps for each sex-age class in figures 4-6. These simplify the interpretation of grizzly bear habitat, but do result in the incorporation of seasonal noise.

Discussion-

The extrapolation of resource selection function (RSF) models to the expanded study region proved useful as evidenced by the validation of sex-age and season maps using independently with-held 2003 radiotelemetry data. This suggests that RSF habitat maps could be useful for meso-scale (~ 1 ha.) management and conservation planning. We would suggest, however, that the seasonal average adult female habitat model be considered the primary conservation habitat map. While if a single sex-age and season strata had to be chosen, we would recommend that the critically important late hyperphagic season for adult females be considered. In either case, protection of adult female habitat would be the most sensible sex-age target, given their importance to population dynamics. Adult female maps also agreed well with sub-adult maps (Nielsen 2004), suggesting that use of the adult female map alone would be representative of a large portion of the population. We did not find, however, similarity between adult male and both adult female and sub-adult maps (Nielsen 2004), suggesting that adult male habitat use was substantially different from that of adult females and sub-adults. Overall, adult male habitats appeared to be more uniform in distribution. In contrast, adult female and sub-adult habitats appeared to be concentrated in the alpine/herbaceous and open conifer stands along the upper foothills and sub-alpine zones. Some additionally important habitats appeared within old clearcut sites supporting the suggestion by Nielsen *et al*. (2004a) that certain clearcuts can provide habitat surrogates when other natural herbaceous-like habitats are lacking in the immediate area. These sites would make excellent conservation targets, as risk of human-caused mortality is likely to be high given the prevalence of human access (Nielsen *et al*., 2004c). Controlling access at high-quality clearcut habitats, as well as altering the location of new roads in other high-quality habitats would be a useful management focus.

Some caution should be given to the use of RSF products, as there are uncertainties in the quality of GIS and remote sensing data used to produce RSF maps. This is especially evident in the land cover remote sensing product from the UofA. This map lacked an anthropogenic class and needed further modeling of open and closed conifer forests. This is particularly relevant as RSF modeling for the 2001 reference area showed open conifer to be one of the most important land cover categories, while closed conifer was generally the least used (per availability) habitat (Nielsen 2004). Although we did use a canopy model from Greg McDermid (University of Calgary, Department of Geography), this model was in draft format and not finalized. Therefore, accuracy of open and closed conifer forests for the expanded region should be examined further. Finally, we did not mask pixels that probably should be given non-habitat values *a priori*. This includes urban areas, active open pit mines, white zones (e.g., agricultural fields), large bodies of water, and high mountain glaciers. Herbaceous areas in the white zone, for instance, appeared particularly sensitive to bias, as we lacked a class to distinguish agricultural fields from natural herbaceous areas such as alpine meadows. With these areas considered similar, over-prediction of agricultural sites inevitably occurred. We suggest that future grizzly bear habitat mapping recognize the need for specific decision rules in recognizing non-habitat, as well as additional mapping needs (i.e., identification of agricultural fields). Recent remote sensing products from the University of Calgary should be used for RSF products in the remaining expanded study region.

Literature Cited-

Aebischer, N.J., Roberston, P.A., Kenward, R.E., 1993. Compositional analysis of habitat use from animal radio-tracking data. *Ecology* **74**, 1313–1325.

Bowen-Jones, E., and Entwistle, A., 2002. Identifying appropriate flagship species: the importance of culture and local contexts. *Oryx*, **36**, 189–195.

Boyce, M.S., Vernier, P.R., Nielsen, S.E., Schmiegelow, F.K.A., 2002. Evaluating resource selection functions. *Ecological Modelling* **157**, 281–300.

Carroll, C., Noss, R.F., and Paquet, P.C., 2001. Carnivores as focal species for conservation planning in the Rocky Mountain region. *Ecological Applications*, **11**, 961–980.

Chatterjee, S., Hadi, A.S., Price, B., 2000. Regression analysis by example, third ed. John Wiley & Sons, New York.

Dahle, B., and Swenson, J.E., 2003. Home ranges in adult Scandinavian brown bears (*Ursus arctos)*: effect of mass, sex, reproductive category, population density and habitat type. *Journal of the Zoological Society of London* **260**, 329–335.

Dussault, C., Courtois, R., Ouellet, J.P., Huot, J., 1999. Evaluation of GPS telemetry collar performance for habitat studies in the boreal forest. *Wildlife Society Bulletin* **27**, 965–972.

ESRI, 2002. Environmental Systems Research Institute. ArcGIS: Release 8.3 [software]. Redlands, California: Environmental Systems Research Institute, 1999-2002.

Frair, J.L., Nielsen, S.E., Merrill, E.H., Lele, S., Boyce, M.S., Munro, R.H.M., Stenhouse, G.B., 2004. Removing habitat-induced, GPS-collar bias from inferences of habitat selection. *Journal of Applied Ecology,* **41**, 201–212.

Franklin, S.E., Stenhouse, G.B., Hansen, M.J., Popplewell, C.C., Dechka, J.A., and Peddle, D.R., 2001. An integrated decision tree approach (IDTA) to mapping landcover using satellite remote sensing in support of grizzly bear habitat analysis in the Alberta Yellowhead Ecosystem. *Canadian Journal of Remote Sensing* **27**, 579–592.

Franklin, S.E., Hansen, M.J., and Stenhouse, G.B., 2002a. Quantifying landscape structure with vegetation inventory maps and remote sensing. *Forestry Chronicle* **78**, 866–875.

Franklin, S.E., Peddle, D.R., Dechka, J.A., and Stenhouse, G.B., 2002b. Evidential reasoning with Landsat TM, DEM and GIS data for landcover classification in support of grizzly bear habitat mapping. *International Journal of Remote Sensing* **23**, pp. 4633–4652.

Hamer, D., Herrero, S., 1987. Grizzly bear food and habitat in the front ranges of Banff National Park, Alberta. *International Conference on Bear Research and Management* **7**, 199–213.

Hamer, D., Herrero, S., 1991. Elk, *Cervus elaphus*, calves as food for grizzly bears, *Ursus arctos*, in Banff National Park, Alberta. *Canadian Field Naturalist* **105**, 101–103.

Hamer, D., Herrero, S., Brady, K., 1991. Food and habitat used by grizzly bears, *Ursus arctos*, along the continental divide in Waterton Lakes National Park, Alberta. *Canadian Field Naturalist* **105**, 325–329.

Johnson, C.J., Heard, D.C., Parker, K.L., 2002. Expectations and realities of GPS animal location collars: results of three years in the field. *Wildlife Biology* **8**, 153–159.

Johnson, D.H., 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* **61**, 65–71.

Mace, R.D., Waller, J.S., Manley, T.L., Ake, K., and Wittinger, W.T., 1999. Landscape evaluation of grizzly bear habitat in western Montana. *Conservation Biology*, **13**, 367–277.

Manly, B.F.J., McDonald, L.L., and Thomas, D.L., 1993. Resource selection by animals: statistical design and analysis for field studies. Chapman and Hall, London.

Manly, B.F.J., McDonald, L.L., Thomas, D.L., McDonald, T.L., and Erickson, W.P., 2002. Resource selection by animals: statistical design and analysis for field studies. Second edition. Kluwer Academic Publishers, Dordrecht.

McLellan, B.N., and Hovey, F.W., 2001. Habitats selected by grizzly bears in a multiple use landscape. *Journal of Wildlife Management*, **65**, 92–99.

Nellemann, C., and Cameron, R.D., 1996. Effects of petroleum development on terrain preferences of calving caribou. *Arctic* **49**, 23–28.

Nielsen, S.E., Boyce, M.S., Stenhouse, G.B., Munro, R.H.M., 2002. Modeling grizzly bear habitats in the Yellowhead Ecosystem of Alberta: Taking autocorrelation seriously. *Ursus* **13**, 45–56.

Nielsen, S.E., Boyce, M.S., Stenhouse, G.B., Munro, R.H.M., 2003. Development and testing of phonologically driven grizzly bear habitat models. *Ecoscience* **10**, 1–10.

Nielsen, S.E., 2004. Grizzly bear habitat ecology and population viability for the Yellowhead region of Alberta, Canada. Ph.D. dissertation. University of Alberta, Edmonton, Alberta, Canada.

Nielsen, S.E., Boyce, M.S., and Stenhouse, G.B., 2004a. Grizzly bears and forestry I: selection of clearcuts by grizzly bears in west-central Alberta, Canada. *Forest Ecology and Management*, In press.

Nielsen, S.E., Munro, R.H.M., Bainbridge, E.L., Stenhouse, G.B., and Boyce, M.S., 2004b. Grizzly bears and forestry II: distribution of grizzly bear foods in clearcuts of west-central Alberta, Canada. *Forest Ecology and Management*, In press.

Nielsen, S.E., Herrero, S., Boyce, M.S., Mace, R.D., Benn, B., Gibeau, M.L., and Jevons, S., 2004. Modelling the spatial distribution of human-caused grizzly bear mortalities in the Central Rockies ecosystem of Canada. *Biological Conservation*, In press.

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

Obbard, M.E., Pond, B.A., Perera, A., 1998. Preliminary evaluation of GPS collars for analysis of habitat use and activity patterns of black bears. *Ursus* **10**, 209–217.

Pearson, A.M., Nolan, J., 1976. The ecology of the grizzly bear (*Ursus arctos* L.) in Jasper National Park- Report for 1975. Canadian Wildlife Service, Edmonton, Alberta, Canada.

Rode, K.D., Robbins, C.T., and Shipley, L.A., 2001. Constraints on herbivory by grizzly bears. *Oecologia* **128**, 62–71.

Schooley, R.L., 1994. Annual variation in habitat selection: patterns concealed by pooled data. *Journal Wildlife Management* **58**, 367–374.

Stata. 2001. Stata version 7.0. College Station, Texas.

Swenson, J.E., Sandegren, F., Soderberg, A., Bjarvall, A., Franzen, R., and Wabakken, P., 1997. Infanticide caused by hunting of male bears. Nature **386**, 450–451.

Theberge, J.C., 2002. Scale-dependent selection of resource characteristics and landscape pattern by female grizzly bears in the eastern slopes of the Canadian Rocky Mountains. Ph.D. dissertation, University of Calgary, Calgary, Alberta, Canada.

Thomas, D.L., Taylor, E.J., 1990. Study designs and tests for comparing resource use and availability. *J. Wildl. Manage*. **54**, 322–330.

Ulfstrand, S., Alatalo, R.V., Carlson, A., Landberg, A., 1981. Habitat distribution and body size of the great tit *Parus major*. Ibis **123**, 494–499.

Vaughan, I.P., and Ormerod, S.J., 2003. Improving the quality of distribution models for conservation by addressing shortcomings in the field collection of training. *Conservation Biology* **17**, 1601–1611.

Waller, J.S., and Mace, R.D., 1997. Grizzly bear habitat selection in the Swan Mountains, Montana. *Journal of Wildlife Management*, **61**, 1032–1039.

White, H., 1980. A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometric* **48**, 817–838.

Wielgus, R.B., and Bunnell, F.L., 1994. Sexual segregation and female grizzly bear avoidance of males. *Journal of Wildlife Management* **58**, 405–413.

Wielgus, R.B., and Bunnell, F.L., 1995. Tests of hypotheses for sexual segregation in grizzly bears. *Journal of Wildlife Management* **59**, 552–560.

Zharikov, Y., Skilleter, G.A., 2002. Sex-specific intertidal habitat use in subtropically wintering bar-tailed godwits. *Canadian Journal of Zoology* **80**, 1918–1929.

Table 1. GIS and remote sensing variables used for describing the relative probability of occurrence for grizzly bears in the 2001 reference area (from Nielsen 2004).

Model Variable	Code	Linear or Non-linear	Units/Scale	Data Range
Land cover:				
alpine/herbaceous	alpine	category	n.a.	0 or 1
anthropogenic	anthro	category	n.a.	0 or 1
closed conifer	clscon	category	n.a.	0 or 1
deciduous forest	decid	category	n.a.	0 or 1
mixed forest	mixed	category	n.a.	0 or 1
non-vegetated	nonveg	category	n.a.	0 or 1
open-bog/shrub	opnbog	category	n.a.	0 or 1
open conifer	opncon	category	n.a.	0 or 1
regenerating forest	regen	category	n.a.	0 or 1
wetland- treed bog	treedbg	category	n.a.	0 or 1
edge distance	edge	linear	100 m	0 - 35
compound topographic index	cti	non-linear	unitless	1.89 - 31.7
terrain ruggedness index	tri	non-linear	unitless	0 - 0.29
forest age	for-age	non-linear	10-yr age class	1 - 15
regenerating clearcut age	cut-age	non-linear	10-yr age class	1 - 5
global radiation x alpine	rad x alp	linear	kJ/m^2	17,133 - 91,836
global radiation x clscon	rad x clscon	linear	kJ/m^2	21,698 - 91,835
global radiation x regen	rad x regen	linear	kJ/m^2	57,110 - 91,831
cti x age class	cti x age	linear	unit-less	0 - 402
cti x edge distance	cti x edge	linear	unit-less	0 - 522

Table 2. Estimated seasonal habitat selection coefficients for adult (≥5 years of age) female grizzly bears in the Yellowhead region of west-central Alberta, Canada. Models were based on GPS radiotelemetry data (bias-corrected) collected from 15 adult female animals during the 1999 through 2002 seasons. Robust standard errors (Std. Err.) and significance levels (*P*) are based on modified sandwich estimates of variance among animals (from Nielsen 2004).

	Season 1-hypophagia			Season 2-early hyperphagia			Season 3-late hyperphagia		
Variable (code)	Coef.	Robust Std. Err.	*P*	Coef.	Robust Std. Err.	*P*	Coef.	Robust Std. Err.	*P*
alpine	-0.253	0.851	0.767	2.935	0.319	<0.001	0.218	0.941	0.817
anthro	0.038	0.567	0.947	0.385	0.293	0.189	-0.114	0.344	0.740
clscon	0.585	0.716	0.414	3.502	1.305	0.007	2.530	0.703	<0.001
decid	0.574	0.255	0.024	0.630	0.262	0.016	1.366	0.309	<0.001
mixed	0.727	0.212	0.001	0.079	0.299	0.791	0.778	0.553	0.159
nonveg	0.036	0.286	0.901	0.488	0.175	0.005	0.510	0.445	0.252
opnbog	-0.152	0.329	0.643	0.018	0.293	0.950	0.322	0.502	0.522
opncon	1.236	0.243	<0.001	1.268	0.255	<0.001	1.909	0.348	<0.001
regen	-3.653	1.583	0.021	-10.089	1.716	<0.001	-8.865	2.856	0.002
treedbg	0.863	0.243	<0.001	0.783	0.327	0.017	1.346	0.377	<0.001
edge	-0.281	0.063	<0.001	-0.274	0.045	<0.001	-0.302	0.061	<0.001
cti	-0.070	0.053	0.183	0.176	0.040	<0.001	0.107	0.049	0.029
[†]cti^2	0.349	0.182	0.055	-0.677	0.169	<0.001	-0.294	0.195	0.130
tri	21.516	6.541	0.001	34.959	6.496	<0.001	34.009	7.564	<0.001
tri^2	-93.662	28.670	0.001	-170.01	26.791	<0.001	-147.07	31.835	<0.001
forest × age	-0.269	0.080	0.001	-0.150	0.101	0.138	-0.219	0.058	<0.001
[†]forest × age^2	1.095	0.469	0.019	0.279	0.544	0.609	0.766	0.364	0.036
regen × age	-0.640	0.565	0.258	1.202	0.151	<0.001	-0.262	0.390	0.545
regen × age^2	0.123	0.087	0.159	-0.189	0.027	<0.001	0.097	0.075	0.197
[§]rad. × clscon	-0.019	0.092	0.840	-0.382	0.164	0.020	-0.207	0.093	0.026
[§]rad. × regen	0.496	0.290	0.087	0.998	0.225	<0.001	0.934	0.355	0.009
[§]rad. × alpine	0.133	0.119	0.264	-0.171	0.037	<0.001	0.166	0.123	0.180
[†]cti × age	0.583	0.187	0.002	0.562	0.316	0.075	0.633	0.126	<0.001
cti × edge	0.015	0.006	0.012	0.014	0.004	0.001	0.017	0.005	<0.001

[†] estimated coefficients and standard errors reported at 100 times their actual value

[§] estimated coefficients and standard errors reported at 10,000 times their actual value

Table 3. Estimated seasonal habitat selection coefficients for adult (≥5 years of age) male grizzly bears in the Yellowhead region of west-central Alberta, Canada. Models are based on GPS radiotelemetry data (bias corrected) collected from 7 adult male animals during the 1999 through 2002 seasons. Robust standard errors (Std. Err.) and significance levels (*P*) are based on modified sandwich estimates of variance among animals (from Nielsen 2004).

	Season 1-hypophagia			Season 2-early hyperphagia			Season 3-late hyperphagia		
Variable (code)	Coef.	Robust Std. Err.	*P*	Coef.	Robust Std. Err.	*P*	Coef.	Robust Std. Err.	*P*
alpine	-1.856	1.037	0.073	2.653	0.810	0.001	2.307	1.078	0.032
anthro	-0.365	0.395	0.356	0.397	0.350	0.256	-0.516	0.706	0.465
clscon	-0.208	1.053	0.843	0.310	1.431	0.828	-3.420	3.246	0.292
decid	-0.278	0.698	0.690	0.492	0.478	0.304	-0.202	0.432	0.640
mixed	-0.581	0.718	0.418	-0.099	0.458	0.829	-0.758	0.185	<0.001
nonveg	-0.325	0.210	0.122	-0.199	0.425	0.640	-0.107	0.170	0.528
opnbog	0.399	0.481	0.406	-0.128	0.413	0.756	-0.795	0.171	<0.001
opncon	0.522	0.429	0.224	0.219	0.354	0.537	0.026	0.562	0.963
regen	2.333	1.449	0.107	-4.081	2.761	0.139	3.731	1.372	0.007
treedbg	0.360	0.677	0.595	0.436	0.443	0.324	-0.267	0.603	0.658
edge	0.021	0.213	0.922	-0.180	0.083	0.030	-0.516	0.142	<0.001
cti	0.132	0.068	0.050	0.275	0.078	<0.001	0.107	0.068	0.116
[†]cti^2	-0.057	0.284	0.842	-0.882	0.453	0.051	-0.089	0.394	0.821
tri	17.263	5.469	0.002	31.996	6.487	<0.001	11.544	8.812	0.190
tri^2	-93.164	23.340	<0.001	-181.94	33.684	<0.001	-113.69	36.423	0.002
forest × age	-0.106	0.090	0.239	-0.037	0.048	0.448	0.064	0.149	0.665
[†]forest × age^2	0.737	0.651	0.257	0.307	0.194	0.113	-0.147	1.418	0.917
regen × age	3.027	0.801	<0.001	1.024	0.935	0.274	-0.346	0.153	0.024
regen × age^2	-0.431	0.121	<0.001	-0.143	0.141	0.309	0.032	0.018	0.077
[§]rad. × clscon	-0.023	0.192	0.905	-0.061	0.199	0.760	0.334	0.433	0.441
[§]rad. × regen	-0.884	0.205	<0.001	0.297	0.296	0.315	-0.477	0.136	<0.001
[§]rad. × alpine	0.281	0.121	<0.001	-0.234	0.097	0.016	-0.198	0.0771	0.010
[†]cti × age	0.200	0.375	0.594	0.022	0.374	0.954	-0.100	0.313	0.749
cti × edge	-0.023	0.024	0.344	0.003	0.006	0.602	0.019	0.013	0.145

[†] estimated coefficients and standard errors reported at 100 times their actual value

[§] estimated coefficients and standard errors reported at 10,000 times their actual value

Table 4. Estimated seasonal habitat selection coefficients for sub-adult (2–5 years of age) grizzly bears in the Yellowhead region of west-central Alberta, Canada. Models are based on GPS radiotelemetry data (bias corrected) collected from 10 sub-adult animals during the 1999 through 2002 seasons. Robust standard errors (Std. Err.) and significance levels (*P*) are based on modified sandwich estimates of variance among animals (from Nielsen 2004).

	Season 1-hypophagia			Season 2-early hyperphagia			Season 3-late hyperphagia		
Variable (code)	Coef.	Robust Std. Err.	*P*	Coef.	Robust Std. Err.	*P*	Coef.	Robust Std. Err.	*P*
alpine	-0.684	1.118	0.541	2.033	1.185	0.086	1.861	0.881	0.035
anthro	-0.735	0.702	0.295	0.094	0.268	0.728	-0.587	0.378	0.121
clscon	1.518	1.849	0.412	1.173	0.798	0.142	1.060	0.894	0.236
decid	0.058	0.640	0.927	0.586	0.397	0.140	0.370	0.441	0.402
mixed	-0.104	0.741	0.889	-0.337	0.320	0.292	-0.697	0.455	0.126
nonveg	-1.050	0.654	0.108	-0.069	0.210	0.744	-0.322	0.435	0.459
opnbog	-0.692	0.702	0.324	0.002	0.244	0.992	-0.853	0.344	0.013
opncon	0.312	0.794	0.694	0.289	0.272	0.288	0.050	0.528	0.925
regen	1.365	2.998	0.649	-3.701	1.920	0.054	-0.249	2.990	0.934
treedbg	0.012	0.783	0.988	-0.071	0.297	0.811	-0.632	0.342	0.064
edge	-0.366	0.097	<0.001	-0.298	0.099	0.002	-0.528	0.151	<0.001
cti	-0.085	0.086	0.325	-0.074	0.049	0.129	0.007	0.058	0.897
[†]cti^2	0.583	0.268	0.029	0.345	0.210	0.101	0.010	0.262	0.968
tri	10.556	5.567	0.058	26.266	10.756	0.015	22.280	6.919	0.001
tri^2	-12.611	7.576	0.096	-151.47	45.436	0.001	-122.36	31.194	<0.001
forest × age	-0.138	0.060	0.022	-0.127	0.058	0.029	0.138	0.097	0.157
[†]forest × age^2	0.631	0.244	0.010	0.409	0.518	0.430	-0.855	0.824	0.300
regen × age	0.302	0.885	0.733	0.362	0.578	0.532	-1.281	0.905	0.157
regen × age^2	-0.007	0.116	0.950	-0.064	0.096	0.505	0.164	0.141	0.244
[§]rad. × clscon	-0.226	0.299	0.451	-0.165	0.086	0.055	-0.234	0.148	0.114
[§]rad. × regen	-0.341	0.419	0.416	0.329	0.194	0.090	0.143	0.364	0.693
[§]rad. × alpine	0.098	0.168	0.559	-0.159	0.105	0.132	-0.178	0.080	0.026
[†]cti × age	0.095	0.437	0.827	0.485	0.258	0.060	-0.997	0.398	0.012
cti × edge	0.031	0.007	<0.001	0.013	0.011	0.240	0.030	0.009	<0.001

[†] estimated coefficients and standard errors reported at 100 times their actual value

[§] estimated coefficients and standard errors reported at 10,000 times their actual value

Table 5. Map validation for the 2001 reference area representing the predictive accuracy of sex-age class habitat selection models (binned map) based on data used to train the model (in-sample validation) and independent data from 2003 (out-of-sample validation).

	Number	Number of	Spearman rank		Somer's *D*		
Model	of bears	locations	r_s	*P*	*D*	S.E.	*P*
1. *In-sample validation*							
Adult female, season 1	14	4,058	1.0	<0.001	1.0	<0.001	<0.001
Adult female, season 2	15	6,876	0.988	<0.001	0.956	0.067	<0.001
Adult female, season 3	14	5,210	0.867	0.001	0.778	0.183	<0.001
Adult male, season 1	7	2,721	0.988	<0.001	0.956	0.067	<0.001
Adult male, season 2	7	2,581	1.0	<0.001	1.0	<0.001	<0.001
Adult male, season 3	7	1,384	0.939	<0.001	0.822	0.145	<0.001
Sub-adult, season 1	10	1,418	0.952	<0.001	0.867	0.111	<0.001
Sub-adult, season 2	10	2,206	0.976	<0.001	0.911	0.082	<0.001
Sub-adult, season 3	9	2,005	1.0	<0.001	1.0	<0.001	<0.001
2. *Out-of-sample validation*							
Adult female, season 1	9	1,097	0.733	0.016	0.689	0.281	0.014
Adult female, season 2	7	1,171	0.649	0.043	0.644	0.318	0.043
Adult female, season 3	6	1,147	0.867	0.001	0.778	0.183	<0.001
Adult male, season 1	2	205	0.588	0.074	0.467	0.249	0.061
Adult male, season 2	3	180	0.927	<0.001	0.822	0.125	<0.001
Adult male, season 3	1	88	0.879	0.001	0.733	0.245	0.003
Sub-adult, season 1	6	549	0.934	<0.001	0.822	0.100	<0.001
Sub-adult, season 2	7	1,061	0.964	<0.001	0.911	0.111	<0.001
Sub-adult, season 3	6	1,023	0.952	<0.001	0.867	0.111	<0.001

Table 6. Identification, gender (M-male; F-female), age class (adult ≥5 yrs old; sub-adult 2–5 yrs old), age in 2003, and number of 2003 radio-telemetry locations, by season, for the 2004 expanded study area. Locations were used for validating sex-age and season specific habitat selection models. Italicized bear numbers indicate an independent out-of-sample animal captured in 2003 and not previously used for model building.

Bear identity	Gender	Age class	Age in 2003	Hypophagia	Early Hyperphagia	Late Hyperphagia
GB03	F	adult	10	45	69	30
GB07	F	adult	8	30	–	–
GB12	F	adult	10	199	170	–
GB23	F	adult	15	105	132	115
GB28	F	adult	9	–	87	46
GB33	M	adult	7	164	118	–
GB40	F	adult	6	163	181	206
GB43	M	sub-adult	3	174	227	279
GB44	M	sub-adult	3	72	163	188
GB45	M	adult	6	49	19	–
GB55	M	sub-adult	4	101	205	137
GB57[§]	F	adult	?	116	96	–
GB58	M	sub-adult	3	35	181	192
GB60	F	adult	21	103	–	–
GB61	F	sub-adult	2	124	253	297
GB62	M	adult	5	19	90	58
GB65	F	adult	7	15	116	153
GB70	F	adult	5	18	194	226
GB100	F	adult	6	87	132	180
GB106	F	sub-adult	2	50	160	195
			TOTAL	1,669	2,593	2,302

[§] Adult female relocated in 1997 from the Pincher Creek area of southern Alberta.

Table 7. Model validation of RSF models for the 2004 expanded study area using 2003 radiotelemetry data described in Table 8. Somer's *D* represents the correspondence (–1 to +1) between predicted bin value (ordinal rank; 1 to 10) and observed frequency (area-adjusted) of animal occurrences per bin. A significant positive relationship indicates a strong predictive capacity.

Sex-age	Hypophagia			Early hyperphagia			Late hyperphagia		
class	*D*	S.E.	*P*	*D*	S.E.	*P*	*D*	S.E.	*P*
Adult female	0.911	0.082	<0.001	0.956	0.067	<0.001	0.956	0.067	<0.001
Adult male	0.644	0.226	0.004	0.556	0.269	0.039	0.333	0.307	0.278
Sub-adult	0.956	0.067	<0.001	1.00	0.000	<0.001	0.867	0.111	<0.001

Figure 1. Location and elevation of the 2001 Foothills Model Forest (FMF) grizzly bear study area. We refer to this region as the reference area as data from this region are used to predict habitats elsewhere (e.g., the expanded study region).

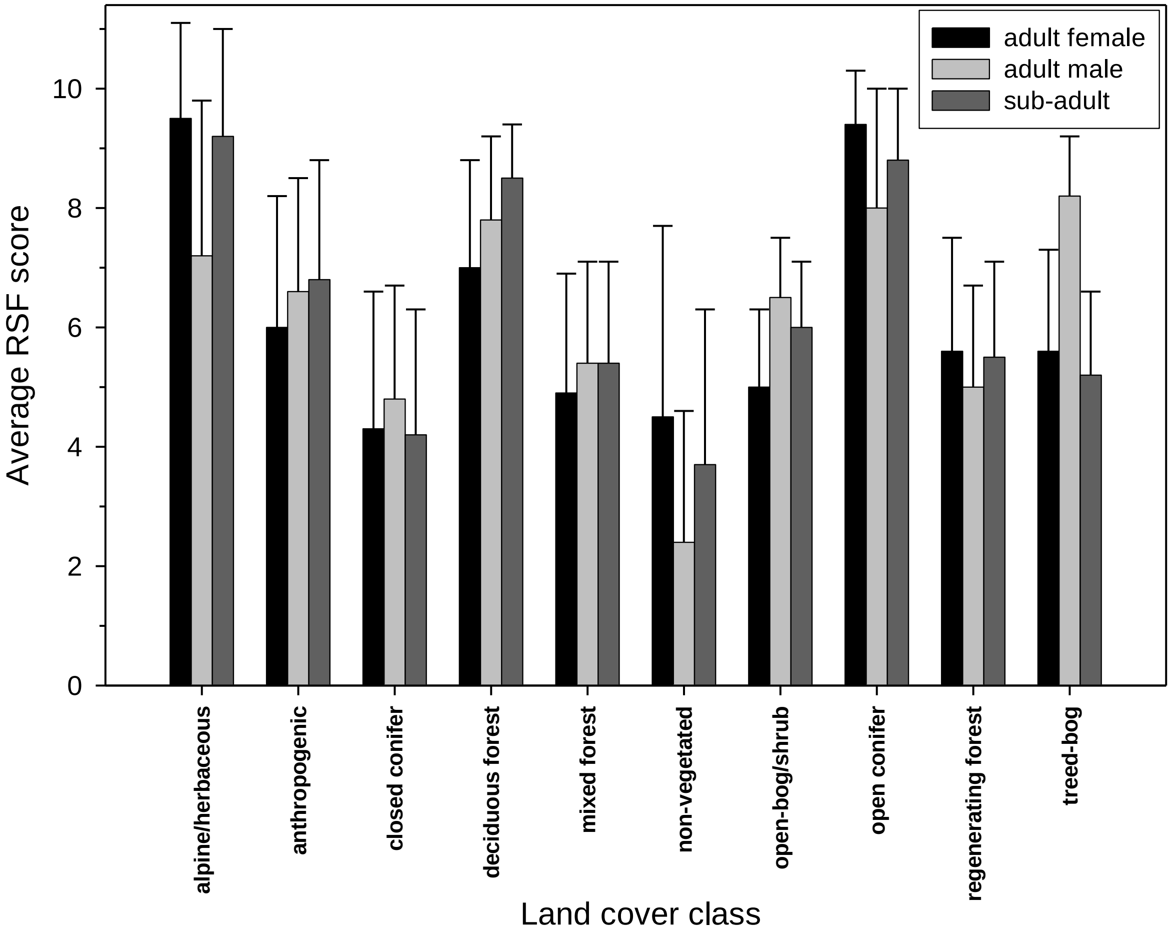

Figure 2. Average (± standard deviation) seasonal RSF scores for individual land cover classes by sex-age strata (adult female, adult male, and sub-adult).

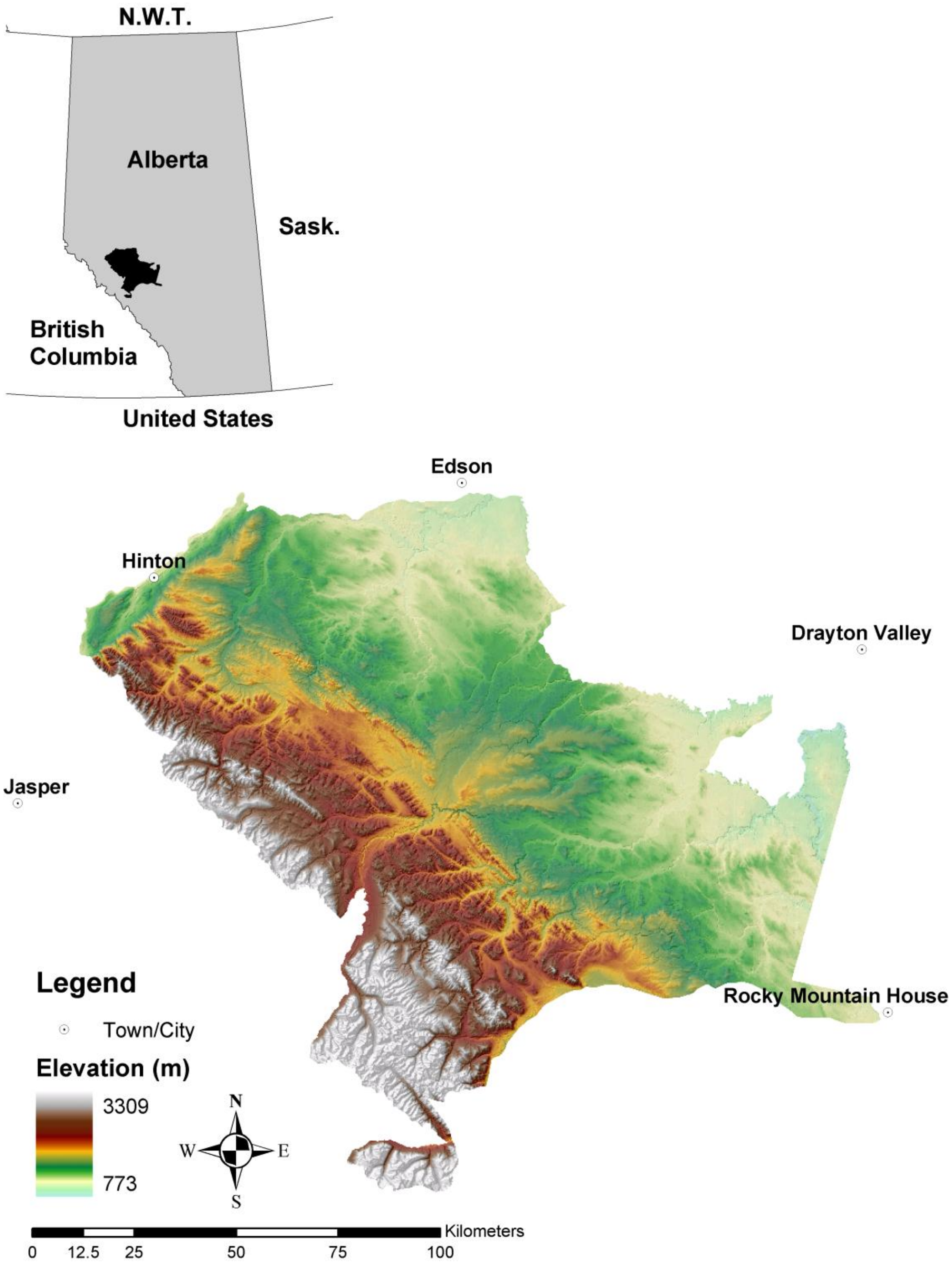

Figure 3. Expanded grizzly bear study area depicting towns and topography.

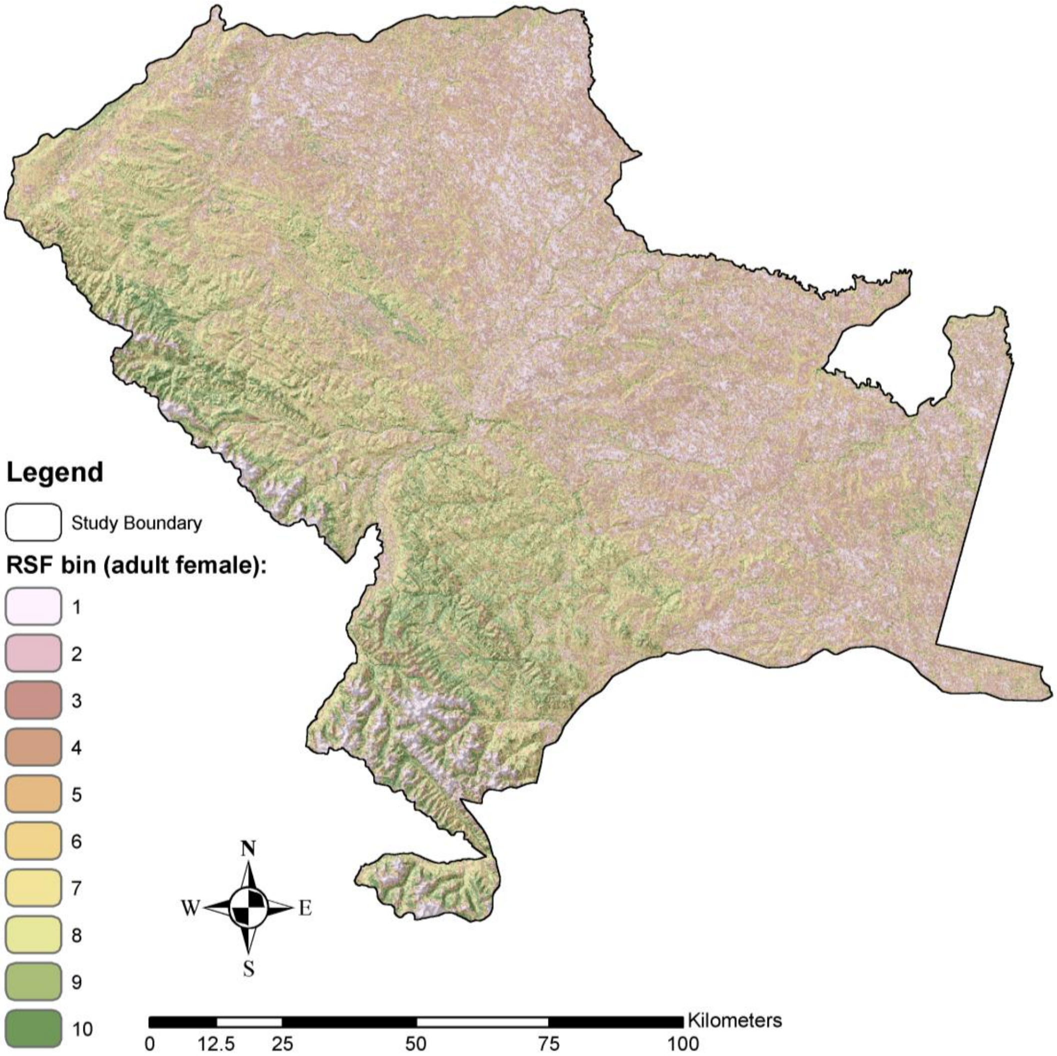

Figure 4. Average seasonal habitat values (RSF bin scores) for adult female grizzly bears in the 2004 expanded grizzly bear study area.

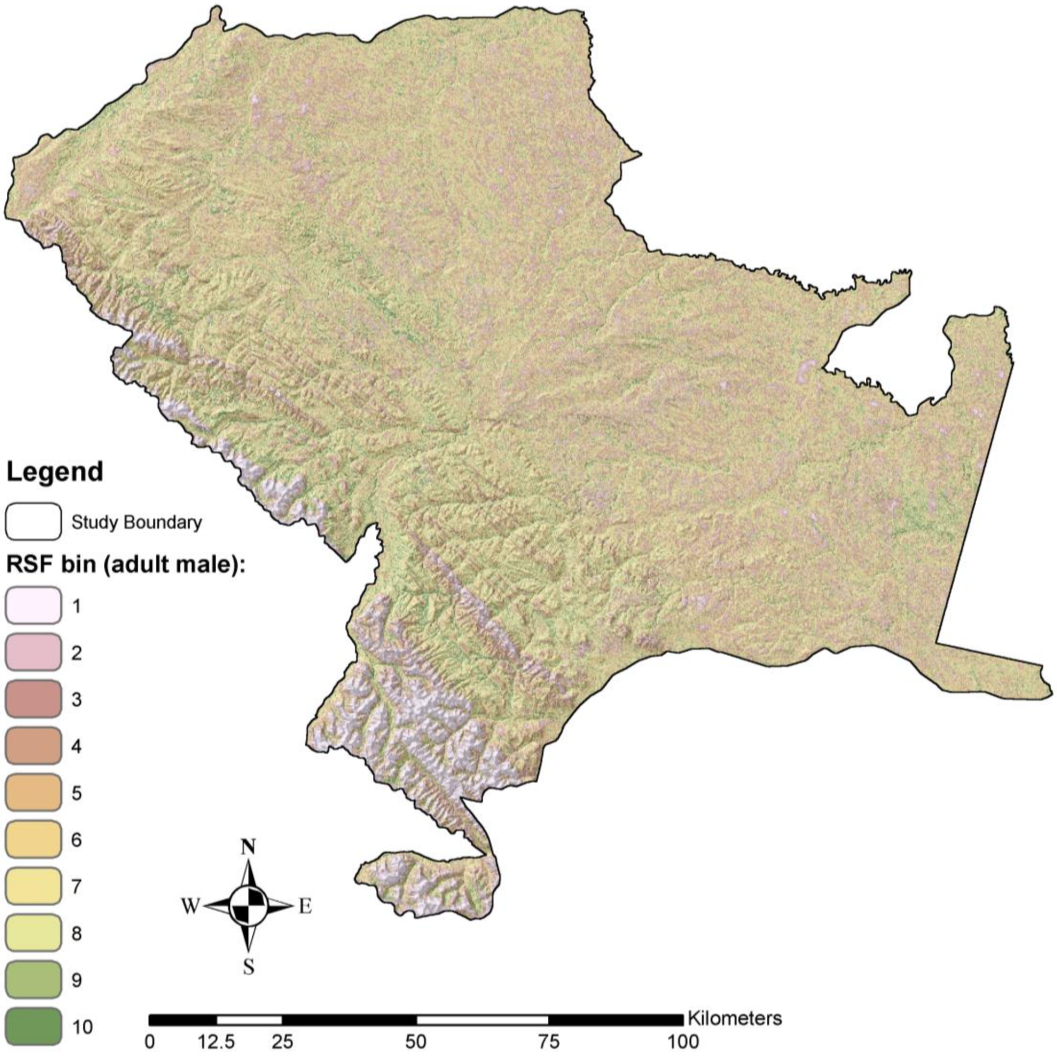

Figure 5. Average seasonal habitat values (RSF bin scores) for adult male grizzly bears in the 2004 expanded grizzly bear study area.

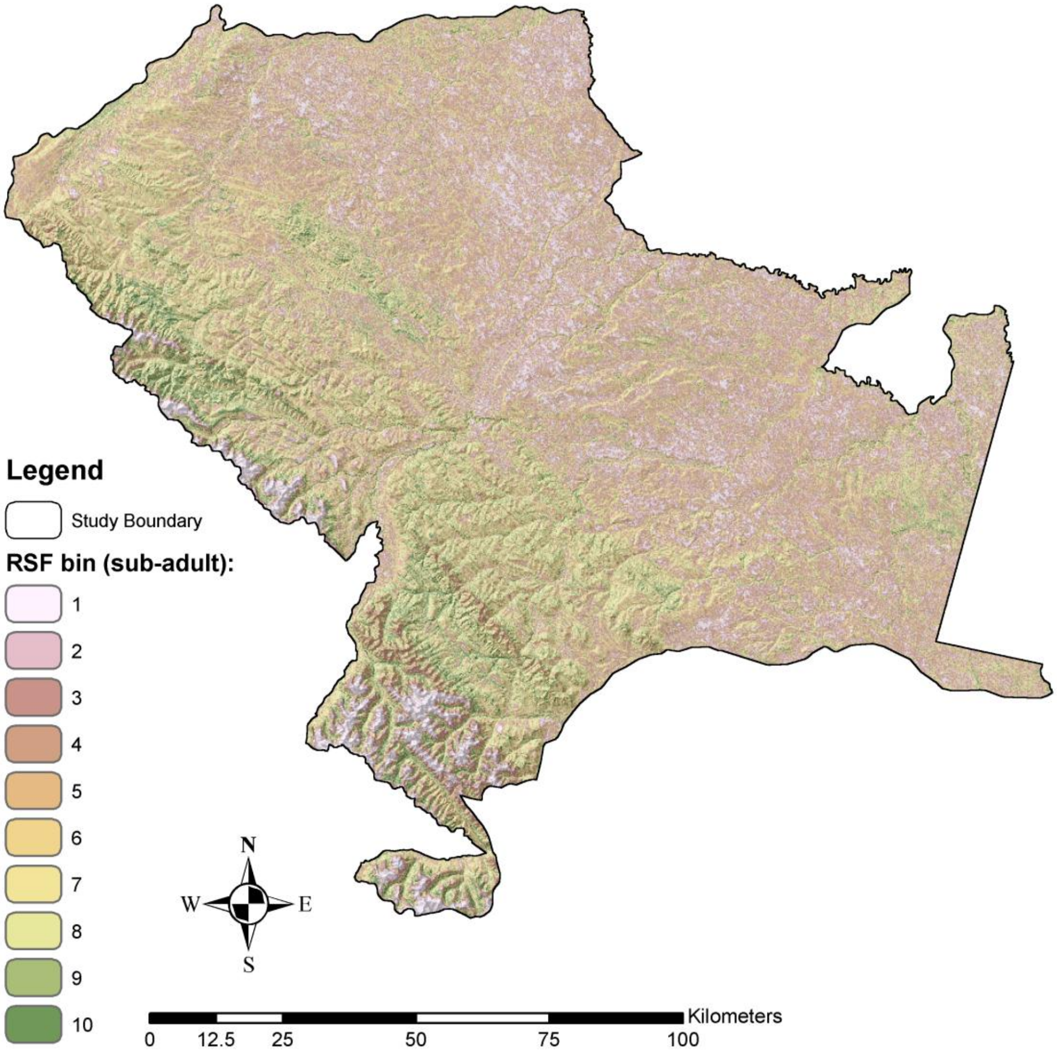

Figure 6. Average seasonal habitat values (RSF bin scores) for sub-adult grizzly bears in the 2004 expanded grizzly bear study area.