

**FOOTHILLS RESEARCH INSTITUTE  
GRIZZLY BEAR PROGRAM  
2010 ANNUAL REPORT**

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## **DISCLAIMER**

This report presents preliminary findings from the 2010 research program within the Foothills Research Institute (FRI) Grizzly Bear Program. It must be stressed that these data are preliminary in nature and all findings must be interpreted with caution. Opinions presented are those of the authors and collaborating scientists and are subject to revision based on the ongoing findings over the course of these studies.

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***This is an interim report not to be cited without the express written consent of the senior author.***

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## INTRODUCTION

Over the past twelve years the Foothills Research Institute's (FRI) Grizzly Bear Program (GBP) has made significant advances in improving our understanding of habitat use, mortality risk, health and the ecology of grizzly bears within their range in Alberta.

Our research program continues developing new tools and models to assist in sustainable forest and land management practices that may impact the long-term conservation of grizzly bears. A new tool developed in 2010 allows the spatial portrayal of seasonal important bear foods and provides the capacity to quantify both the current abundance and distribution of these foods at multiple scales. We also developed a new predictive model to show how forest harvesting (first pass) will impact high value bear foods. Another GIS application was created to allow assessment of different harvest block layout patterns on key grizzly bear foods over space and time (See 2010 Deliverables DVD for Program Partners– HSP Report).

In 2010 we continued examining the relationship between environmental variables on grizzly bear's denning activities and habitat use (Chapter 3) and began an assessment of the response of grizzly bears to oil and gas activities (Chapter 2).

This year we continued with our nutritional landscapes work which first began in 2001 when grizzly bear locations were visited and intensive vegetation quantification was conducted. This vegetation data collected from 2001-2009, was used to create food models that predicted when and where on the landscape grizzly bear foods occur at 15 day intervals (see 2009 Annual Report). Building on these food models, we now plan to determine the food energy available to grizzly bears on the landscape as well as the energy a grizzly bear requires during its day to day activities. In 2010 we made significant progress in this regard. We quantified the energy and nutrients available both temporally and spatially for various grizzly bear foods, with a focus on alpine sweetvetch (Chapter 7). We also completed a literature review and from that review we calculated the daily energy requirements for individual grizzly bears (Chapter 9). Finally we are examining how food and energy will impact the body condition of grizzly bears at the individual and population level (Chapter 8). In 2011, we plan to combine data to estimate the grizzly bear carrying capacity for west-central Alberta.

Also as part of the energetic work; our remote sensing specialists are examining the possibility of using remote sensing products to track the phenology of bear foods (Chapter 12) which will allow the ability to link with what we know about the energy in various bear foods at different phenological stages. This could then provide a relatively quick and consistent method to track how bear foods change spatially and temporally and help improve our understanding of bear foods and energy availability at large landscape scales.

Field work for our mountain pine beetle project to examine mountain pine beetle forestry activities and its impacts on grizzly bears is completed. Preliminary analysis on how bear foods will be impacted as a result of MPB forestry activities is provided in Chapter 4. Also as part of this project, our remote sensing / spatial analysis team from University of British Columbia and University of Victoria developed new techniques that now allow landscape condition maps to be produced at 16 day intervals. We have completed these 16 day disturbance maps for all grizzly bear habitat for 2000-2008 for the area ranging from the Montana border to the Grande Prairie area (Chapter 12 and also Deliverables DVD for Program Partners -Gaulton et al. 2011). This MPB work was undertaken at the request of SRD and is linked to the FRI Mountain Pine Beetle

Ecology Program through funding support and the sharing of remote sensing products for use in both projects. In addition the landscape condition map layers that were created have value for other FRI programs (and partners) who need to understand and monitor changing landscape conditions over time.

Our 5 year health initiative was completed in March 2011 (Chapter 11). This project involved a multi-disciplinary team of researchers from the University of Saskatchewan, University of Waterloo, University of Alberta, University of Calgary, the Foothills Research Institute, and eight industry partners (3 forestry, 5 oil and gas) extracting resources across an area of approximately 228,000 km<sup>2</sup> in the western part of Alberta coincident with the distributional range of grizzly bears for the province. The broad objective of this research was to investigate relationships between landscape structure, human-caused landscape change, grizzly bear health and population performance through combined use of remote sensing technology, Global Positioning System (GPS) radio-telemetry, wildlife health and stress evaluation, and molecular techniques in biomarker development. A final report and several published papers will be forthcoming (See Chapter 11). Although this project focuses on Alberta grizzly bear populations, many of the concepts, techniques and relationships uncovered can be applied to a variety of species at risk in Alberta and Canada. These leading edge innovative products and techniques will make Alberta a recognized world leader in ecosystem management and monitoring.

Funding for our 2 year collaboration between Canadian (FRI and CCWHC) and Scandinavian (SBBRP) brown bear research teams also ended in March 2011. Under the Circumboreal Forest Initiative within FRI, the objective of this collaboration was focused on sustainability of brown bear populations in boreal forest landscapes. The Scandinavian brown bear study has been in existence since 1984 and has one of the longest term and unique data sets on brown bears in the world. Brown bears in Scandinavia went from about 130 animals in the 1930s to over 3,300 animals today and illustrate the potential brown bear populations have in recovery and recolonization. The final report for this collaboration was completed and includes a draft paper on a comparison between the body mass and growth of grizzly bears from Canada and Scandinavia (in review - Journal Ecography). A separate paper on hair cortisol levels from the two areas has also been completed and will be presented at the July 2011 International Bear Association meetings in Ottawa. Both of these papers represent important new research findings in the area of brown bear ecology; research and management (See also Deliverables DVD for Program Partners – International Collaboration Brown Bear Report). An international exchange also occurred as part of this initiative. The FRI GBP Project Lead, Gord Stenhouse and project veterinarian and health project coordinator Marc Cattet participated with the spring grizzly bear captures that occur in Sweden each spring and a MSc Student, Ellinor Sahlén from the Swedish University of Agricultural Sciences spent a portion of the summer in 2010 in Alberta, collecting data for her MSc. Degree, which was completed in the winter of 2010 (See Deliverables DVD for Program Partners–Sahlén\_MSc\_Thesis)

This annual program report for the Foothills Research Institute's Grizzly Bear Program is divided into separate sections which provide detail on the various program elements within the research effort. These sections have been prepared by the principal investigators of these elements who have or will be publishing most results in scientific peer reviewed journals. A listing of research publications is presented in Appendix 3. Our research team had a great year in 2010, writing a large number of peer reviewed publications along with many that have been published this year or are currently under review.

On behalf of our research team we want to extend our gratitude to every program partner for your ongoing support and encouragement of our work.

Gordon Stenhouse  
Karen Graham  
April 2011

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## CHAPTER 1:SUMMARY OF 2010 CAPTURE PROGRAM

**Karen Graham**

Foothills Research Institute

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### **Introduction**

The 2010 Foothills Research Institute's (FRI) Grizzly Bear Program (GBP) focused its capture and collaring efforts on grizzly bears located within ongoing oil and gas activities. The purpose was to collect grizzly bear location and movement data to examine habitat use with respect to resource extraction activities and denning behaviour. We continued to collect important information on health parameters from all grizzly bears handled during our operations.

In 2010 we also provided capture and handling assistance to an independent study being conducted by University of Alberta PhD candidate Bogdan Cristescu in the Cheviot mine area south of Hinton.

### **Study Areas**

We captured and sampled grizzly bears in two distinct study areas in 2010 (Figure 1). Grizzly bears were captured in the Grande Cache grizzly bear population unit between Grande Prairie and Grande Cache, known as the Kakwa study area. Grizzly bears were also captured in the Yellowhead grizzly bear population unit, south of Hinton and east of Jasper National Park, known as the Cheviot study area. Bears were captured in this latter area to assist with the independent University of Alberta PhD project and was not managed within the FRI Grizzly Bear Program.

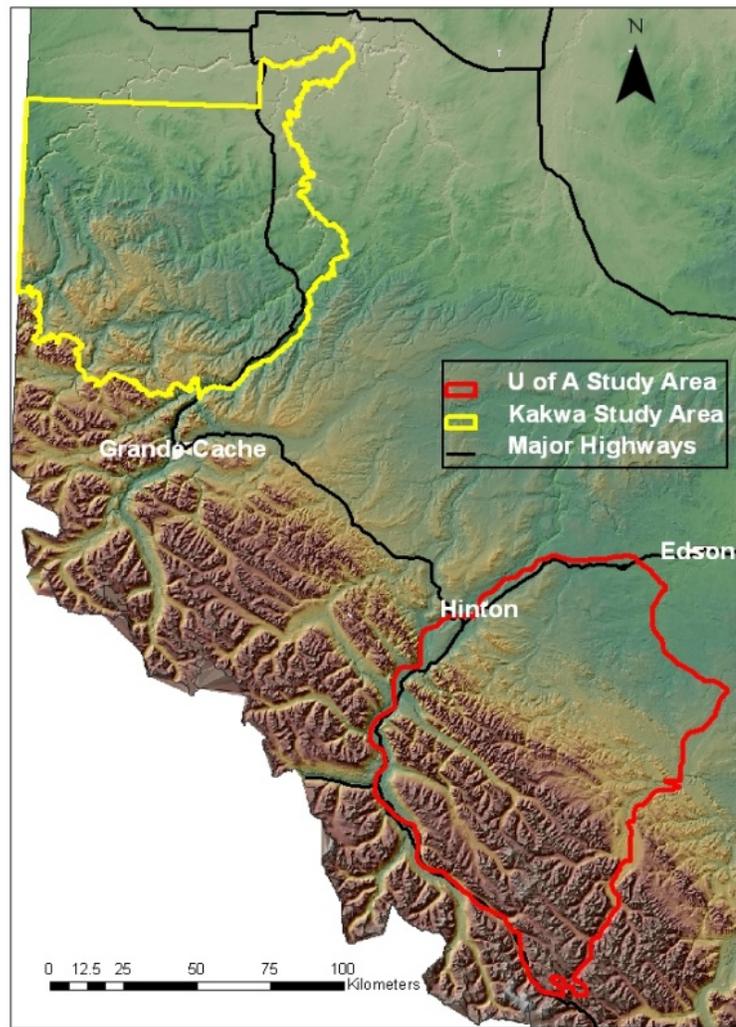
### **Grizzly Bear Captures**

The capture crew consisted of biologists and veterinarians with experience in grizzly bear capture. Grizzly bears were captured via helidarting or culvert traps fitted with satellite trap alarm systems that were placed along existing forest access roads. No snaring of grizzly bears occurred in 2010.

Field capture efforts began in late April in the Cheviot study area. Early in the season, helidarting was employed to locate and capture new grizzly bears by following tracks in the snow. Culvert traps were employed once most of the snow in the high country had melted. Helidarting also occurred if a collared bear had to be recaptured for collar replacement.

Capture efforts for the Kakwa study area began in early May. The crew was based out of the Kakwa Tower camp. A limited amount of helicopter darting was employed which targeted specific bears for recapture and collar replacement but most captures were from culvert traps.

Only 2 fall captures occurred (both in the Kakwa study area) and both were recaptures of previously collared bears.



**Figure 1. Kakwa (yellow) and the University of Alberta (U ofA) Cheviot (red) capture areas. The Cheviot captures were for an independent PhD project that was not part of the FRI Grizzly Bear Program.**

We anaesthetized grizzly bears using a combination of xylazine and Telazol administered by remote drug delivery, e.g., dart rifle or jab pole. Once immobilized, grizzly bears were weighed, and measured (chest girth, zoological length, and straight-line length). Samples were collected (blood, hair, skin biopsy, and tooth). Radio-collar and ear tag transmitters were attached. A transponder (microchip) was also inserted beneath the skin for future identification purposes. Vital functions and blood-oxygen levels were monitored throughout the handling period. Following handling, we administered atipamezole to reverse the effects of anaesthesia and monitored the grizzly bears until they showed imminent signs of recovery. We re-checked all bears again within 24 hours of capture to ensure they had recovered fully from immobilization.

All details of capture operations conformed to national standards and provincial standards on the capture and handling of ursids.

In total, we captured 15 grizzly bears in our 2010 field season (Table 1). Eight bears were caught in the Kakwa area, and 7 were captured in the Cheviot mine area south of Hinton, Alberta. No black bears were handled this field season and no other non-target species were captured. No capture related mortalities occurred during the 2010 field season.

**Table 1. Capture summary for 2010 field season.**

Name	capture_date	recapture	Sex	PopulationUnit	age_class	capture_method
G037	11-Jun-10	yes	F	Yellowhead	adult	culvert trap
G053	26-Apr-10	yes	M	Yellowhead	adult	heli dart
G110	16-Jun-10	yes	M	Yellowhead	adult	heli dart
G111	07-May-10	yes	F	Yellowhead	adult	heli dart
G115	11-Jun-10	yes	M	Yellowhead	adult	culvert trap
G117	12-Jun-10	yes	F	Yellowhead	adult	culvert trap
G118	17-Jun-10	no	F	Yellowhead	subadult	culvert trap
G257	08-Oct-10	yes	M	Grande Cache	adult	culvert trap
G258	03-Jun-10	yes	F	Grande Cache	adult	culvert trap
G260	06-Oct-10	yes	F	Grande Cache	adult	heli dart
G262	19-May-10	yes	M	Grande Cache	adult	heli dart
G269	23-May-10	yes	F	Grande Cache	adult	heli dart
G270	13-May-10	no	M	Grande Cache	subadult	culvert trap
G270	23-May-10	yes	M	Grande Cache	subadult	culvert trap
G271	21-May-10	no	F	Grande Cache	adult	culvert trap
G272	24-May-10	no	M	Grande Cache	adult	culvert trap

### Sex and Age Characteristics

Of the 15 grizzly bears captured 13 (87%) were adults, 2 (13%) were sub-adults, 7 (47%) were males, 8 (53%) were females (Table 1). Adult females were captured most often (47%), followed by adult males (40%) and subadult females and males (0.07% each). One subadult male (G270) was captured twice in a culvert trap. No cubs of the year were caught.

### GPS Radio-Telemetry Data

We deployed a Global Positioning System (GPS) radio-collar and (VHF) ear-tag transmitter on captured bears. All radio-collars have an integrated remote release mechanism in addition to a rot-off system as a backup in case of electronic failure. Twelve radio-collars were deployed. Radio-collars deployed consisted of Follow-it (Tellus II) and a single Follow-it Satellite collar deployed on a large adult male. Follow-it collars collect locations on the following schedule:

- April 1 to November 31 - 1 location/ hours.
- December 1 to March 31 - 1 location/2 hours.

We conducted data upload flights from all collared bears in the Kakwa study area throughout the summer and fall and, as of October 15th we obtained 100,000 GPS location points. Additional GPS data collection took place in January 2011 once denning had occurred. As in previous years we used the individual GPS locations to determine locations of all den sites in order to investigate denning behaviour. We installed weather monitoring stations at a number of grizzly bear dens in early January to collect microsite weather data to relate to temperature data being collected from collars in dens.

### **Grizzly Bear Health Evaluation**

We gathered health information from all 15 grizzly bears as part of our research activities. The data from these bears include data on physical and physiological measurements recorded at capture as well as results from subsequent laboratory analyses of blood serum, skin, and hair. All health data for 2010 are now entered into our project health database bringing the total number of health records for the project to 349 cases representing 210 unique animals of which 82 have multiple (2-8) records over intervals ranging from 1 month to 8 years.

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## **CHAPTER 2: GRIZZLY BEAR RESPONSE TO OIL AND GAS DEVELOPMENT AND ACTIVITIES IN ALBERTA - ALBERTA UPSTREAM PETROLEUM RESEARCH FUND - 2010 PROJECT STATUS UPDATE**

**Gordon Stenhouse**  
Foothills Research Institute

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### **Program Background**

The goal of this research project is to assist the oil and gas industry in providing scientific data to increase our understanding how grizzly bears respond to oil and gas operations in provincial grizzly bear range. At the current time no published literature exists on how grizzly bears respond (behaviorally or numerically) to energy sector activities in the province. By using our existing data sets, which have been compiled with 10 years of funding support from a number of CAPP, SEPAC and PTAC member oil/gas companies, we will utilize the current research investment to address pressing species at risk management questions. These data and analysis will be important in addressing management actions that may be associated with provincial grizzly bear recovery efforts and future land management decisions within provincial grizzly bear range.

This summary report is an update on research activities and progress in the first year of this two year research program.

#### Research Hypothesis:

1. Are grizzly bear movement patterns affected spatially and/or temporally by oil and gas development and activities?
2. Do grizzly bears show any avoidance or attraction to oil and gas operations or facilities?
3. Are grizzly bears displaced from high quality habitat when oil and gas activities are present, and do they return to these habitats at any point during the life cycle of oil and gas operations and facilities?

We also propose to analyze our data sets to address the following broader objectives:

4. Evaluate current grizzly bear cumulative effects assessment models (CEA) in relation to existing high resolution data sets to understand their applications and limitations.
5. Evaluate current landscape conditions associated with oil and gas and forestry activities in the Kakwa area in relation to current (2008- DNA inventory) grizzly bear population distribution and abundance.

## Research Progress in 2010

### Data Sets

1. The foundation of this research is based on three primary data sets:

- GPS location data sets from radio collared grizzly bears
- Annual landscape condition GIS data layers within the study area
- 16 day landscape conditions GIS day layers associated with finer scale landscape change.

In 2010 we maintained a total of 10 GPS collared adult grizzly bears within the Kakwa study area. Capture and collaring activities took place in both May and October to ensure data collection was continuous and that working collars could be maintained on known individuals through the final year of data collection (2011). Denning locations for all study animals were identified in December 2010 and final data uploads for the 2010 field season was completed at this time. These data supplement our 2005-2009 GPS data sets from grizzly bears within this same area.

Using remote sensing imagery our research team completed the preparation of the annual landscape condition map layers for the period 2004-2010. These annual landscape condition maps utilized imagery from August – September each year. These map layers included all visible features associated with both forest management activities, oil and gas activities and all associated road construction within the study area. Our research team also compiled annual landscape condition layers dating back to 1972 using available satellite imagery and has a paper under review at this time (Wulder et al. 2010, in review).

In order to better match our hourly GPS grizzly bear location data our research team developed a new technique to identify and delineate landscape change at 16 day intervals. This work is now published (Gaulton et al 2011, Hiker et al 2010 a and b) and represents an important advance in relating animal movement data to landscape conditions at a finer scale. The team assembled a 16 day change layer for the study area for the period 2004-2010 to match GPS data sets.

Working with Alberta Energy we were also able to assemble and integrate a new data set that identifies oil and gas sites and their status (active, inactive, etc.) for each year of interest and these data were integrated with landscape condition map layers. All needed data for the period 2004-2010 have now been assembled for analysis.

### Preliminary Analysis

Although this is the first year of a two year project we have undertaken some preliminary analysis to test the linkages between the animal (GPS Bear Data) and habitat (Landscape Condition) data sets. Two graduate students (Ellinor Sahleen - Sweden and Benjamin Stewart-University of Victoria) were involved in two separate analyses. The key findings to date from this work are:

1. Some grizzly bears are readily attracted to wellsites but avoid human activity by making temporal adjustments in their behaviour, and by using cover as compensation when in proximity to human activity. Positive selection for wellsites which are easily accessible

by humans increases the risk of bear-human conflicts, which may in turn lead to increased direct mortality for threatened bear populations.

2. Within the Kakwa study area roads are selected by females, but avoided by males. Oil/gas pipelines show similar selection as roads, indicating edge habitat along these pipelines are also important to grizzly bear habitat use. Seasonal differences indicate that females and males select for these edges more in the fall, possibly due to changes in feeding requirements and security. These results indicate that while managing for anthropogenic disturbances in grizzly bear habitat is of utmost concern, understanding bears' reactions to natural transitions can provide new management opportunities. The home ranges of female bears are found to have a higher density of pipelines and roads than males. The difference between genders is significant ( $\alpha = 0.05$ ) for spring and fall for pipelines, and spring and summer for roads.

### **Next Steps (2011)**

We have applied for funding from AUPRF (Alberta Upstream Petroleum Research Fund) and our other program partners to allow us to complete this research effort in 2011. At this time we are awaiting funding decisions. However our program plan is to collar approximately 4 more grizzly bears in the Kakwa area in the spring of 2011 and monitor and collect GPS data from these bears until denning in the fall of 2011. We will remove all collars from our research bears in the fall of 2011 to meet provincial research permit conditions.

Our research team will again prepare annual and 16 landscape condition map layers for the 2011 field season and integrate these with our current data sets.

Detailed spatial analysis of all data will continue in 2011 with current data with reports to be completed and final papers submitted by April 2012.

### **References to date**

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## CHAPTER 3: DENNING BEHAVIOUR AND CLIMATE CHANGE: LINKING ENVIRONMENTAL VARIABLES TO DENNING OF GRIZZLY BEARS IN THE ROCKY MOUNTAINS AND BOREAL FOREST OF ALBERTA, CANADA

**Karine Pigeon, PhD Candidate**, Etienne Cardinal, Steeve D. Côté  
Laval University, Quebec City

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### Introduction

Climate change is undeniable (IPCC, 2007) and now a major concern for the long-term conservation of ecosystems and species (Parmesan and Yohe. 2003, Scholze et al. 2006). Long-term data sets ( $\geq 30$  years) are often unavailable but necessary to observe direct relationships amongst ecological processes and climate. Researchers focusing their efforts on predicting the impacts of climate change on species of concern are therefore faced with a great challenge. Still, a number of recent studies have documented and modeled, through empirical or mechanistic approaches, the impact of climate change on natural systems and species (e.g. Carroll. 2007, Rosenzweig et al. 2008, Molnár et al. 2011).

Climate change may act as an additional strain on fragile wildlife populations affected by other factors such as habitat loss and excessive human-caused mortality. The effects of climate change on fragile populations will likely be more pronounced during energetically demanding periods such as winter. Hibernation patterns, which are widely viewed as an adaptation to cope with unfavourable environmental conditions primarily driven by a decrease in food availability and ambient temperatures, may be modified by recent climate change. The consequences of altered denning behaviour for grizzly bears, a threatened species in Alberta, are unknown. Climate-induced changes in the denning behaviour of grizzly bears may increase human-bear interactions as climate continues to warm. Since human-bear conflict is the primary cause of grizzly bear mortality in Alberta, our results may have important management implications for the long-term survival of grizzly bear populations. Modifications in hibernation patterns may require important changes in management-related conservation actions and land management practices.

Our objective was to identify the potential consequences of climate change on the denning behaviour of grizzly bears by investigating links between environmental variables and hibernation patterns. We hypothesized that sex, reproductive status and weather conditions determined the timing of den entry and den emergence, and therefore the length of the hibernation period. We predicted that persistent unfavourable weather conditions would lead to early den entry and persistent favourable weather conditions to early den emergence.

### Methods

#### Study Area

This study was conducted in two distinct regions of North Central Alberta including the Weyerhaeuser Grande Prairie (WGP) Forest Management Area (13,031km<sup>2</sup>) directly south of Grande Prairie, and the Hinton-Cadomin area (18,907km<sup>2</sup>) directly south of Hinton. Bears were

captured between 1999 and 2010 using aerial darting, leg snares, or culvert traps and were fitted with ATS (Advance Telemetry Systems), Simplex or Tellus(Followit) collars. Prior to 2004, collars were programmed to acquire one location every 4-hrs while they acquired one location every 1-hr between 2004 and 2010.

#### Meteorological Variables

We obtained daily temperature and precipitation data from relevant Environment Canada and Alberta Sustainable Resource Development weather stations (data available online for Environment Canada<sup>1</sup> and on demand for Alberta SRD<sup>2</sup>). For the Hinton-Cadomin area, we obtained data recorded at the Jasper Warden Environment Canada weather station located 6 km northeast of the town of Jasper, Alberta (52.93, -118.03), at an elevation of 1020m. For the Kakwa area, temperature data were recorded at the Kakwa (G1) provincial automatic station (54.18, -119.06; elevation=1344m). Precipitation data were incomplete at this station; we therefore obtained complete precipitation data from the nearest weather station (115 km straight-line distance), in Grande-Prairie (Environment Canada station; 55.18, -118.89; elevation=669m).

We derived monthly specific temperature and precipitation-related variables from the daily temperature and precipitation data (Table 1). We then used a Principal Component Analysis (PCA) in SAS 9.2 (SAS INSTITUTE Inc. 2008) to summarize these variables into principal components describing monthly weather. Using monthly data, we conducted season-driven PCAs by study areas (spring: March-April-May; and fall: September-October-November). Using the season-driven PCAs, we averaged the principal components (scores) by year and performed a Cluster Analysis in order to group years depicting similar weather (Huth et al. 1993). Clusters were formed using the mean Euclidian distances between points (years) and associated variance, i.e. points with similar distance and variance represent a cluster.

**Table 1. Monthly temperature and precipitation-related variables included in a Principal Component Analysis describing spring and fall weather.**

Monthly variables	Abbreviation	Description
Temperature	T	Mean of the daily mean temperature
Total rainfall	TR	Sum of daily rainfall
Total snowfall	TS	Sum of daily snowfall
Total precipitations	TP	Sum of daily rainfall and snowfall
Growing degree-days	GDD	Sum of daily number of °C exceeding 5°C
Freezing days	FD	Number of days with temperature not exceeding 0°C
Freezing period	FP	Highest number of consecutive days reaching below 0°C

We validated the weather PCA ordination of years by looking at differences between temperature and precipitation recorded at weather stations and the temperature and precipitation normals calculated with the ClimateAB software (Wang et al. 2006; climate normals based on data from 1971 to 2000). The ClimateAB software provides monthly climate

<sup>1</sup>Environment Canada: [Hhttp://climate.weatheroffice.gc.ca/climateData/canada\\_e.html](http://climate.weatheroffice.gc.ca/climateData/canada_e.html)H [Accessed 10 January 2011]

<sup>2</sup>Alberta Sustainable Resources and Development: [Hhttp://www.srd.alberta.ca/UpdatesFireAlerts/FireWeather/WeatherStations/Default.aspx](http://www.srd.alberta.ca/UpdatesFireAlerts/FireWeather/WeatherStations/Default.aspx)H [Accessed 10 January 2011]

normals for minimum, maximum, and mean temperatures, as well as total precipitations. We averaged the monthly differences between recorded values and climate normals by season (spring and fall) and ranked years according to differences. We expected years with distinct weather according to PCAs to also have larger differences with climate normals.

#### Timing Of Den Entry And Den Emergence

Den entry and emergence dates (entry:  $n=74$ , emergence:  $n=65$ ) were determined at a day-level accuracy for individuals with at least one GPS-location per day during the den entry and/or den emergence periods. Sample sizes varied between den entry and den emergence dates because collars installed on individuals captured prior to 2007 were often programmed to release during the denning period in order to facilitate collar and data retrieval. We used a combination of methods including the rate of successfully acquired GPS-locations, the rate of individual movements, collar temperatures, and the visualization of spatial clustering in ArcGIS 9.3 to determine actual den site location as well as den entry and emergence dates. We used a constant collar error of 35m to delineate den centers and subsequently infer den entry and emergence dates from spatial clustering. We choose an error of 35m as this was the maximum error recorded from a collar placed within a den during a field test and because it was the most common radius observed for all den clusters. In a few instances ( $n=9$ ), collar errors were greater than 35m and den centers were adjusted accordingly. The collar errors observed in our study were not particularly surprising as a number of scientific papers have shown that topography, habitat type, collar type, and animal position affect the accuracy and frequency of GPS locations (e.g. Dussault et al. 1999, D'Eon et al. 2002, Hebblewhite et al. 2007). Finally, the use of spatial clustering to estimate den centers yielded a mean error of  $9.6\text{m} \pm 1.7$  ( $n=20$ ) when compared to visited den sites.

#### Statistical Analyses

We used linear mixed models (PROC MIXED – SAS INSTITUTE Inc. 2008) and an information theoretic model selection approach based on the Akaike Information Criterion for small sample sizes ( $AIC_c$ ) to assess the effect of environmental variables on the timing of den entry and den emergence. It is well known that the sex and reproductive status of individuals affect den entry and den emergence (e.g. Haroldson et al. 2002, Manchi and Swenson. 2005, Figure 3). We therefore built a reference model which included a synthetic variable combining both sex and reproductive status to act as the reference model (null model) and test the effect of environmental variables on the timing of den entry and den emergence. Environmental variables were compared to the reference model in sets of candidate models built a priori. We ranked candidate models based on  $AIC_c$ , and calculated delta  $AIC_c$  ( $\Delta AIC_c$ ) to select the best models (Burnham and Anderson, 2002). Using this method, a model with a low  $AIC_c$  is a better model and models with  $\Delta AIC_c \leq 2$  are considered equivalent (Burnham and Anderson, 2002). We only built models with biologically meaningful covariate combinations and did not test interactions to avoid overparameterization of the models. Variables that were correlated at  $\geq 0.6$  were not included in the same model (Pearson correlation, PROC CORR-SAS INSTITUTE Inc. 2008). All models included individual bears as a random factor because some individuals were present in more than one denning period.

To measure the strength of the relationships established in the selected models, we verified the coefficient of determination ( $r^2$ ) of the best models ( $\Delta AIC_c \leq 2$ ). As the PROC MIXED (SAS INSTITUTE Inc. 2008) procedure does not provide  $r^2$  values, we determined the proportion of the total variation in our dependent variable (den entry or den emergence) that was explained by

model covariates from the square of the correlation coefficient between predicted and observed values of each model (Xu 2003).

## Results and Discussion

### Meteorological Variables

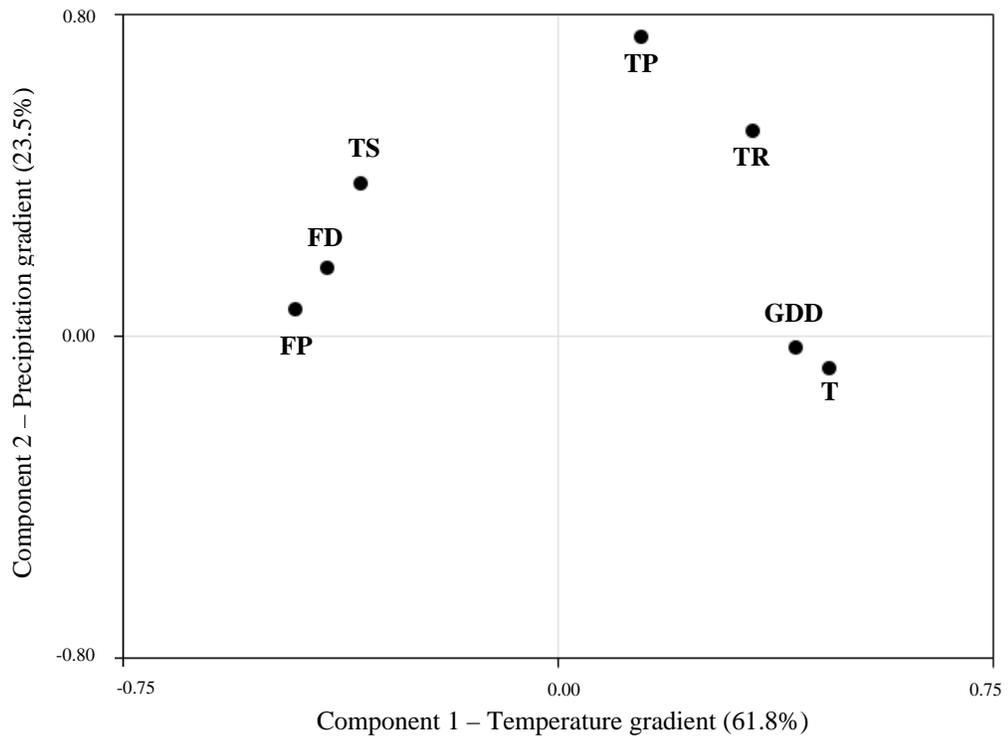
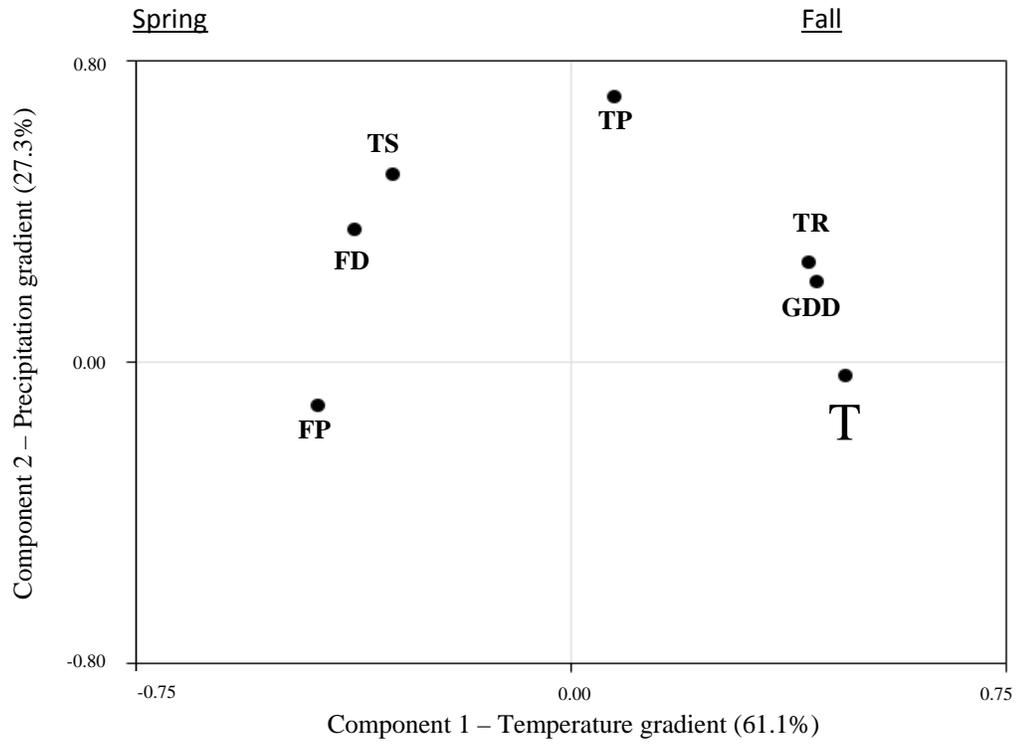
Spring and fall weather were well summarized along temperature and precipitation gradients. Using these gradients, we were able to differentiate weather patterns amongst years and identify years of extreme weather. The four PCAs (two seasons, spring and fall, for each study area) recovered most of the variability within the temperature and precipitation variables on the first two principal components (Table 2). The first components explained between 2.2 and 3.8 times more variance than the second components. Subsequent components added little additional variance explanation (Table 2).

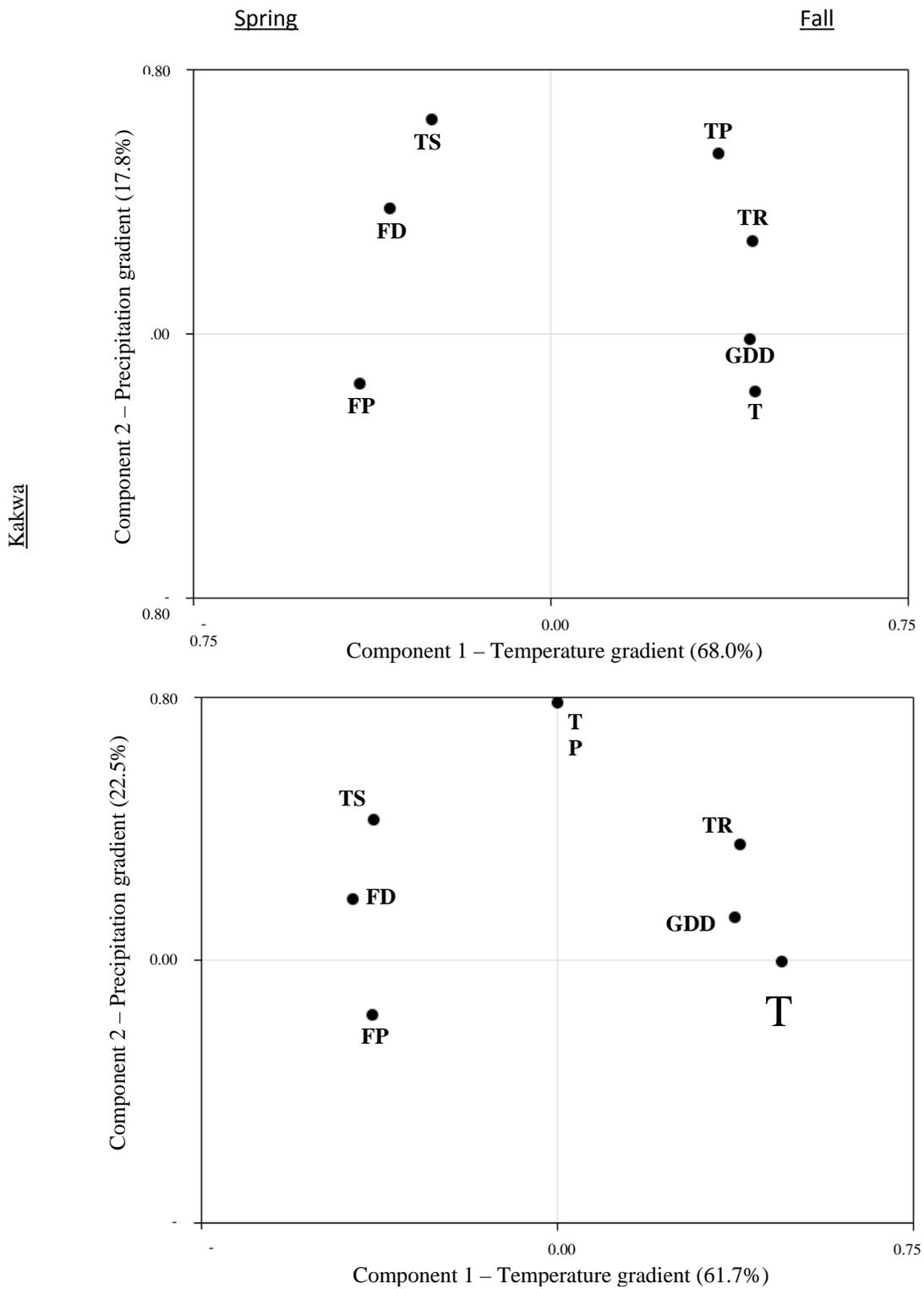
**Table 2. Principal Component Analyses of temperature and precipitation variables describing weather in the Kakwa and Hinton-Cadomin study areas for the spring and fall seasons.**

Study area	Season	Principal components	Eigenvalue	Proportion of total variance (%)	Cumulative variance explained (%)
Hinton-Cadomin	Spring	1	4.27	61.1	61.1
		2	1.91	27.3	88.4
		3	0.41	5.8	94.2
		4	0.23	3.3	97.5
	Fall	1	4.32	61.8	61.8
		2	1.64	23.5	85.3
		3	0.45	6.4	91.7
		4	0.44	6.4	98.1
Kakwa	Spring	1	4.76	68.0	68.0
		2	1.25	17.8	85.8
		3	0.56	8.0	93.8
		4	0.23	3.2	97.0
	Fall	1	4.32	61.7	61.7
		2	1.57	22.5	84.2
		3	0.68	9.7	94.0
		4	0.26	3.6	97.6

Ordination of the weather variables with the PCAs created a temperature gradient on the first component where positive scores indicated warmer weather while negative scores indicated colder weather (Figure 1). The second components represented a precipitation gradient with more precipitations on positive scores and less precipitations on negative scores (Figure1). As a result of the combination of these two gradients, snowier years had negative scores on the first components and positive scores on the second one, while rainy years had positive scores on both components. Snow had more weight than rain in the second components during spring, but the opposite was observed for fall (Figure 1).

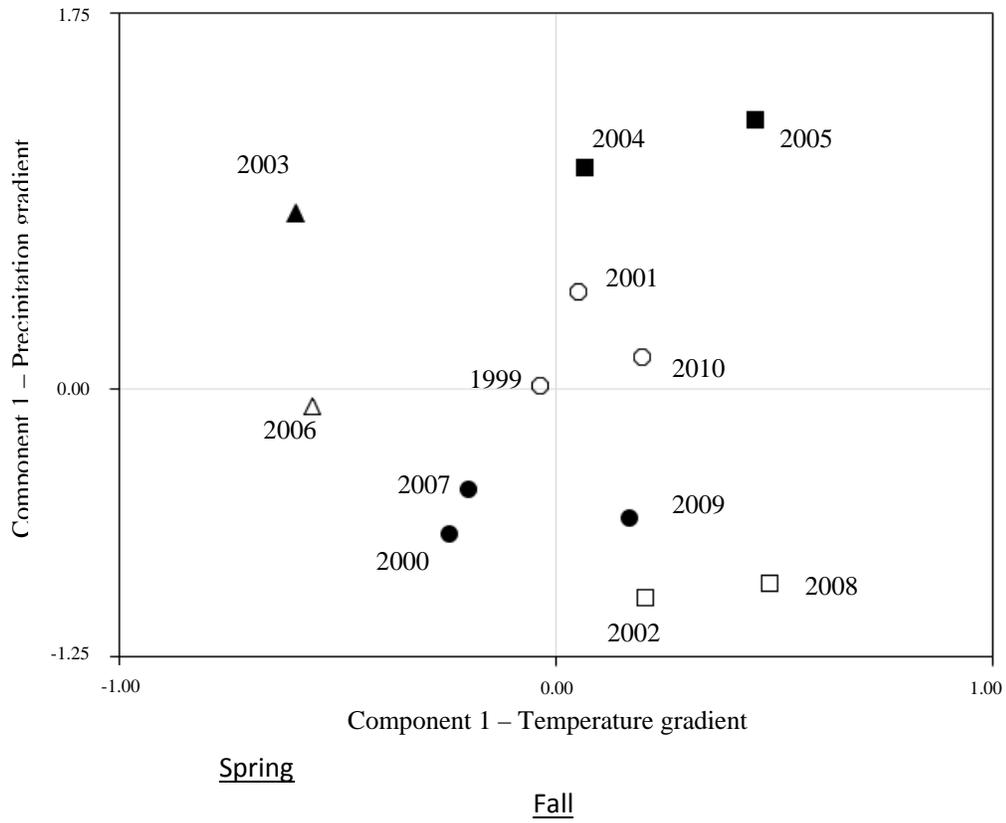
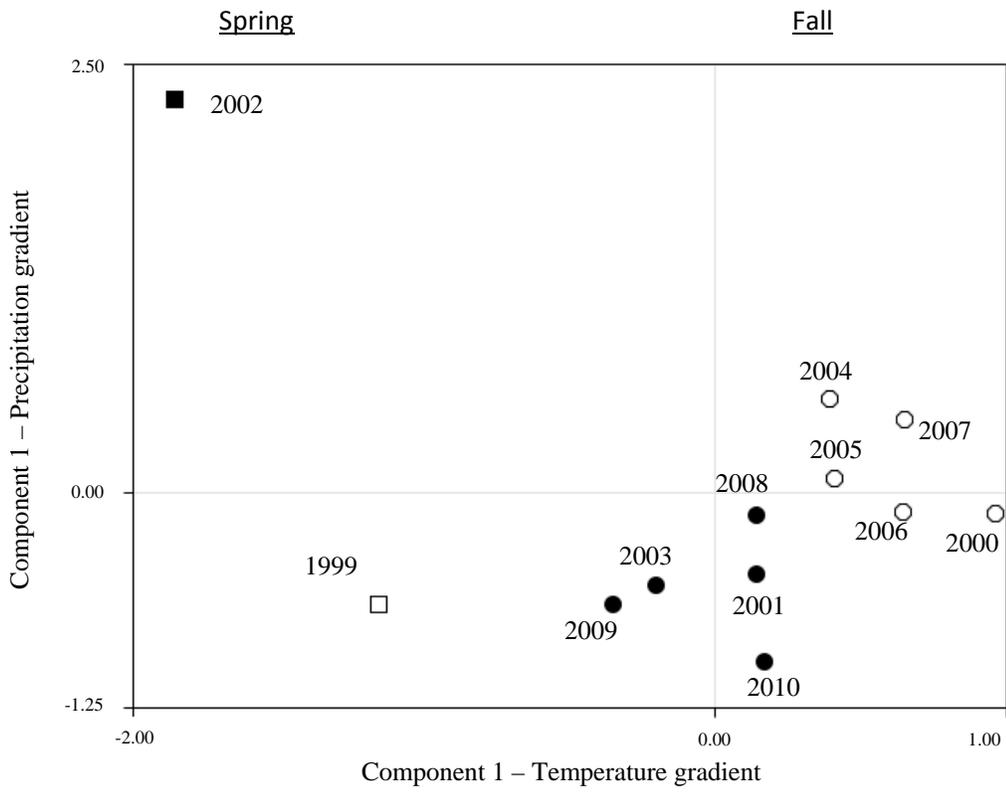
Hinton-Cadomin



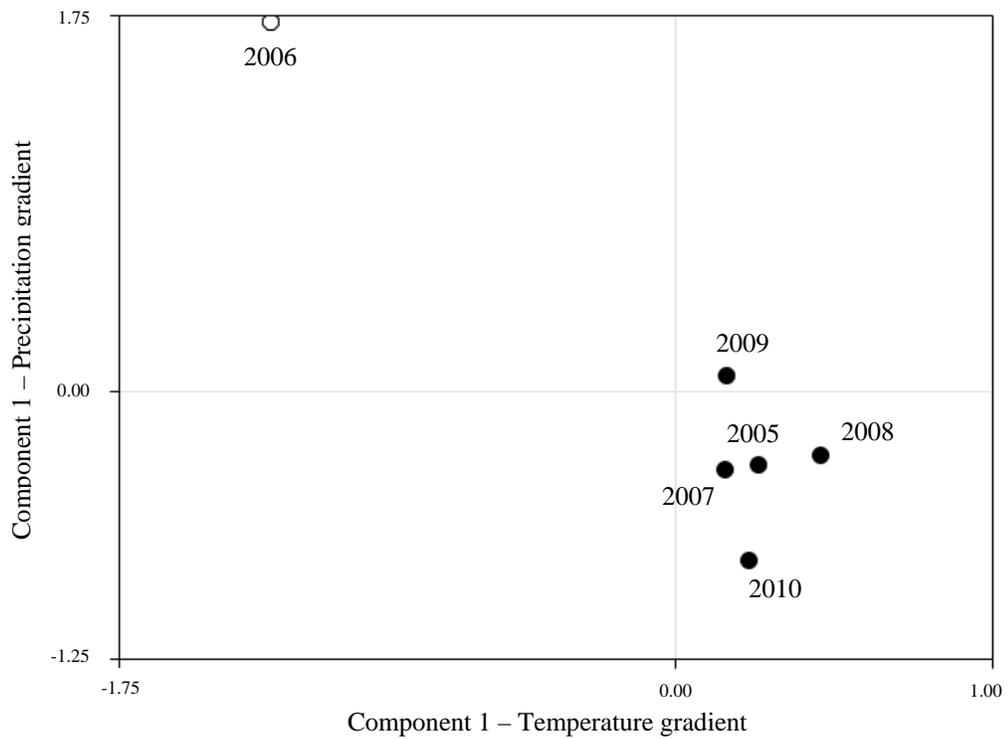
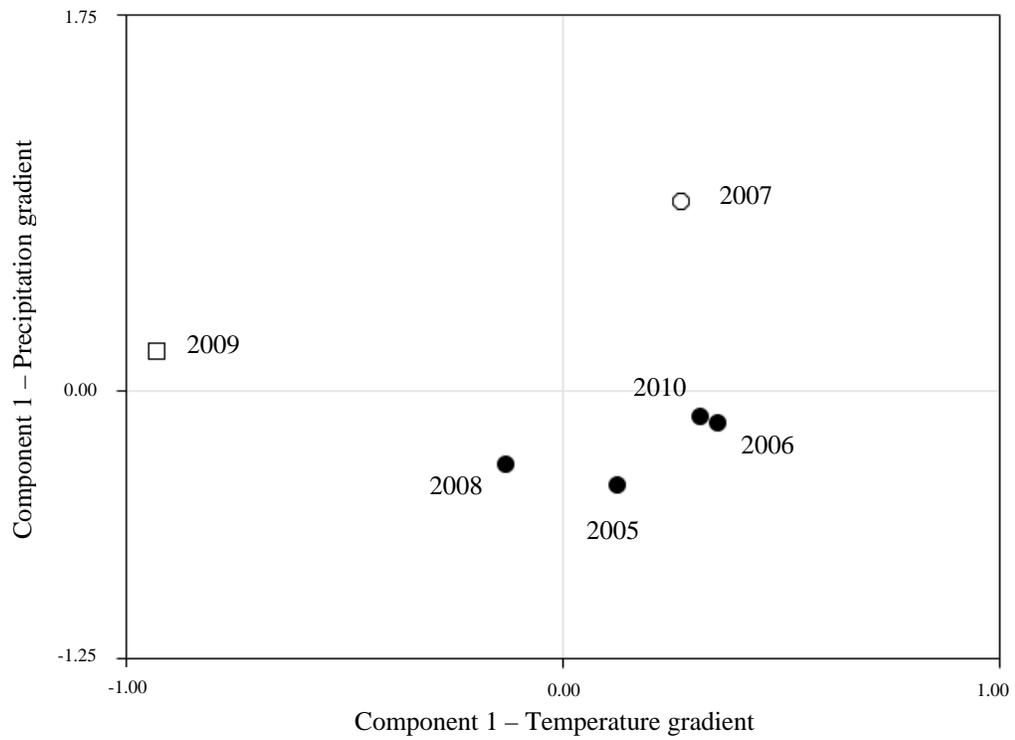


**Figure 1. Ordination of weather variables on the first two components of Principal Component Analyses explaining over 83% of the total variance in the variables. TS: Total snowfall, TR: Total rainfall, TP: Total precipitations, FD: Freezing days, FP: Freezing period, GDD: Growing degree-days, T: Temperature (see Table 1 for description of variables). The top two graphs are the Hinton-Cadomin results and the bottom two are the Kakwa results.**

Hinton--Cadomin



Kakwa



**Figure 2. Ordination of years along temperature and precipitation gradients from Principal Components Analyses of weather variables. Years with different symbols form distinct clusters. ). The top two graphs are the Hinton-Cadomin results and the bottom two are the Kakwa results.**

**Table 3. Differences between the climate normals (1971-2000) and the temperature and precipitation values recorded for the Hinton-Cadomin and Kakwa study areas. The temperature difference presented is the average difference from the minimum, maximum, and mean temperatures. Temperatures are in °C and precipitations are in mm.**

Study area	Spring				Fall			
	Year	Temperature difference	Year	Precipitation difference	Year	Temperature difference	Year	Precipitation difference
Hinton-Cadomin	2002	-3.9	2002	18.5	2006	-1.2	2005	19.6
	2009	-1.2	2004	6.8	2000	-0.5	2004	15.4
	2003	-0.8	2007	5.4	2003	-0.2	2003	9.6
	2008	-0.5	2008	0.1	2010	-0.2	2001	8.4
	1999	0.0	2006	-0.2	2007	0.0	2010	4.0
	2000	0.1	1999	-0.3	2002	0.5	1999	3.1
	2001	0.5	2005	-1.0	2005	0.5	1998	2.7
	2007	0.9	2000	-3.8	2001	0.6	2006	-1.4
	2006	0.9	2001	-4.0	2004	0.6	2007	-4.4
	2010	1.1	2009	-6.3	1999	0.9	2009	-5.3
	2004	1.4	2003	-6.5	2009	1.0	2000	-7.1
	2005	1.7	2010	-8.6	2008	1.5	2002	-9.5
Kakwa	2009	-5.4	2007	27.0	2006	-6.4	2004	29.5
	2008	-4.6	2010	16.9	2010	-3.0	2009	6.2
	2006	-4.3	2006	9.7	2005	-2.8	2008	3.2
	2007	-3.9	2009	6.6	2007	-2.6	2005	3.0
	2005	-2.7	2005	4.7	2009	-1.9	2007	2.6
	2010	-2.4	2008	1.2	2008	-1.6	2010	-3.7

Using the clustering procedure following PCAs, we were able to visualize some differences in weather amongst years. In the Hinton-Cadomin area, 2002 was by far the coldest and snowiest year in the spring. Spring 2002 was also the spring with the most divergence from climate normals (Figure 2, Table 3). March 2002 is still, to this day, the month with the highest single-day snowfall and daily low temperature records in the area over the past 30 years<sup>1</sup>. Spring 1999 was markedly colder than other years although no different than climate normals (Figure 2, Table 3). The black dot cluster years were the driest of all with precipitations being lower than normal and temperatures being average (Figure 2, Table 3). The years in the open circle cluster were slightly warmer than normal but not systematically wetter (Figure 2, Table 3). In the fall, 2003 and 2006 were the coldest years while 2003 was also the snowiest. The warmest year was 2008 along with 2002, which was the driest year (Figure 2, Table 3). In 2004 and 2005, falls were wetter than normal, followed by 1999, 2001, and 2010 which were all above climate normal (Figure 2, Table 3). Finally, 2000, 2007, and 2009 had average temperatures and less precipitation than normal (Figure 2, Table 3).

In the Kakwa area, 2007 was the spring with the most precipitation, 2009 was the coldest, and the other years were dryer with average temperatures (Figure 2, Table 3). In the fall, 2006 was

<sup>1</sup> The Weather Network : H<http://www.theweathernetwork.com/statistics/summary/cl3053536/caab0173H> [Accessed 16 March 2011]

by far the coldest and snowiest year, other years being warmer and dryer (Figure 2, Table 3). For both seasons, all years were colder and wetter than climate normals, except for 2010 (Table 3).

#### Timing Of Den Entry And Den Emergence

As previously observed in other grizzly bear populations, females in our study areas denned significantly longer than males ( $F_{14}=7.67$ ,  $n=50$ ,  $p=0.01$ ), with pregnant females denning the longest (Figure 3).

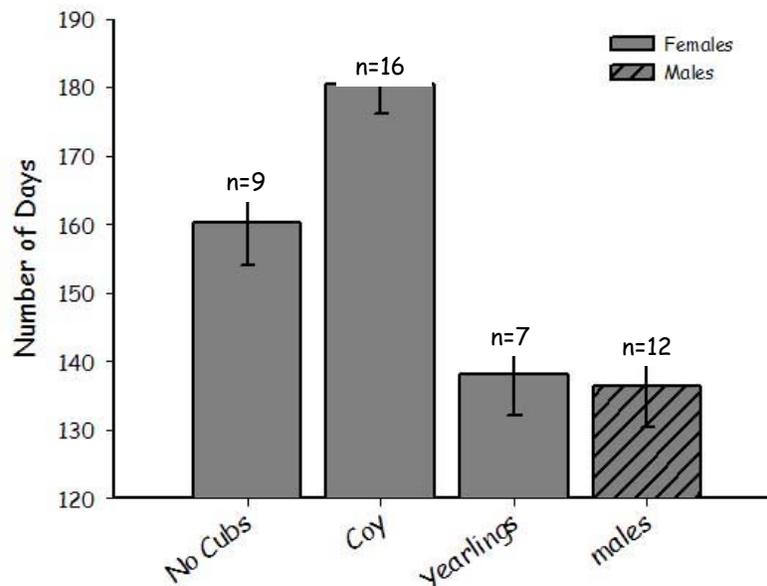


Figure 3. Length of grizzly bear hibernation period by sex and female reproductive status at den emergence for study areas combined ( $F_8=16.17$ ,  $n=41$ ,  $p=0.0009$ , Coy=cub of the year).

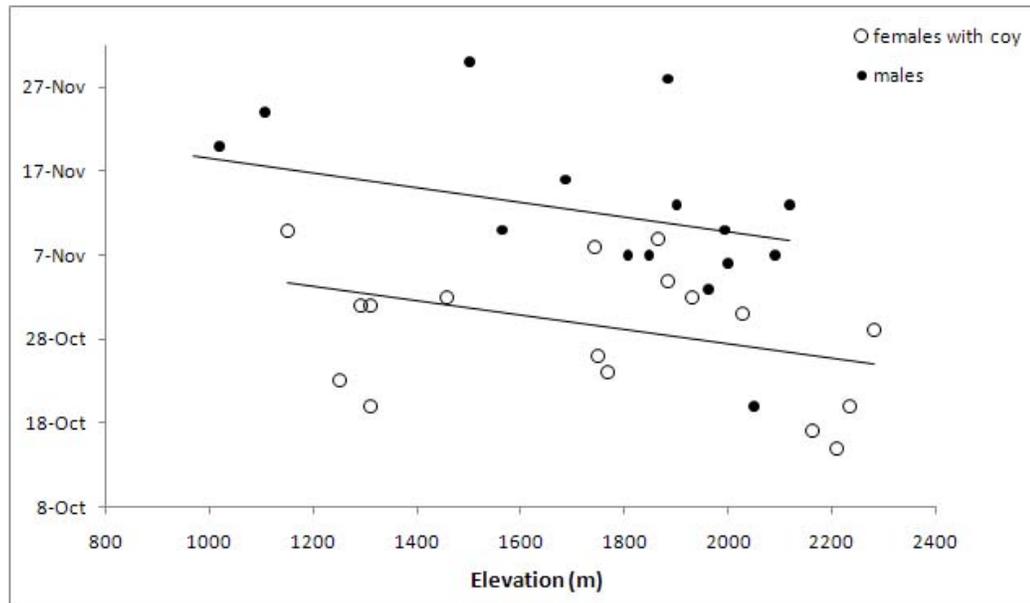
#### *Den entry*

From a total of 50 den entries (14 males and 36 females), we tested the influence of environmental variables on the timing of den entry with a set of 20 candidate models including the reference model (Table 4). As any model with a delta AICc of less than 2 should be considered equivalent, 4 out of 20 models were considered best models (Table 4).

**Table 4. Model selection of candidate models testing for the effects of environmental variables on the timing of grizzly bear den entry. AIC<sub>c</sub>: Aikake Information Criterion for small sample size,  $\Delta$ AIC<sub>c</sub>: delta AIC<sub>c</sub>, K: parameters. SR : Sex and reproductive status, E : Elevation, NPi : North Pacific Index, T: Mean maximum Temperature in September (°C), GDD: Growing degree days above 5°C, PCA1: Principal component 1, PCA2 : Principal Component 2, (B):individual bears as random factor. Best models are in bold.**

ID	Candidate models	AIC <sub>c</sub>	$\Delta$ AIC <sub>c</sub>	K
<b>1</b>	<b>SR E (B)</b>	<b>369.7</b>	<b>0</b>	<b>5</b>
<b>2</b>	<b>SR NPI E (B)</b>	<b>370.4</b>	<b>0.7</b>	<b>6</b>
<b>3</b>	<b>SR T (B)</b>	<b>370.4</b>	<b>0.7</b>	<b>5</b>
<b>4</b>	<b>SR PCA2 E (B)</b>	<b>371.1</b>	<b>1.4</b>	<b>6</b>
5	SR (B)	372.1	2.4	4
6	SR GDD (B)	372.3	2.6	5
7	SR T NPI (B)	372.4	2.7	6
8	SR NPI (B)	373	3.3	5
9	SR NPI GDD (B)	373.4	3.7	6
10	SR PCA2 (B)	373.5	3.8	5
11	SR PCA2 NPI E (B)	373.5	3.8	7
12	SR PCA1 E (B)	373.9	4.2	6
13	SR PCA1 NPI (B)	375.5	5.8	6
14	SR PCA1 PCA2 E (B)	375.6	5.9	7
15	SR PCA2 NPI (B)	375.8	6.1	6
16	SR T PCA2 (B)	376	6.3	6
17	SR PCA1 (B)	377.6	7.9	5
18	SR PCA1 NPI E (B)	378.5	8.8	7
19	SR PCA1 PCA2 (B)	379.2	9.5	6
20	SR T PCA1 (B)	380	10.3	6

Model selection suggested a strong influence of elevation on the timing of den entry. Bears denning at higher elevations enter dens earlier than bears denning at lower elevations regardless of their sex and reproductive status (Figure 4). The other variables included as part of the best models were the average mean maximum temperature in September, the 2<sup>nd</sup> component of the fall PCAs, and the North Pacific Index (NPI). The 2<sup>nd</sup> component of the fall PCAs represent a precipitation gradient with more precipitation on positive scores and the North Pacific Index displays the intensity of the Aleutian low with positive values reflecting colder, snowier years in our study areas (Trenberth and Hurrell, 1994; Hamel et al. 2009). The best models therefore agree that bears enter dens earlier during colder years with greater fall precipitations than during years with drier, warmer falls. The coefficient of determination for the best models were all within 0.37 and 0.41 indicating that from the reference model ( $r^2=0.30$ ), an additional 10% of the variation in den entry was explained by variables added in the best models.



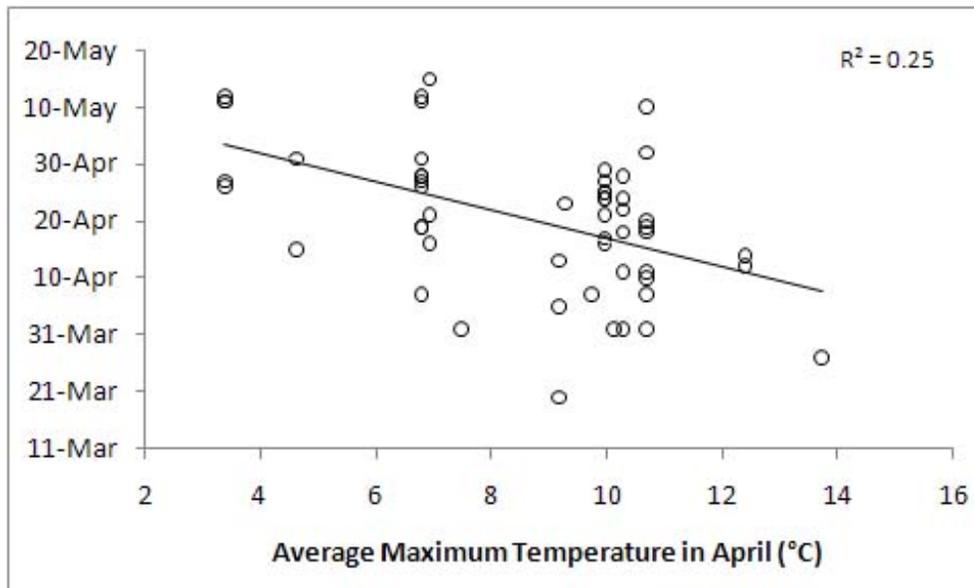
**Figure 4. Den entry dates for grizzly bear males (filled-in circle) and pregnant females (open circle) as a function of elevation (m). Lone females and females with yearlings also showed the same pattern ( $F_{10}=5.10$ ,  $p=0.05$ ,  $n=50$ ).**

#### *Den emergence*

From a total of 50 den emergence (12 males and 38 females), we tested the influence of environmental variables on the timing of den emergence with a set of 15 candidate models including the reference model (Table 5). Only one of the 15 models had a delta AICc of less than 2. This model added one covariate, the average monthly maximum temperature in April, to the reference model. Spring temperatures clearly had an influence on the timing of den emergence with grizzly bears emerging from their dens earlier in years with warmer springs (Figure 5). The best model explained an additional 15% of the variation in den emergence that was explained by the reference model alone (best model:  $r^2=0.65$ , reference model:  $r^2=0.50$ ).

**Table 5. Model selection of candidate models testing for the effects of environmental variables on the timing of grizzly bear den emergence. AIC<sub>c</sub>: Aikake Information Criterion for small sample size,  $\Delta$ AIC<sub>c</sub>: delta AIC<sub>c</sub>, K: parameters. SR : Sex and reproductive status, E : Elevation, NPi : North Pacific Index, T: Mean maximum Temperature in September (°C), GDD: Growing degree days above 5°C, PCA1: Principal component 1, PCA2 : Principal Component 2, (B):individual bears as random factor. The best models is in bold.**

ID	Candidate models	AIC <sub>c</sub>	$\Delta$ AIC <sub>c</sub>	K
<b>1</b>	<b>SR T (B)</b>	<b>364.3</b>	<b>0</b>	<b>5</b>
2	SR T E (B)	366.6	2.3	6
3	SR NPi (B)	369.3	5	5
4	SR T PCA2 (B)	371.7	7.4	6
5	SR GDD (B)	372	7.7	5
6	SR T PCA2 E (B)	374.6	10.3	7
7	SR GDD E (B)	374.8	10.5	6
8	SR PCA1 E (B)	374.9	10.6	6
9	SR PCA1 (B)	375.1	10.8	5
10	SR PCA2 GDD (B)	375.5	11.2	6
11	SR PCA2 NPi (B)	376.7	12.4	6
12	SR PCA2 (B)	376.9	12.6	5
13	SR (B)	378.4	14.1	4
14	SR PCA2 E (B)	379.8	15.5	6
15	SR E (B)	380.1	15.8	5



**Figure 5. Den emergence dates for grizzly bears as a function of the average maximum monthly temperature in April (°C). ( $F_{16}=20.72$ ,  $p=0.0003$ ,  $n=50$ ).**

## Conclusion

Our results indicate that although sex and reproductive status are important factors governing both the timing of den entry and den emergence of grizzly bears in our study area, different environmental variables affect den entry and den emergence. While elevation, the North Pacific Index, and the 2<sup>nd</sup> principal component of the PCAs were important variables in the timing of den entry, these variables were not significant in the timing of den emergence. However, average monthly maximum temperatures were important for both den entry and den emergence.

As our best models for den entry explained about 40% of the observed variation in den entry while our best model for den emergence explained up to 65% of the observed variation in den emergence, other key factors such as the abundance and availability of fall foods most likely play a significant role in the timing of den entry. Further investigation has to be done in order to assess the influence of fall foods on the timing of den entry and the duration of denning.

Our results have important implications for the long-term conservation of grizzly bear populations in Alberta as changes in denning behaviour can be expected under predicted climate conditions. Most global climate models agree that global average surface temperatures will increase by at least 2°C within the next 80 years (IPCC, 2007). In our study, warm average maximum fall temperatures were associated with late den entry and warm average spring temperatures were associated with early den emergence, we can therefore expect a reduction in the length of the denning period under future climate conditions. As human-bear conflict is the primary cause of grizzly bear mortality in Alberta, climate-induced changes in the denning behaviour of grizzly bears may increase human-bear interactions by lengthening the active period of grizzly bears.

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## CHAPTER 4: GRIZZLY BEAR HABITAT USE AND FOOD AVAILABILITY IN LEADING PINE FOREST: EVALUATING PROPOSED HARVESTING PLANS FOR MOUNTAIN PINE BEETLE MANAGEMENT

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### Introduction

In North America, the mountain pine beetle (*Dendroctonus ponderosae*) MPB) has expanded its range considerably over the past three decades reaching epidemic levels in British Columbia. Favourable climate in areas previously unsuitable for MPB colonization have allowed populations to spread across British Columbia and into Alberta. For the first time in recorded history, MPB infestations were detected in northwest central Alberta (Carroll et al. 2003). The threat of infestations at the provincial level and further spread into the boreal forest prompted Alberta Sustainable Resource Development to implement the MPB Action Plan (Mountain Pine Beetle Action Plan – Alberta 2007). The plan outlined short and long term strategies to deal with the MPB issue. In the short-term, localized infestations would be contained using single tree cut and burn treatments. However, the long-term solution to the problem was to reduce the amount of lodgepole pine (*Pinus contorta*) stands susceptible to MPB infestation within the Foothills Natural Region and across the eastern slopes. The provincial government directed forest companies to increase annual timber volumes and modify operational ground rules to meet the objective of reducing susceptible stands by 75% over a 20 year period. Proposed harvesting will result in a dramatic shift in the age distribution of pine over a relatively short time frame. Not only will there be an excess of young pine stands, as these stands regenerate and cutting progresses over the next sixty years, the landscape will be dominated by young and intermediate age classes of pine. With a provincial recovery plan in place for grizzly bears (*Ursus arctos*), the accelerated harvesting of pine occurring in prime bear habitat raised management concern.

Forest harvesting has the potential to impact grizzly bear populations indirectly. Road networks increase the opportunity for human bear conflicts and the risk of grizzly bear mortality (Alberta Grizzly Bear Recovery Plan 2008-2013 2008). Disturbance may displace bears from optimal habitats (Gibeau et al. 2002, McLellan and Shackleton 1988, Rode et al. 2006) or alter the productivity of habitats. Conceptually, all these factors interact in space and time together influencing grizzly bear habitat quality. While the issues of mortality are well known, the impacts of non lethal influences and their role in shaping grizzly bear populations is less understood. Forest harvesting has the potential to benefit bears by increasing the availability of seasonal food resources (Nielsen et al. 2004B). Nevertheless, the benefits of harvesting relative to food are conditional on a multitude of factors such as forest silviculture, stand age, tree species composition, structure (edge), and environmental gradients (moisture, solar radiation, elevation) (Nielsen et al. 2004B). Understanding how these factors influence food distribution and abundance is therefore a fundamental step in assessing the impacts of forest harvesting. While food availability is a critical limiting factor influencing individual bear size (Zedrosser et al. 2006), population vital rates (Reynolds-Hogland et al. 2007, Schwartz et al. 2006), and density

(Nielsen et al. 2010), habitats are also important for other processes such as resting, security, thermal regulation, and finding mates (Moe et al. 2007; Munro et al. 2006; Waller and Mace 1997). For these reasons, not only is there a need to understand how food availability might change under different forest conditions, but focus should also be directed at understanding bear behaviour and patterns of habitat use to collectively assess habitat quality for grizzly bears in the context of forest management and planning.

Here we explore the habitat value of pine for a population of grizzly bears in northwest Alberta where MPB management is in progress. Our goal was to determine what some of the potential impacts of pine harvesting might be to provide managers with information and direction with regards to managing grizzly bear habitat. Specifically, we aim to better understand what the habitat value of leading pine forest is for grizzly bears because these stands are the focus of MPB management. In this report, we present some of our research results in two parts. In Part I we investigate the seasonal use of leading pine forest stands by female grizzly bears. In Part II, we quantify food abundance and project food supply based on the preferred forest management strategy for MPB control harvesting. We close with a discussion and synthesis of our results including management recommendations and other work in progress related to forest harvesting and MPB management.

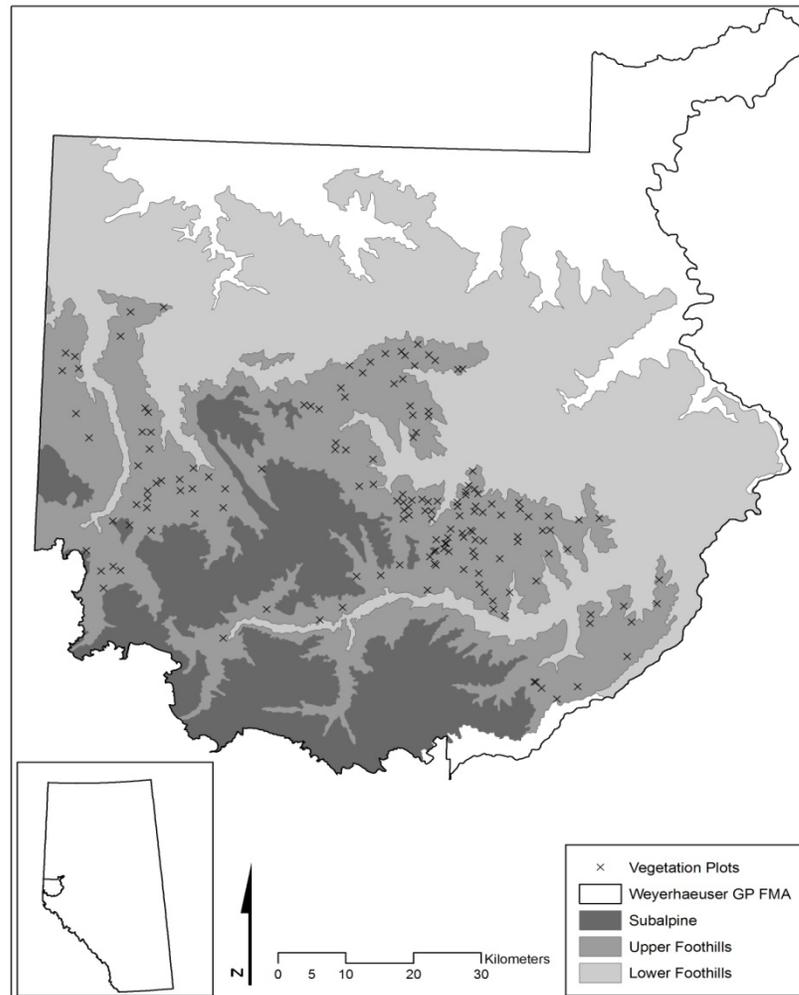
To determine the habitat value of pine forest for grizzly bears, we asked five specific questions:

- 1) How much time do female grizzly bears spend in pine versus other forest types and does this vary by season?
- 2) How much time do female grizzly bears spend in harvested, intermediate, and mature stands of leading pine and does this vary by season and elevation?
- 3) How much time do female grizzly bears spend in different age classes of harvested pine and does this vary by season?
- 4) What is the relationship between food abundance to stand age, tree species composition, and site specific environmental conditions?
- 5) What effect will the accelerated harvesting of pine have on food supply over the next sixty years?

### **Study Area**

The study area is the southern boundary of Weyerhaeuser Grande Prairie Forest Management Agreement (WGPFMA) in north-west central Alberta, Canada (10,000 Km<sup>2</sup>; 119° 13'W and 54° 32'N; Figure 1). Approximately 76% of the forested land base is managed for timber harvesting with 57% of the area being conifer or conifer leading mixed wood species. Of these conifer leading stands, 38% are lodgepole pine as the leading species with the majority of pine found within the Upper and Lower Foothills Natural Subregions. Timber harvesting primarily occurs within the Foothills and outside of caribou (*Rangifer taradantus*) management zones. The landscape is a mosaic of seral age classes dominated by large tracts of mature coniferous forest at higher elevations. There is a prominent elevation gradient from the south-west to the north-east with elevations ranging from 650 - 2300 m (Natural Regions Committee 2006). Annual

precipitation varies from 550 – 1050 mm and temperatures range from 4.7 - 11.3°C (Natural Regions Committee 2006).



**Figure 1. Natural Subregions, vegetation plot locations, and Weyerhaeuser Grande Prairie Forest Management Agreement Area.**

## **PART I – GRIZZLY BEAR HABITAT USE**

### **Methods**

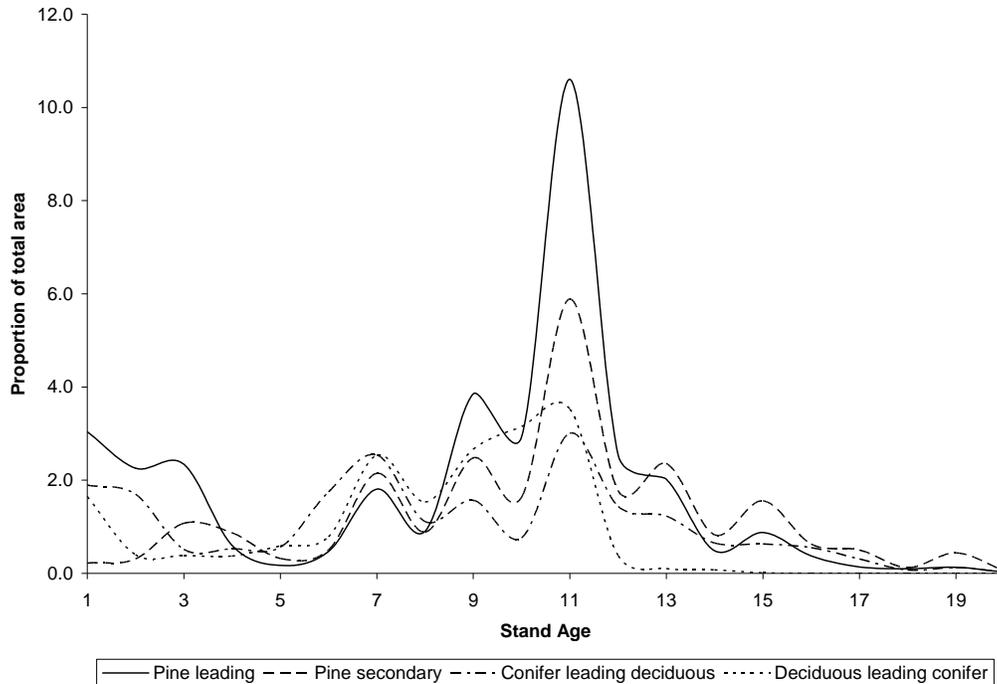
#### Habitat Classification

We used a Geographical Information System (GIS) forest inventory polygon database provided by WGP to classify grizzly bear habitat in our study area (Appendix A - Landbase Assignment 2008). The inventory data is the basis for defining the net harvestable land base and is the spatial input for the revised (2010) Timber Supply Model for MPB management. The net harvestable land base identifies forested areas that can be allocated for timber harvesting based on a series of operational ground rules and exclusions that consider values such as water quality, fish and wildlife habitat, soil productivity, and human culture and history. Non forested, non merchantable forested, riparian buffers, steep slopes, protected areas, seismic lines, and other human land use features are excluded from the net harvestable land base.

In our first step, we removed all polygons that were of unknown origin, if they were missing canopy tree information, or if they were assumed to have been one year of age. All forested stands were considered in our classification of grizzly bear habitat. The next step was to remove all anthropogenic land use features corresponding to each year of grizzly bear data (2007 and 2009). In addition to this, we also removed anthropogenic features that corresponded to the landscape in 2005. This was the median year of period 1 and the beginning of the MPB surge cut. We removed polygons identified as seismic and anthropogenic non-vegetated but did not remove land use dispositions. Rather than using the land use disposition identifier in the inventory data, we excluded land use features by intersecting buffered roads (25 m), well sites (60 m), and pipelines (25 m) using landscape change layers provided by the Foothills Research Institute's Grizzly Bear Program (FRIGBP).

The second step was to classify grizzly bear habitat using stand age and forest species composition information. In the net harvestable land base process, age and tree composition have the potential to be calculated from three data sources including Alberta Vegetation Inventory (AVI; updated in 2004), Regenerating Stand Inventory (RSI; 1999), and the Alberta Reforestation Information System (ARIS). AVI is used for stands that have not been harvested and ARIS is used preferentially to SRI for harvested blocks. Stand age is calculated as the average age of origin (10 year interval) for stands that have not been harvested and the skid clear date is assigned to harvested blocks. Weyerhaeuser's harvest year is between May 1 and April 30. Any areas harvested prior to this period in any given year would be deemed a cut from the previous year; therefore, stands were at least one year of age in the habitat classification.

Within the net harvestable land base, forest species composition is calculated for overstory and understory tree species in 10 percent crown closure classes. For our purposes, we reclassified the overstory cover values to stratify grizzly bear habitat into four broad classes. The four classes represent pine leading ( $\geq 6$ ), pine secondary ( $\leq 5$  and  $> 0$ ), conifer leading deciduous (no pine;  $\geq 6$  conifer), and deciduous leading conifer (no pine;  $\geq 6$  deciduous). We did not consider additional categories to distinguish pine stands containing varying amounts of deciduous or coniferous species. The age distribution by habitat strata is highly skewed towards mature stands (110 years) in the FMA (Figure 2). We used ARCGIS 9.2 for all GIS based analysis in this document.



**Figure 2. The proportion of habitat strata in 10 year age categories from the habitat classification (2005) of Weyerhaeuser Grande Prairie’s Forest Management Agreement Area. Stands older than 200 years are not included.**

#### Grizzly Bear Location Data

We used Global Positioning System (GPS) locations of female grizzly bears to investigate seasonal habitat use between 2007 and 2009. Bears were captured using helicopter darting, leg hold snares, or culvert traps and fit with a Televilt brand GPS collar programmed to collect locations at an hourly interval. For detailed capture methods, refer to Cattet et al. (2008). We used females to quantify habitat use and make inference about the value of pine because females are generally the focus of management concerns (Nielsen et al. 2006). We separated locations for each bear by year into pre-defined seasonal categories that generally correspond to major shifts in grizzly bear diet (Munro et al. 2006). The spring season was from May 1 until June 15, summer from June 16 to July 31, and fall from August 1 to October 15.

In our analysis, we only considered using bears that had at least 100 locations per bear, season, and year. Grizzly bear locations were intersected with the corresponding habitat classification layer by year to identify what habitat strata and stand age was associated with each bear location. From the total number of locations (31909), approximately 83% occurred within operable forest (98% in conifer leading stands), 9% were within riparian buffers, 7% were on steep slopes, and less than a percent were in non-merchantable forest. Considering only the subset of locations (24272) that were within operable or potentially productive stands, the minimum number of locations by bear, season, and year was 124 (median 564, 25 percentile 430, and 75 percentile 882). Most of the grizzly bear locations were in the Upper Foothills (UF; 78%) and Subalpine (20%) Natural Subregions. We used Hawth’s Tools (Beyer 2004) to intersect bear locations with a Digital Elevation Model (DEM; DMTI 2003). Grizzly bear locations range ranged from 817 – 1772 m elevation (median 1221 m).

### Grizzly Bear Habitat Use Models

To answer our first question, how much time do female grizzly bears spend in pine versus other forest types and does this vary by season? We used linear regression in a factorial design to model the proportion of grizzly bear locations (24272) within each habitat strata broken down by bear, season, and year as our dependent variable. To ensure that the dependent variable was normally distributed, we performed the logit transformation on the data (Papke and Wooldridge 1996). Because our modelling procedure included some of the same individual bears over multiple years, we used bear id as a cluster variable to adjust for within-cluster correlations (Williams 2000). We used Akaike information criterion (AIC) to select the best fitting model from a series of *a priori* models and an intercept only model (Burnham and Anderson 2002). These same procedures were used in subsequent analyses. Statistical significance was accepted at an alpha of 0.05. For this question, our *a priori* models tested the individual effects of habitat strata and season, and the interaction between these variables.

To answer our second question, how much time do female grizzly bears spend in different age classes of leading pine and does this vary by season and elevation? We used all bear locations that occurred within leading pine forest (15,150). For these locations, we reclassified stand age into four categories (age strata) representative of major changes in canopy closure and forest structure. The four categories of age in years are: 1) young regenerating stands (1 to 20); 2) old regenerating stands (21-36); 3) intermediate stands (39-80); 4) mature stands (>80). We used linear regression to model the proportion of grizzly bear locations within each age strata broken down by bear, season, and year as our dependent variable. We used the mean elevation within the break down of our dependent variable as a predictor. Rather than using the continuous form, we represented elevation as a binomial variable using the median elevation (1232m) as the cut-off. We hypothesized that habitat productivity (food abundance) in leading pine may be different above and below the median elevation. The *a priori* models included parameters for age strata and elevation, and the interaction between these variables.

The third part of our analysis, we asked how much time do female grizzly bears spend in different age classes of harvested leading pine habitat and does this vary by season? We used all bear locations that occurred within harvested leading pine forest (8,669). For these locations, we reclassified stand age into three categories (harvested strata): 1-10; 11-20; and 21-36. This analysis differed slightly from question 2) in that, we wanted to investigate more closely how much time bears are spending in these different age classes of harvested blocks and whether there is a seasonal effect. We used linear regression to model the proportion of grizzly bear locations within each harvested strata broken down by bear, season, and year as our dependent variable. The *a priori* models included parameters for harvested strata and season, and the interaction between these variables.

## **Results**

### Habitat Strata

We found a significant effect of habitat strata ( $F_{3,10}=90.17$ ,  $P<0.01$ ,  $R^2$  0.80) on grizzly bear habitat use. There was some support for the model with habitat strata and season; however, no improvement in AIC suggests that this parameter has no effect on the overall model (Table 1). Female grizzly bears spent most of their time in pine leading habitat followed by pine secondary, conifer leading and finally deciduous leading. We found very little variation in the proportion of

time spent among these habitat strata across seasons (Table 2). Pine leading habitat makes up the majority of what is available to grizzly bears in this system and consequently it is used the most.

**Table 1. AIC<sub>c</sub> selected models and Akaike weights (w<sub>i</sub>) of linear regression models testing the effect of season on female grizzly bears use of habitat strata.**

Model	Ki	-2LL	AIC	Δi	Wi
Intercept	1	-355.5	713.1	276.7	0.00
Habitat strata	4	-214.2	436.4	0.0	0.71
Season	3	-355.1	716.2	279.8	0.00
Habitat strata + Season	6	-213.5	438.9	2.5	0.20
Habitat strata * Season	10	-210.2	440.5	4.1	0.09

**Table 2. Mean proportion of female grizzly bears locations over three seasons and habitat strata.**

Habitat Strata	Spring		Summer		Fall		Average	
	Mean	Se	Mean	Se	Mean	Se	Mean	Se
Pine Leading	0.58	0.07	0.62	0.05	0.63	0.05	0.61	0.06
Pine Secondary	0.26	0.05	0.25	0.04	0.24	0.04	0.25	0.04
Conifer Leading	0.14	0.05	0.12	0.02	0.11	0.03	0.12	0.04
Deciduous Leading	0.03	0.03	0.03	0.02	0.01	0.00	0.02	0.02

#### Age Strata

We found a significant effect of age strata on grizzly bear habitat use in the spring ( $F_{3,7}=26.99$ ,  $P<0.01$ ,  $R^2$  0.37) and summer ( $F_{3,10}=13.78$ ,  $P<0.01$ ,  $R^2$  0.49). There was no support for the elevation model in either season (Table 3). Female grizzly bears spent most of their time in mature and regenerating stands with little use of intermediate aged leading pine forest (Table 4.) Elevation seemed to have no effect on grizzly bear use of regenerating habitat in either season. On the other hand, mature stands in the summer tended to have higher use at higher elevations although this difference was not statistically significant. We found a significant effect of age interacting with elevation in the fall season ( $F_{7,8}=82.92$ ,  $P<0.01$ ,  $R^2$  0.59). The only significant interaction parameter in the model was for mature stands meaning that grizzly bears used mature stands significantly more at higher elevations. Although not a significant interaction, the model suggested an increase in the use of young regenerating stands compared to old regenerating stands in this season (Table 4). Use of young regenerating stands tended to be higher at lower elevations although this was not statistically significant. Irrespective of elevation, grizzly bears spent most of their time in mature and regenerating forest in all seasons. Use of intermediate ages was low overall. The likely explanation was the lack of intermediate aged stands in the system.

**Table 3. AIC<sub>c</sub> selected models and Akaike weights ( $w_i$ ) of linear regression models testing the effect of age and elevation on female grizzly bears seasonal use of pine leading habitat.**

Season	Model	Ki	-2LL	AIC	$\Delta_i$	$w_i$
Spring	Intercept	1	-119.8	241.5	36.2	0.00
	Age strata	4	-98.7	205.3	0.0	0.68
	Elevation	2	-110.4	224.7	19.4	0.00
	Age strata + Elevation	5	-98.6	207.1	1.8	0.28
	Age strata * Elevation	7	-98.4	210.8	5.5	0.04
Summer	Intercept	1	-119.8	241.5	35.7	0.00
	Age strata	4	-99.2	206.4	0.5	0.38
	Elevation	2	-119.6	243.3	37.4	0.00
	Age strata + Elevation	5	-97.9	205.9	0.0	0.48
	Age strata * Elevation	8	-96.2	208.3	2.4	0.14
Fall	Intercept	1	-107.3	216.6	29.4	0.00
	Age strata	2	-107.2	218.4	31.2	0.00
	Elevation	4	-91.3	190.6	3.4	0.14
	Age strata + Elevation	5	-91.1	192.2	5.0	0.07
	Age strata*Elevation	8	-85.6	187.2	0.0	0.79

**Table 4. Mean proportion of female grizzly bears locations by age strata over three seasons in leading pine forest.**

Season	Age Strata (years)	Elevation			
		< 1232 m		>1232 m	
		Mean	Se	Mean	Se
Spring	1 – 20	0.24	0.07	0.32	0.12
	21 – 35	0.31	0.12	0.30	0.08
	40 - 80	0.03	0.01	0.05	0.02
	>81	0.46	0.09	0.49	0.19
Summer	1 – 20	0.29	0.05	0.22	0.04
	21 – 35	0.28	0.09	0.31	0.07
	40 - 80	0.04	0.03	0.07	0.03
	>81	0.39	0.09	0.58	0.10
Fall	1 – 20	0.43	0.09	0.28	0.08
	21 – 35	0.20	0.06	0.18	0.05
	40 - 80	0.06	0.03	0.05	0.03
	>81	0.26	0.07	0.70	0.09

Harvested strata

We found no support for age or season as factors influencing the use of harvested habitat by female grizzly bears (Table 5). Use was similar across harvested age strata, although in the fall use tended to be higher in harvested stands younger than 20 years (Table 6).

**Table 5. AIC<sub>c</sub> selected models and Akaike weights ( $w_i$ ) of linear regression models testing the effect of block age and season on female grizzly bears use of harvested leading pine habitat.**

Model	Ki	-2LL	AIC	$\Delta_i$	$w_i$
Intercept	1	-241.53	485.07	0.00	0.79
Age harvested	3	-240.77	487.53	2.47	0.23
Age harvested + Season	5	-239.36	488.72	3.65	0.13
Age harvested * Season	9	-237.60	493.20	8.14	0.01

**Table 6. Mean proportion of female grizzly bears locations in harvested strata over three seasons in leading pine forest.**

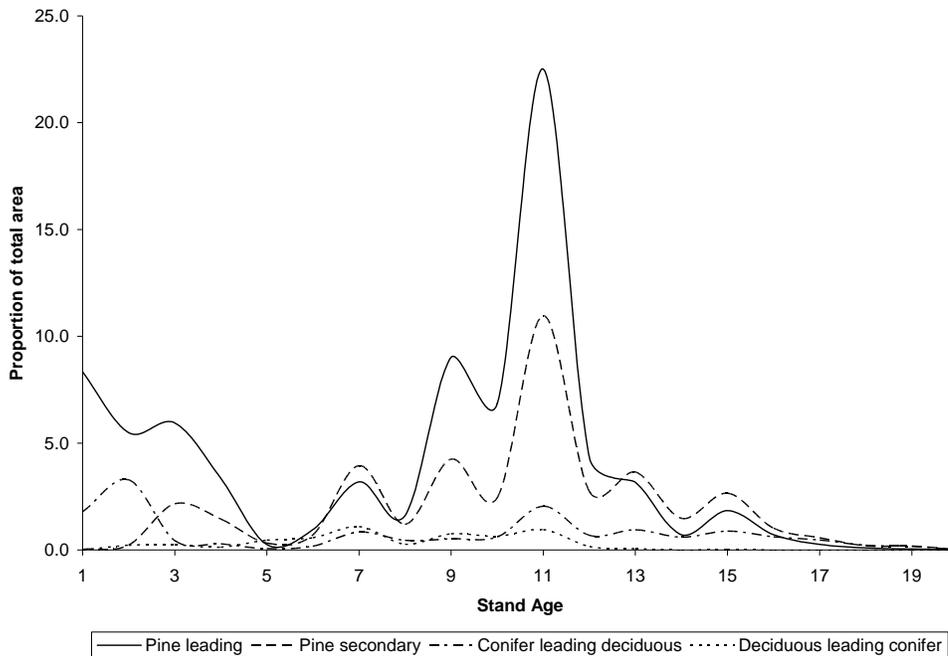
Harvested strata	Spring		Summer		Fall		Average	
	Mean	Se	Mean	Se	Mean	Se	Mean	Se
1 – 10	0.32	0.09	0.35	0.09	0.46	0.09	0.38	0.09
11 – 20	0.28	0.07	0.35	0.06	0.47	0.09	0.36	0.08
21 – 36	0.49	0.10	0.55	0.06	0.36	0.07	0.47	0.07

## PART II – FOOD ABUNDANCE

### Methods

#### Field Sampling Design

We defined our sample population for each field season (2008 and 2009) using stands identified as pine leading and pine secondary within the UF of the habitat classification. Pine was the dominant forest cover type in the UF with age skewed towards mature stands (110 years) (Figure 3.). Compared to other areas of the FMA, deciduous leading stands made up a small portion of the total area. We stratified our sample population by stand age using a 5 year interval in harvested stands and a 30 year interval in mature. Our intent was to sample more intensively in harvested pine because we expected greater variation in food abundance. Harvested stands were between 1 and 36 years of age and mature stands were from 58 to 198 years. Pine stands that were greater than 198 years and between 39 and 57 years of age were excluded because there were relatively few available in the UF area to sample. We used Hawth's Tools (Beyer 2004) to generate random location coordinates within the stratified sampling area, but limited our sampling of mature pine to within 1 km of a road. Our design captured the range of environmental conditions (climate and terrain) found within pine forests of the UF.



**Figure 3. The proportion of each habitat strata by stand age (10 year interval) calculated from the habitat classification layer (2005) within the Upper Foothills of Weyerhaeuser Grande Prairies Forest Management Agreement Area.**

#### Field Sampling

We established 30 x 30 meter vegetation plots at random coordinates from June 17 to September 1, 2008 and from June 28 to October 1, 2009. Plot center was determined by locating the nearest coordinate with the lowest GPS error that did not exceed 10 m. We chose a 900-m<sup>2</sup> sampling area because it matched the grain (30 m pixel) of our GIS raster grids that would be used as predictor variables in food abundance models. To ensure that our sampling was representative of interior forest conditions, plots that were within 30 m of a harvested area boundary, or any other anthropogenic land use feature (road, trail, seismic line, or well-site) were moved 30 meters in a random cardinal direction most perpendicular to the edge or feature. A 30 m minimum distance from the sampling unit was used to avoid possible edge effects related to forest structure (wind throw) and understory vegetation composition (Lopez et al. 2006, Redding et al. 2003, Harper and Macdonald 2002). Plots were also moved 30 m in a random cardinal direction if over story retention trees were present within the sampling area. All plots were orientated in a south to north direction. Of the 249 plots sampled, 136 in 2008 and 113 in 2009, 148 were in harvested and 101 were in mature pine forest.

#### Food Resources

We measured the abundance of foods known to be of seasonal importance to grizzly bears (Munro et al. 2006). In particular, we focused on quantifying herbaceous items, roots, and berries since these items make up a significant proportion of a grizzly bears' annual diet (Mowat and Heard 2006, Munro et al. 2006). In addition to counting berries, we also measured the abundance of berry producing shrubs for two reasons. Firstly, annual berry crops are highly variable and dependent on current and past weather (Krebs et al. 2009) and secondly, even at high and low shrub density, spatial factors related to environmental conditions or the condition

of individual stems may influence berry abundance. Although not technically food items, we use this term to describe all species modelled here including shrub species. We considered the following species in our sampling of bear foods: cow parsnip (*Heracleum Lanatum*), horsetails (*Equisetum arvense, pratense, and sylvaticum*), clover (*Trifolium spp.*), dandelion (*Taraxacum officinale*), twisted-stalk (*Streptopus amplexifolius*), sweet-vetch root (*Hedysarum alpinum and boreale*), buffalo berry (*Shepherdia canadensis*), crowberry (*Empetrum nigrum*), huckleberry (*Vaccinium membranaceum*), velvet-leaved blueberry (*Vaccinium myrtilloides*), dwarf blueberry (*Vaccinium caespitosum*), lingonberry (*Vaccinium vitis-idea*), raspberry (*Rubus idaeus*), sarsaparilla (*Aralia nudicaulis*), and bearberry (*Arctostaphylos uva-ursi*).

Vegetation and berries were quantified using 25 quadrats (1x1 m) and 5 transects (1x30m) systematically spaced throughout the plot. Transects were orientated south to north and equally spaced from west to east at the 0.5, 7.5, 15, 22.5, and 29.5 meter marks. Along each transect, quadrats were established at the 0.5, 7.5, 15, 22.5, and 29.5 meter mark using the center of the 1 x 1 m square area. We counted individual stems for those species that we could but for the *Vaccinium spp* we estimated percent cover using one percent increment values if cover estimates were below or including 20 percent and in five percent increments if estimates were above 20. Because we wanted to convert our predicted count or percent cover estimates to dry biomass, we collected samples of vegetation and berries during the 2009 field season. We randomly selected a maximum of 5 quadrats and 5 transect sections (6 m lengths per transect) where foods were present. All ripe fruit and vegetation was clipped to ground level and collected. Fruit was weighed in the field using a 10 g PESOLA scale while vegetation was collected and allowed to dry at room temperature. Dried vegetation was weighed using an OHAUS Adventurer SL digital scale and mean weight (g/stem or g/percent cover) calculated for each species at the plot level (Table 7). Mean fresh weight for each berry species was converted to grams of dry weight using conversion values obtained from the literature (Welch et al. 1997).

**Table 7. Mean dry and wet (berries) weight of food items used to convert final model abundance estimates to dry biomass. Wet weight (fruit) was converted to dry using a conversion factor.**

Common name	Species code	Mean wt.	Se	n	% dry	Dry wt.
Huckleberry	VAME	0.57	0.06	26		
	VAMEF*	0.38	0.07	13	14.6	0.06
Velvet-leaved blueberry	VAMY	0.88	0.10	27		
	VAMYF*	0.07	0.01	13	12.2	0.01
Dwarf blueberry	VACA	0.50	0.07	26		
	VACAF*	0.07	0.01	13	12.2	0.01
Ligonberry	VAVI	1.02	0.15	30		
	VAVIF*	0.13	0.01	10	12.2	0.02
Raspberry	RUID	1.60	0.20	46		
	RUIDF*	0.49	0.05	14	15.1	0.07
Horsetails	EQ	0.57	0.07	83		
Cow parsnip	HELA	1.30	0.15	39		
Twisted stalk	STAM	1.83	0.26	34		

\*Mean estimates are in wet weight

We quantified tree species composition by ocularly estimating percent cover values for those tree species that formed the canopy. Percent cover values were represented as 12 categories (0, 1-5, 6-10...90-100). For each tree species, we used the median of the percent cover value within each category to calculate a final mean value rounded up to the nearest integer ranging from 1 to 10. Of the 249 plots sampled over two years, 10 contained no trees and 189 had pine composition of six or greater. We retained the ten treeless plots in the analysis because they had been harvested within eight years and forest inventory data identified these locations as pine leading regeneration.

#### Predictor Variables

The following criteria were used to assign our predictor variables (Table 8). Stand age was represented as equal interval age categorized (1-18) in ten year increments that ranged from 1 to 180 years. Plots older than 180 years were lumped in a final category (19). We also considered age as a binomial variable (block) separating harvested from mature pine forest. Canopy tree species composition was represented by two binomial variables, one to capture the effect of pine as the leading species ( $\geq 6$  percent canopy tree composition) and the other to distinguish plots that had deciduous species present.

We used GIS raster grids (30m pixel) to represent site specific environmental conditions (terrain and climate) at each plot (Table8). Terrain variables were created using two digital elevation models (DEM), one at 30 m resolution (DMTI 2003) and the other at 5 m t derived from Light Detection and Ranging (LIDAR) technique. We resampled the 5 m LIDAR DEM to a 30 m pixel for variable processing. We used the Spatial Analyst Extension in ARCGIS 9.2 to create aspect and slope grids from each DEM that would be used to calculate a solar radiation index (SRI; Keating et al. 2007). Aspect was scaled from -180 to +180, -180 representing more westerly aspects and +180 more easterly. An Arc Macro Language (AML) script (Evans 2002) and the 30 m DEM were used to calculate a compound topographic index (CTI). A second CTI index (CTI5) was generated from the LIDAR DEM using the same AML and a second input grid (contributing area) derived from the D-infinity algorithm (Tarboton 1997) available in the TauDEM 5.0 extension (Tarboton 2010) for ARCGIS 9.2. We used the more robust D-infinity algorithm to calculate contributing area rather than the default D8 algorithm because the D8 algorithm limits flow to eight directions introducing grid bias and produces unrealistic results (Tarboton 1997). We did not use the D-infinity procedure for contributing area to calculate CTI so that we could compare our results to other studies that used this index to model food distribution in the study area.

**Table 8. Predictor variables used in General Estimating Equation models to predict the relative change in food abundance.**

Variable group/code	Description	Variable Type	Units	Range
<i>Age/year</i>				
AGE	age forest polygon (10 year increments)	Interval	Years	1 - 198
YR	year of data collection (2008=0 2009=1)	Binomial	-	-
BLOCK	harvested vs. mature pine forest	Binomial	-	-
<i>Forest Composition</i>				
PLD	leading vs. secondary pine composition	Binomial	-	-
DXP	deciduous species presence/absence\	Binomial	-	-
<i>Terrain</i>				
CTI	compound topographic index (DMTI DEM)	Interval	Unitless	5.7 - 10.1
CTI5	compound topographic index (LIDAR DEM)	Interval	Unitless	7.9 - 14.7
ASP	aspect scaled (DMTI DEM)	Interval	°	-177 - 180
ASP5	aspect scaled (LIDAR DEM)	Interval	°	-179 - 180
SRI	solar radiation index (DMTI DEM)	Interval	Unitless	-0.99 - 1
SRI5	solar radiation index (LIDAR DEM)	Interval	Unitless	-1 - 0.99
<i>Climate</i>				
GSP	growing season precipitation	Interval	Millimeters	402.7 - 481.7
MAP	mean annual precipitation	Interval	Millimeters	593.6 - 784
AMI	annual moisture index	Interval	Unitless	1.08 - 1.89
SMI	summer moisture index	Interval	Unitless	1.74 - 2.78
MAT	mean annual temperature	Interval	°C	0.73 - 1.95
DD5	growing degree days above 5	Interval	Degree days	839 - 1124.5
ELEV	Elevation	Interval	Meters	930 - 1428

### Statistical Models

To answer question 4) we used a General Estimating Equation (GEE; Liang and Zeger 1986) with robust estimates of variance to model the population averaged response of our dependent variables (count or density) as a function of predictor variables. An extension of the Generalized Linear Model (Nelder and Wedderburn 1972), the GEE was useful in our approach because the model allows for correlated observations within clustered groups (Liang and Zeger 1986). In our case, we used plot as the group variable so that we could estimate abundance at the quadrat and subplot level while maintaining statistical independence. For each of the dependent variables, plot level variance exceeded the mean indicating over-dispersion and the need to fit each model with a negative binomial error distribution. We only considered those food items that were common enough to model abundance as a function of pine forest age. All plot data (n=249) were used in models describing herbaceous and berry shrub species abundance; however, we only used plots after June 18 for the berry species (n=240), which was the first day we detected an unripe berry. For all berry species, we used the total count of unripe, ripe, and overripe berries as our dependent variable. We removed two outliers (n=238) in harvested blocks for the VAVIF abundance model.

We used a quasi-likelihood model selection criterion (QIC; Cui 2007, Pan 2001) to generate the best fitting and most parsimonious model for each dependent variable. Because our dependent variables contained high variance, fitting the raw form of the terrain and climate predictors often lead to over prediction. To deal with this potential issue and still allow for non-linear

relationships, we used sextile groupings to generate a new variable for each of the terrain and climate variables. We only considered predictor variable combinations where Pearson correlations were less than 0.6 among variables. Climate variables were strongly correlated, but rather than selecting one arbitrarily we used each of these variables independently within candidate models. The terrain variables were not correlated and as a result could have been included in the candidate model sets. However, we were more interested in whether or not the scale (DEM resolution) at which the variable was derived was an important factor in explaining variance.

Our modelling procedure had two steps. The first step was to fit age as a fractional polynomial with two degrees of freedom, with and without an age-year interaction term and then separately for each year of data. The best fractional polynomial age model was used in the remaining model selection procedure. Although we expected that age would be best represented by a fractional polynomial for most dependent variables, we also considered in our set of candidate models age as a linear and binomial (harvested and mature) variable. For the linear and binomial variables, we also considered year and year age interaction effects independently among the sets of candidate models. Only one of our dependent variables (VAMYF) showed a significant difference in shape between years that could not be explained using a simple year effect. For this species, we modelled age using a fractional polynomial for each year of data.

The second step in our procedure was to select the best fitting model with the least number of parameters from all possible candidate model sets. We modelled separately each age and predictor variable separately and in all possible combinations among predictor variable groups since we *a priori* deemed each variable as a potentially important predictor of abundance. We retained the model with the lowest QIC score and all variables that were statistically significant ( $\alpha=0.05$ ). If marginally significant variables resulted in a lower QIC score, we kept them in the final model. We considered these models as a good approximation of the relative change in food abundance. In our final abundance estimates, we scaled up our final model predictions and converted these values to dry biomass by multiplying the sample unit area (900m<sup>2</sup>) and the mean dry biomass value for each food item (Table 7).

#### Spatial Harvesting Sequence

We merged the habitat classification with output polygons from a revised (2010) timber supply analysis to determine stand age for pine leading and pine secondary stands in the UF over a 60 year planning horizon. The timber supply model outputs spatial polygons selected for harvest over 12, 5 year periods based on specific management constraints. We removed all non operable polygons and reconstructed the age (10 year interval) distribution of pine stands at period 1 (2005), 2 (2009), and every second period from 4 to 12 (2069). This gave us 7 spatial maps depicting the age distribution of pine that we would then apply our food models too. The accelerated harvesting of pine was scheduled to occur until the end of period 3 and with specific constraints on harvesting pine within caribou management zones. No constraints on harvesting pine within the caribou zones were assigned in periods 4 through 12, meaning that the future spatial location of harvested blocks may be different than what is output in the timber supply model.

To answer question 5) we applied our final models (Table 9) with associated predictor variables to each of the seven spatial maps and for each berry and herbaceous food item if age was a

predictor of abundance. The only parameter we did not include in predicting food abundance was *dxp* because the presence or absence of deciduous trees was not accurately mapped at this scale. Because our model only estimates abundance for stands between 1 and 200 years, we did not consider stands older than 200 years in our calculation of total abundance. Once our models were applied, we then summed the estimates of abundance (kg) for each of these food items and for each of the seven periods to quantify change in food supply over 60 years.

## Results

### Food Resources

Of the 15 foods that we set out to quantify only 8 were common enough to warrant developing food abundance models. Clover, dandelion, sweet-vetch root, buffalo berry, crowberry, sarsaparilla, and bearberry were not common in pine forests of the UF. When they did occur, dandelion was found only in harvested areas while sweet-vetch root, crowberry, sarsaparilla, bearberry, and buffaloberry were found in both. All of these species were more common in harvested pine except for crowberry and sweet-vetch. The remaining 7 foods were the focus of our work and include cow parsnip, horsetails, twisted-stalk, huckleberry, velvet-leaved blueberry, dwarf blueberry, lingonberry, and raspberry.

### Predictor Variables

All species responded differently to age, canopy tree composition, environmental condition, and year of data collection (Table 9). The individual contribution of groups of predictors modelled separately from the final model was investigated. Of these groups, age and year explained more variation than environment or forest composition for 9 of the 13 food items (Table 9). Terrain explained more variation in velvet leaved blueberry shrub, dwarf blueberry shrub, and twisted stalk abundance while forest composition explained more variance in cowparsnip abundance. For 9 of the 13 food items, all of these factors were important to explain variation in abundance. To some extent, the factors that influenced berry abundance differed to what predicted berry shrub abundance (Table 9). At the subplot level and using data from 2008, we looked at the correlation between shrub and berry abundance among species. Pearson's correlation coefficient shows a weak positive association between berry and vegetation abundance for huckleberry ( $r=0.63$ ), raspberry ( $r=0.62$ ), dwarf blueberry ( $r=0.56$ ), velvet leaved blueberry ( $r=0.42$ ), huckleberry ( $r=0.63$ ), and lingonberry ( $r=0.41$ ). Spatial factors related to environment or individual plant performance may be influencing these results. For these reasons, we make inference about changes in food abundance relative to MPB harvesting by using berry models rather than our shrub models. We only report differences in berry and shrub abundance in relation to pine forest age in this document.

Year was by far the most important determinant of berry abundance for all species except raspberry (Figure 4 and 5, Table 10). In 2008, there was approximately 4 times (120%) more fruit than in 2009 when comparing total berry load among the *Vaccinium* spp. Of the berry species affected by year, huckleberries were the least affected and decreased by 40% in 2009 while the remaining species decreased substantially more (Figure 5, Table 10). Of the herbaceous items, only twisted stalk showed a decrease in abundance between years and this decrease was limited to harvested pine stands. Twisted stalk remained high in mature pine in 2009. As expected, we found no difference in the abundance of berry producing shrubs between years.

Considering all final model estimates representative of 2008 in leading pine forest while holding all other variables in the model at their mean value, age was the fundamental factor influencing

abundance for all but one food item, dwarf blueberry shrub. Herbaceous and berry foods showed significant non-linear relationships and three distinct patterns emerged. Horsetails, raspberry, velvet-leaved blueberry and dwarf blueberry fruit were highly abundant in the first 20 years then dropped off suddenly (Figure 4 and 6). Cowparsnip and lingonberry showed more of a Gaussian response (Figure 6). Cowparsnip increased rapidly and then decreased as pine aged whereas lingonberry slowly increased and decreased with age (Figure 4 and 6). Huckleberries were the only species that increased as pine matured (Figure 4). Change in shrub abundance only somewhat approximated berry abundance relative to stand age. In fact, raspberry seemed to be the only species where vegetation abundance mirrored fruit abundance (Table 4). Contrary to what we found with our berry models, velvet-leaved blueberry biomass increased in abundance and then slowly decreased with age. Lingonberry and huckleberry more or less increased linearly with age and was different than what we predicted from the berry models (Table 4). In terms of biomass estimates per 900m<sup>2</sup>, raspberries were the most abundant fruit followed by huckleberry, velvet-leaved blueberry, lingonberry, and dwarf blueberry.

Canopy tree composition influenced the abundance of 6 of the 8 herbaceous and berry species (Table 10). Horsetails, cowparsnip, and raspberry were the most abundant in pine secondary, while velvet-leaved blueberry and huckleberry were most abundant in leading pine stands. Cowparsnip was the only species to substantially increase with the presence of deciduous species in the canopy. Lingonberry and velvet-leaved blueberry decreased with the propensity for deciduous species in the canopy.

Terrain and climate were important predictors of abundance. Cowparsnip and horsetail abundance increased linearly with moisture, but at different scales. CTI predicted horsetails and CTI5 predicted cowparsnip. Moisture also influenced berries at different scales. Raspberry fruit decreased and lingonberry fruit increased linearly with moisture described by CTI. Velvet leaved blueberry and dwarf blueberry fruit were associated with drier conditions decreasing linearly with CTI5. Raspberries and twisted stalk showed a non-linear response to aspect. Raspberries were more associated with easterly aspects and twisted stalk with westerly aspects. Lingonberry showed a non linear response to SRI5 and was most abundant at intermediate values. Dwarf blueberry decreased within increasing SRI in a linear fashion.

Climatic factors associated with temperature, precipitation, and elevation was important in predicting abundance for 6 of the 8 herbaceous and berry species. Twisted stalk showed a non linear response to mean annual temperature (MAT) dropping quickly as MAT increased. Horsetails increased quickly with growing season precipitation (GSP) and remained high. Cowparsnip showed a Gaussian response to summer moisture index (SMI) peaking at intermediate levels. Dwarf blueberries increased with mean annual precipitation (MAP) linearly. Velvet leaved blueberry and huckleberry fruit both showed non linear and opposite responses to elevation. Velvet-leaved blueberries were most abundant at low to mid elevations while huckleberries were associated with intermediate and high elevations. In particular, velvet-leaved blueberry and huckleberry were not only spatially separated by stand age, but also by elevation (Figure 8). At approximately 1200 meters, these two species diverge in abundance.

Given the relative changes in food item abundance as a function of stand age, canopy tree composition, and environmental gradients, the accelerated harvesting of leading pine and cutting in general will result in more of some of these foods. All species associated with young pine stands such as velvet leaved blueberry, raspberry, and equisetum increase dramatically

until the end of period 3 (Figure 9 and 10). From period 3, these species decrease as regeneration progresses until period 6 when abundance stabilizes. Irrespective of this, these species remain at higher abundance levels than what we predicted in 2005. Cowparsnip is the only species that increases in every period because the number of intermediate aged pine stands are increasing constantly (Figure 10). Changes in lingonberry and dwarf blueberry were not even noticeable compared to these other species and overall remained consistently at low abundance (Figure 9). The only species that is expected to decline with pine forest harvesting is huckleberry. Initially, there is a sharp decline until the end of period 2. Huckleberry then increases until period 4 as intermediate stands mature. After period 4, huckleberry is predicted to decline.

**Table 9. Table QIC selected models from General Estimating Equations used to predict the relative abundance of herbs, berries, and berry shrubs. Species code, sample size, QIC values for individual and final model parameters, and the final model variables are shown.**

Species Code	n	Null	Age/Year	Terrain/Climate	Forest Comp.	Final	Final Model Variables
VAME	24 9	27497. 0	25022.0	25133.6	25225. 2	22898. 0	age + cti5 + asp5 asp5 <sup>2</sup> + mat + mat2 + pld + dxp
VAMEF	24 0	12261. 2	10474.9	10906.9	11445. 8	9175.2	age + yr + elev + pld
VAMY	24 9	27345. 7	26961.7	25633.8	27406. 1	25342. 8	age + cti5 + sriq + elev + elev <sup>2</sup> + dxp
VAMYF	24 0	25123. 4	19977.7	21429.4	25207. 0	18430. 6	age + cti5 + elev + elev <sup>2</sup> + pld + dxp
VACA	24 9	15307. 7		15161.1		14962. 8	cti5 + sri + gsp
VACAF	24 0	12122. 0	10613.4	11048.3		9277.3	age + yr + cti5 + sri + map
VAVI	24 9	23635. 2	22738.4	23157.4	22655. 0	22016. 2	age + cti + sri5 + sri5 <sup>2</sup> + dxp
VAVIF	23 8	12535. 9	10679.1	11074.6	11815. 8	9801.5	age + yr + cti + sri5 + sri5 <sup>2</sup> + dxp
RUID	24 9	8032.1	6596.2	7484.7	7958.7	6166.5	age + cti + asp5 + asp5 <sup>2</sup> + gsp + pld
RUIDF	24 0	8414.7	7175.9	8185.0	7663.1	6524.1	age + cti + asp5 + asp5 <sup>2</sup> + pld
EQ	24 9	34718. 2	33541.9	34336.0	34423. 8	32900. 1	age + cti5 + gsp + gsp <sup>2</sup> + pld
HELA	24 9	7534.1	7032.0	7362.6	6483.6	6222.7	age + cti5 + smi + smi <sup>2</sup> + pld + dxp
STAM	24 9	3409.1	3400.4	3112.8		3092.0	block + yr + yr x block + cti + asp5 + asp5 <sup>2</sup> + mat + mat <sup>2</sup>

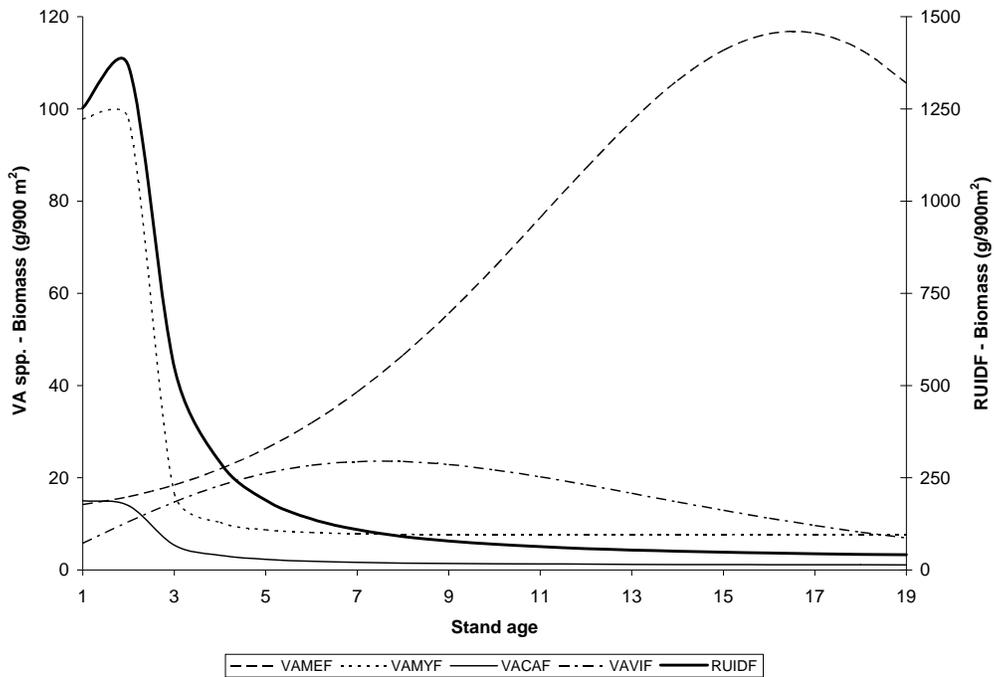
**Table 10. Relative change in mean dry biomass (g/900m<sup>2</sup>) of grizzly bear foods and their associated predictor variable value. Three of the six median sextile categories (1, 3, and 5) were used as values for terrain and climate variables here.**

Variable code	Variable value	VAMEF	VAMYF	VACAF	VAVIF	RUIDF	HELA	EQ	STAM
Age*	Harvested	-	-	-	-	-	-	-	1976.3
	Mature	-	-	-	-	-	-	-	1887.8
PLD**	Leading	66.6	16.8	-	-	241.3	5734.8	1643.0	-
	Secondary	9.4	8.0	-	-	774.7	11640.2	2624.7	-
DXP**	Present	-	10.3	-	2.7	-	14741.4	-	-
	Absent	-	17.9	-	8.2	-	2633.7	-	-
CTI*	6.5	-	-	-	2.8	1207.5	-	1568.5	-
	7.4	-	-	-	4.4	476.5	-	1975.7	-
	8.3	-	-	-	7.1	188.0	-	2488.4	-
CTIS*	9.5	-	18.7	5.5	-	-	5396.7	-	-
	10.9	-	12.9	3.2	-	-	7629.5	-	-
	12.2	-	8.9	1.8	-	-	10786.1	-	-
ASP*	-153	-	-	-	-	833.2	-	-	2462.4
	-7	-	-	-	-	151.6	-	-	1040.6
	115	-	-	-	-	1298.6	-	-	1759.1
SRI*	-0.84	-	-	5.7	-	-	-	-	-
	-0.05	-	-	3.1	-	-	-	-	-
	0.69	-	-	1.7	-	-	-	-	-
SRI5*	-0.82	-	-	-	4.3	-	-	-	-
	0.01	-	-	-	8.6	-	-	-	-
	0.73	-	-	-	3.9	-	-	-	-
GSP*	418	-	-	-	-	-	-	1206.8	-
	439	-	-	-	-	-	-	2493.3	-
	450	-	-	-	-	-	-	2522.7	-
MAP*	628.3	-	-	0.9	-	-	-	-	-
	655.7	-	-	2.0	-	-	-	-	-
	688.5	-	-	4.5	-	-	-	-	-
SMI*	1.92	-	-	-	-	-	6384.6	-	-
	2.15	-	-	-	-	-	12385.0	-	-
	2.33	-	-	-	-	-	7778.1	-	-
MAT*	0.96	-	-	-	-	-	-	-	3029.8
	1.26	-	-	-	-	-	-	-	1683.8
	1.46	-	-	-	-	-	-	-	1518.5
ELEV*	1070	8.9	14.9	-	-	-	-	-	-
	1158	22.5	24.2	-	-	-	-	-	-
	1255	56.7	5.2	-	-	-	-	-	-
YR***	2008	38.0	17.9	3.1	5.4	-	-	-	1932.0
	2009	15.3	4.1	0.8	1.2	-	-	-	1498.0

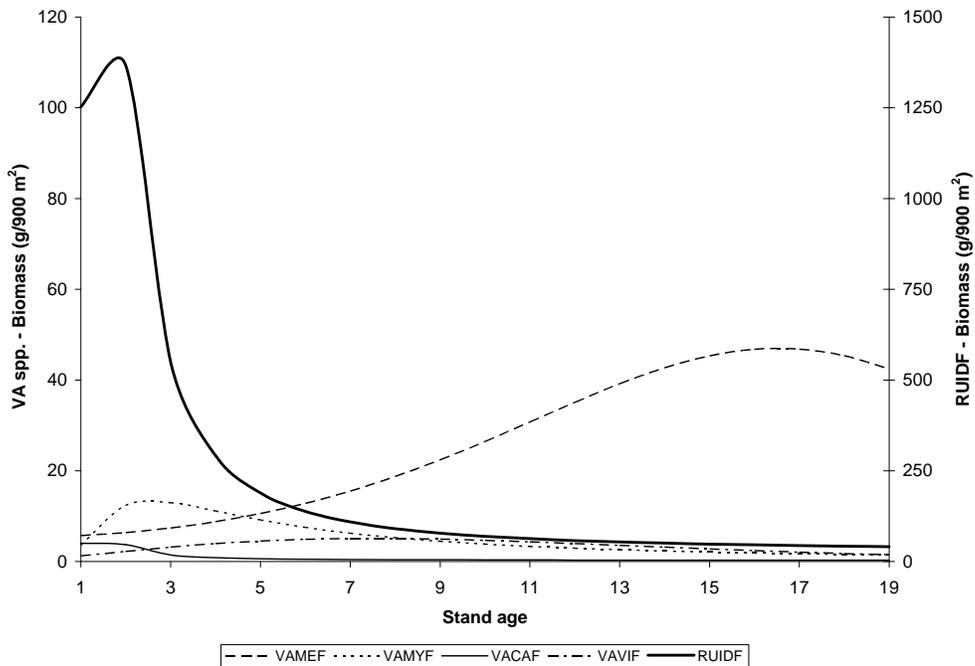
\*Mean estimates are representative of 2008 in pine leading habitat; all other variables held at their mean.

\*\*Mean estimates are representative of 2008; all other variables held at their mean.

\*\*\*Mean estimates are representative of pine leading habitat; all other variables held at their mean.



**Figure 4. Predicted mean dry biomass (g/900m<sup>2</sup>) of fruit by stand age (10 year interval) in pine leading habitat. The mean is representative of conditions in 2008 and holding all other model variables at their mean value.**



**Figure 5. Relative change in mean dry biomass (g/900m<sup>2</sup>) of fruit by stand age (10 year interval) in pine leading habitat. The mean is representative of model estimates in 2009 while holding all other model variables at their mean value.**

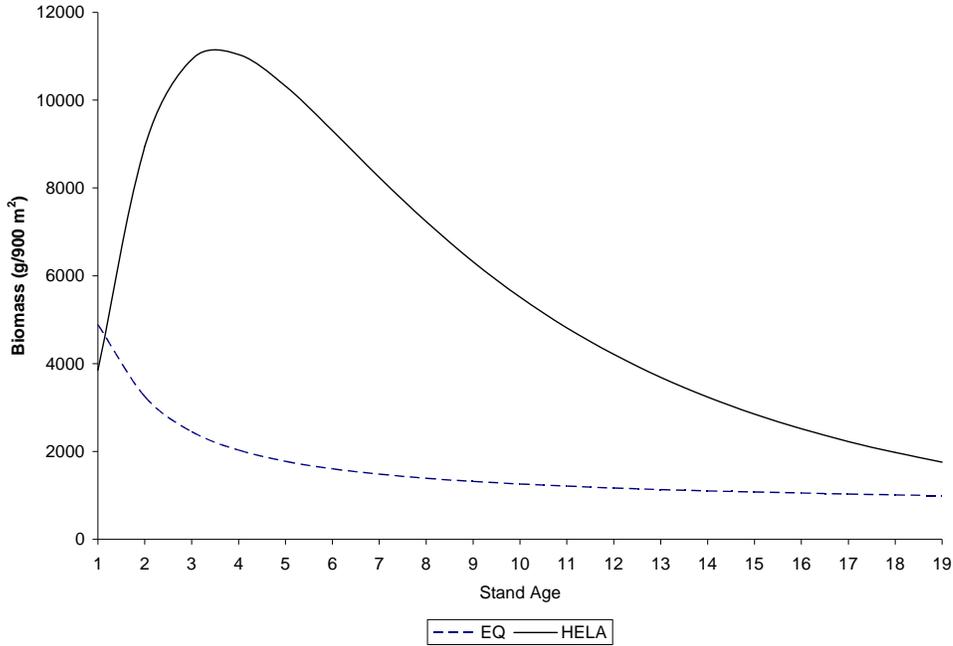


Figure 6. Relative change in mean dry biomass (g/900m<sup>2</sup>) of herbs by stand age (10 year interval) in pine leading habitat. The mean is representative of model estimates in 2008 while holding all other model variables at their mean value.

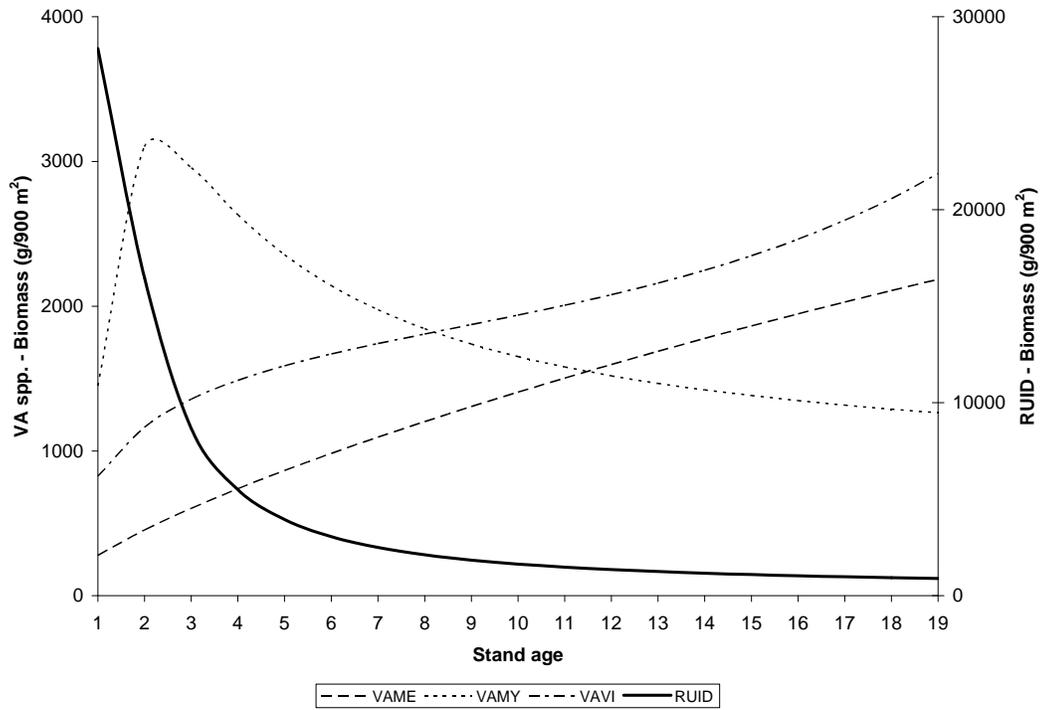
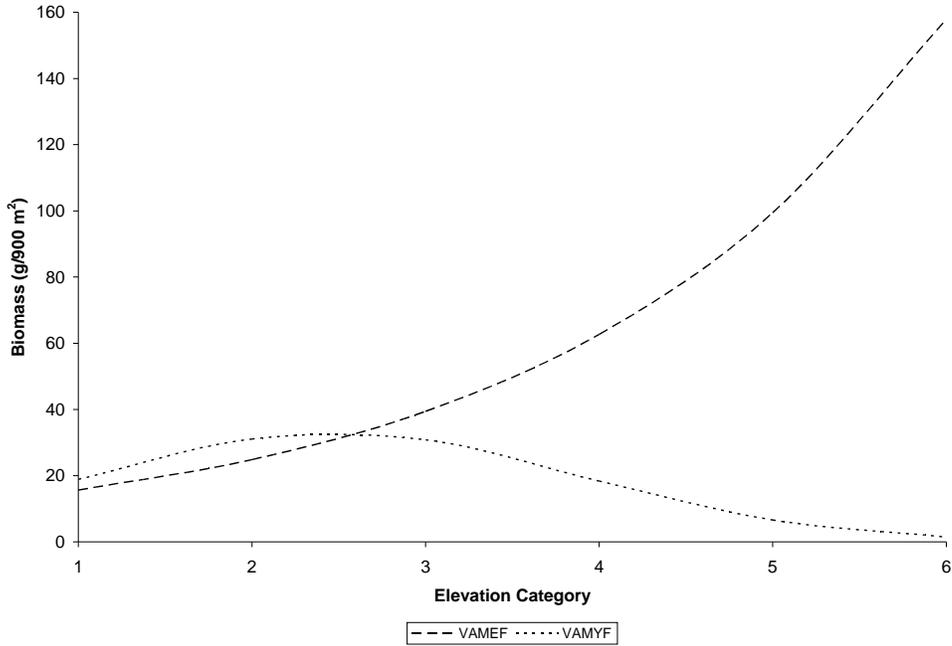
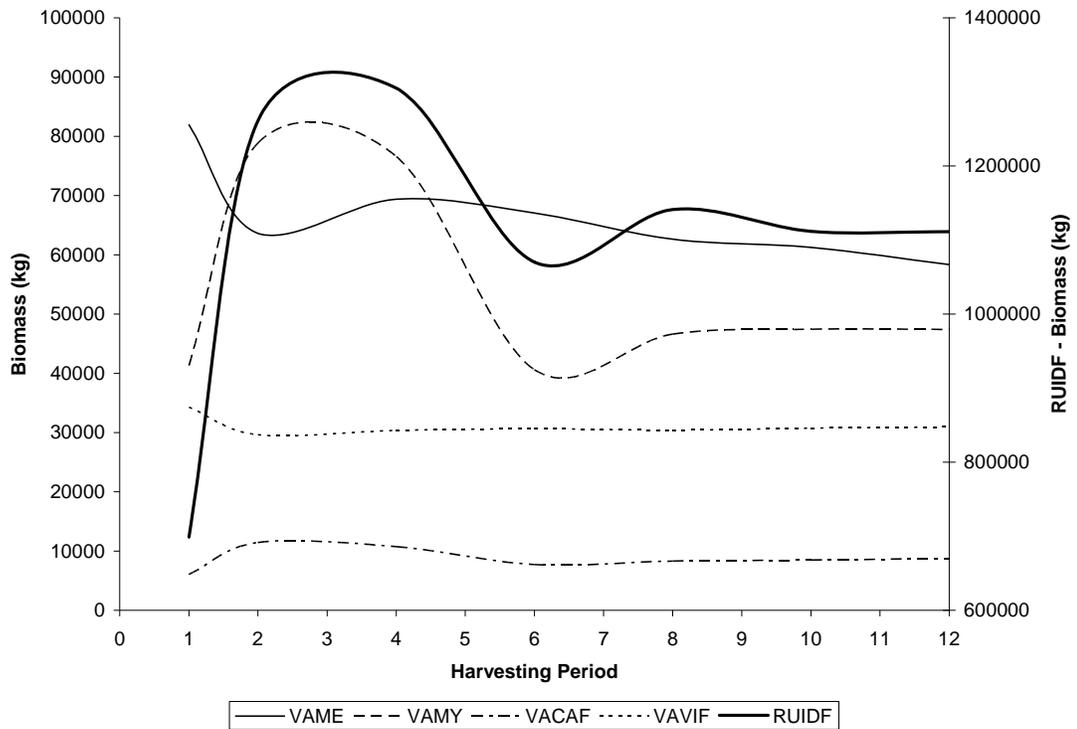


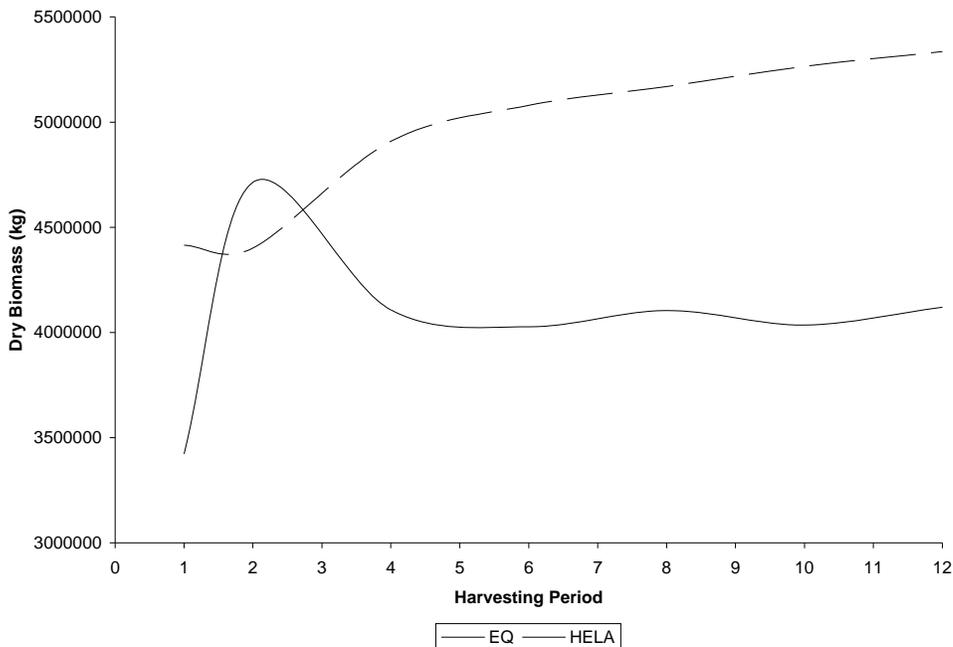
Figure 7. Relative change in mean dry biomass (g/900m<sup>2</sup>) of fruit shrubs by stand age (10 year interval) in pine leading habitat while holding all other model variables at their mean value.



**Figure 8. Relative change in mean dry biomass (g/900m<sup>2</sup>) of huckleberry and velvet-leaved blueberry by elevation sextile bins. The mean is representative of model estimates in 2008 in pine leading habitat while holding all other model variables at their mean value.**



**Figure 9. Projected change in total dry biomass (kg) of berries over 12 harvesting periods.**



**Figure 10. Projected change in total dry biomass (kg) of herbs over 12 harvesting periods.**

### Discussion

Female grizzly bears that occupy the UF Natural Region use leading pine forest more in all seasons than any other broad forest cover type we investigated. Second to leading pine, bears used stands with less than 60 percent pine composition more than stands that did not contain pine at all. Deciduous leading stands were used the least by grizzly bears. This supports the idea that leading pine forests in the Foothills are important habitat for grizzly bears in all seasons.

When using leading pine forests, female grizzly bears used different age classes of pine but spent the majority of their time in mature stands. Bears' use of mature stands was consistently high in all seasons. Young and older regenerating blocks were also used quite extensively by female bears in all seasons with use being the highest during the fall. Intermediate age classes of leading pine were used the least by female grizzly bears in all seasons. We found support for our hypothesis that productivity differed as a function of age and elevation. This effect was only found in the fall season when bears used mature stands more at higher elevations than at lower elevations. During the fall, elevation did not appear to influence harvest block use per se although bears did spend more time in young regenerating stands at lower elevation. We did not find any evidence that intermediate age stands were of any seasonal importance for female bears. Grizzly bears used all age classes of harvested leading pine and although the relationship was not significant, older regeneration did appear to be used more during the spring and summer with bears switching to young stands during the fall. This supports the idea that mature and regenerating leading pine stands are important habitat for grizzly bears, particularly during the fall season.

Food resources in pine forests of the UF in this northern system were substantially different from what has been reported in the Foothills of west-central Alberta (Nielsen et al. 2004B, Nielsen et al. 2010). In the north, food resources such as sweet-vetch roots and buffaloberry are lacking. The observed difference in food distribution suggests that there may be a latitudinal gradient in habitat productivity associated with differences in local and regional climate and soils. Therefore, the value of pine forest as foraging habitat for bears is likely different across the province.

Stand age, canopy tree composition, environmental gradients, and sampling year were important factors influencing food abundance for grizzly bears. Of these, sample year was the most important determinant of berry abundance for all but one species. We believe that annual variation in monthly precipitation during the growing season explains the year effect (Krebs et al. 2009). Commonly, leading pine forests are associated with dry conditions that support berry species rather than herbaceous vegetation, but these leading pine stands can occur across many environmental gradients including moisture. In our system, dry and young regenerating stands contained abundant velvet-leaved blueberries and raspberries within the first 20 years of regeneration. As these stands aged, berry productivity decreased substantially with closing of the canopy. In contrast to this, young and intermediate aged stands with higher moisture values contained more horsetail, cowparsnip, and lingonberry. Contrary to dry stands, these stands that do not have a moisture deficit may remain productive over time. While this general pattern seems to hold, the productivity of leading pine is also influenced by precipitation and temperature differences associated with elevation. Even within the narrow climatic gradient of the UF, there is evidence that at intermediate and high elevations, pine forests are more productive influencing berry and herbaceous food abundance. For instance, huckleberry and velvet leaved blueberry, two species known to be important to grizzly bears during the fall season, show spatial separation due to differences associated with elevation. Velvet leaf blueberry is found at low to intermediate elevations while huckleberry is only found at high elevations. These species diverge around 1200 m of elevation. Nielsen et al. (2010) found that huckleberry distribution increased with elevation in west-central Alberta and in the FlatheadValley of south eastern British Columbia, grizzly bears gorge on huckleberries in a high elevation burn (McLellan and Hovey 2001). If this pattern holds across the eastern slopes, higher elevation pine stands may be an important source of huckleberry for grizzly bears.

Comparing what we know about food in leading pine forest and the habitats used by female grizzly bears in this system, the use of young regenerating stands at low to intermediate elevations and the use of mature forest at higher elevations during the fall season may be related to the abundance of both velvet-leaved blueberries and huckleberries. Whether this is the case or not, we know that even in years when fruit is not available (2009) bears continue to use young harvested areas and mature forest. This suggests that harvested areas and mature pine may contain other important foods that we did not measure such as ants, grasses, and sedges. Bears may also be using mature pine forests or the edges of these forests for other activities such as bedding (Munro et al 2006).

According to our model, the proposed accelerated harvesting of pine is expected to increase the abundance of all bear foods we measured except for huckleberry. Huckleberry unlike the other bear foods that we were interested in, increases in mature leading pine stands. Even though food is expected to increase dramatically with the surge cutting of pine and remain higher than levels prior to MPB management, female grizzly bears do spend a considerable amount of time

in mature stands that varies seasonally. For this reason we suggest that mature stands are likely important for bears.

### **Management Considerations**

Understanding the impacts of MPB harvesting on grizzly bear habitat is challenging. The current age distribution of leading pine forest is skewed towards young and mature age classes, which limits our ability to make inference about the value of intermediate aged pine. Female grizzly bears use both young and mature age classes of leading pine, but spend more time in mature stands in all seasons. This suggests to us that there is value in these mature stands beyond what we can ascertain from our food models. What we do know about food resources in leading pine habitat is that for the most part young age classes contain the most food. As young stands regenerate beyond 30 years of age on dry and relatively unproductive sites, silviculture treatments or prescribed burns may be a management option to enhance these stands for bears.

The accelerated harvesting of pine is expected to increase food resources for grizzly bears relative to the species we inventoried except for huckleberry. Our model predicts that huckleberry is expected to decline over the 60 year planning horizon. Maintaining mature pine stands on the landscape goes against the overarching goal of the MPB Action plan. However, because high elevation pine is less susceptible to MPB infestation, we suggest that managers consider maintaining some of these leading pine stands within their operational plans.

### **Conclusion**

In this report, we have examined the seasonal importance of leading pine forest as habitat for female grizzly bears. In addition to this, we also have explored factors that influence food resources known to be important to grizzly bears and how they might change under MPB harvesting. Because we expect that food resources will increase as harvesting progresses, other issues related to accessibility of resources and security cover are likely to be important habitat issues for grizzly bears.

From here, our goal is to expand on our habitat analysis to investigate additional spatial and temporal factors that may influence the use of leading pine forest by grizzly bears. More specifically, we intend to investigate grizzly bears use of pine habitat relative to the current age distribution, time of day, block size, forested edges, roads, and retention structure.

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## CHAPTER 5: GRIZZLY BEAR HABITAT ENHANCEMENT TRIAL: FINAL REPORT

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### **Project Background**

This final report describes the surveys and treatments applied by the Grizzly Bear Habitat Enhancement Trial (GBHET), conducted by the Foothills Research Institute Grizzly Bear Program (FRIGBP, formerly the Foothills Model Forest Grizzly Bear Research Program) in the Moose Mountain area (Kananaskis) and Tay River area (Clearwater), Alberta, from 2007 to 2009.

The trial was initiated in June 2006 in response to a Request For Proposals issued by Shell Canada Ltd., which awarded funds for environmental restoration projects in the Moose Mountain area near Bragg Creek and the Tay River area near Sundre. The FRIGBP considered this project an opportunity to investigate the practical application of grizzly bear habitat recovery on reclaimed oil and gas facility sites. At issue was whether these sites should be considered a permanent loss of habitat, or whether they could be cultivated as pockets of high-quality habitat (Figure 1). At that time there were estimated to be more than 20,000 well sites within confirmed grizzly bear range in Alberta, each with an associated access road and pipeline right-of-way. Research by the FRIGBP has shown this type of development to be a significant contribution to human ingress into grizzly bear habitat, and consequent high rates of anthropogenic grizzly bear mortality.

The objective of the Grizzly Bear Habitat Enhancement Trial was to determine:

- i) whether grizzly bear foods such as buffaloberry (*Shepherdia canadensis*) and alpine sweet-vetch (*Hedysarum alpinum*) could be established on reclaimed oil and gas sites (Figure 1); and
- ii) once established, whether grizzlies would be attracted to these sites.

The GBHET comprised the planting of 15,860 Buffaloberry (*Shepherdia canadensis*) and 1470 alpine sweet-vetch (*Hedysarum alpinum*) seedlings on seven sites (six reclaimed well sites and one section of the Interconnect pipeline) totaling 9.2 ha. Table 1 lists the sites treated under the GBHET and their attributes, while Table 2 details the planting treatments carried out from 2007 through 2009.

**Table 1.Sites treated under the GBHET.**

	site	UTM E	UTM N	ATS (QS-Sec-Twp-Rge-Mer)	ha	Elev (Min)	Elev (Max)
1	Gunrange wellsite	658845	5650536	SW-26-23-06-W5	1.7	1499	1519
2	PetroCanada wellsite	660310	5646126	NW-12-23-06-W5	1.3	1476	1495
3	Entrance road PetroCanada wellsite	660110	5646152	NW-12-23-06-W5	0.1	1473	1473
4	Interconnect pipeline	657585	5643833	SW-3-23-06-W5	1.3	1624	1683
5	BT-15 wellsite	626140	5727766	NW-26-31-09-W5	2.5	1655	1684
6	BT-13 wellsite	613930	5717500	SW-28-30-10-W5	0.5	1836	1845
7	Limestone East wellsite	620428	5739687	SW-5-33-09-W5	1.8	1551	1579
				☐	<b>9.2</b>		

**Table 2.GBHET planting treatments.**

	site	date	Buffaloberry	<i>Hedysarum</i>	☐
1	Gunrange wellsite	July 11, 2007	1080		1080
2	PetroCanada wellsite	July 9, 10 2007	980	580	1560
3	Entrance road PetroCanada wellsite	July 10, 2007	100		100
		July 3,4 2008	495	400	895
		July 4, 2008	230		230
4	Interconnect pipeline	July 3, 4 2009	4625		4625
5	BT-15 wellsite	July 7, 2008	300		300
		June 9, 2009	4620		4620
		Aug. 18, 2009	190	490	680
6	BT-13 wellsite	June 12, 2009	2160		2160
7	Limestone East wellsite	June 13, 2009	1080		1080
			<b>15860</b>	<b>1470</b>	<b>17330</b>



**Figure 1.**Target condition: site fully occupied by *Shepherdia canadensis* and *Hedysarum alpinum*.

### **Planting stock**

Seed for the Buffaloberry seedlings planted under the GBHET was collected in the Hinton area in late summer of 2006, 2007, and 2008, and grown in styroblock containers by Coast To Coast Reforestation Ltd. at the Smoky Lake Forest Nursery in Smoky Lake, Alberta (Figure 2). Alpine sweet-vetch seedlings were provided by the Alberta Research Council facility in Vegreville, Alberta (Figure 3).



**Figure 2.**Buffaloberry seedlings.



Figure 3. *Hedysarum alpinum* in root-trainers.

### Site Selection

Reconnaissance of potential treatment sites was conducted on July 28, 2006, September 7, 2006, and July 14, 2007. Seven sites were selected for treatment (Figure 4).

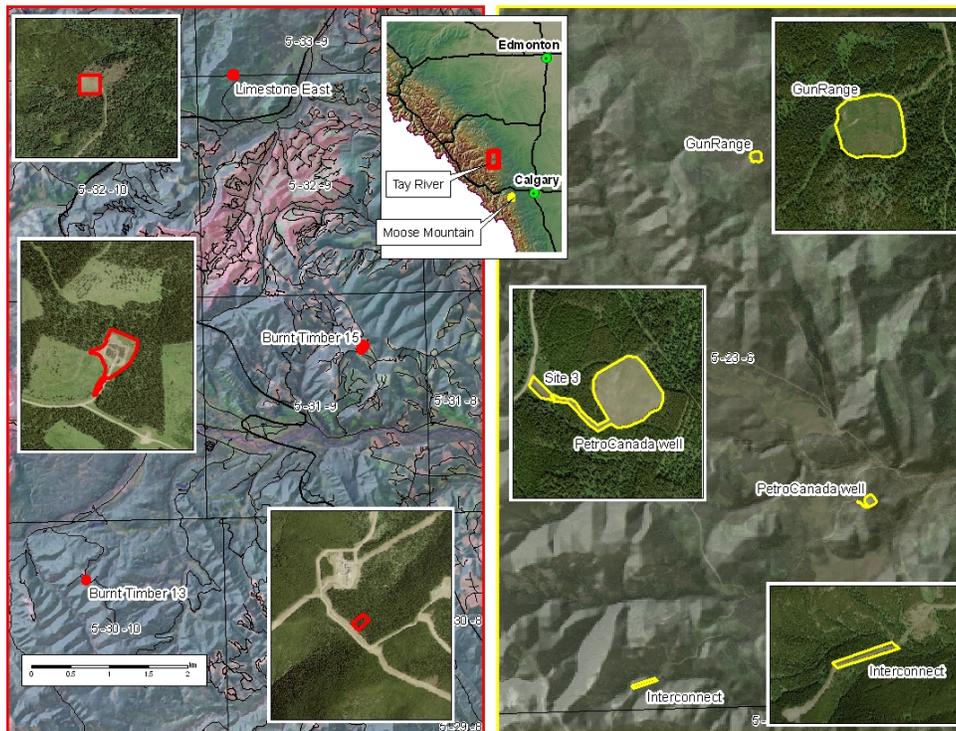


Figure 4. Treatment sites.

**Site 1: Gunrange wellsite (SE-3-23-6-W5)**

This well site (Figure 5) was reclaimed approximately 15 years ago. There were clusters of advanced spruce regen but most of the site was open and grassy. The soil was hard and compacted. There is a recreational trail 100m to the east of the opening. The 4 km access road has been reclaimed. Site 1 was planted with 1080 *Shepherdia* seedlings on July 11<sup>th</sup>, 2007. The weather was hot (> 30C) and dry during planting and for the following two months. The primary growth-limiting factors on this site are competition from grass, soil compaction that may inhibit root development, and seedling desiccation due to hot, dry weather.



**Figure 5. Site 1.**

Site 1 was not surveyed in 2008 due to the difficulty of access (4 km of deactivated road), however, it is likely that the performance of planted stock on this site was comparable to that of Site 2.

**Site 2: PetroCanada wellsite (NW-12-23-6-W5)**

This site (Figure 6) was drilled and reclaimed by Petro-Canada in 2005. There is a 250m access road to the West Bragg Creek Road. Site is flat, with scattered herbaceous cover, primarily clover (*Trifolium spp*) and grass. The soil was compacted but plantable. Lodgepole pine seedlings had been planted in spring 2006, on the site and access road. A small area at the front of the access road had been mechanically tilled (Site 3).

Site 5 was planted with 580 *Hedysarum alpinum* and 1080 *Shepherdia* seedlings on July 9<sup>th</sup> and 10<sup>th</sup>, 2007. A rainstorm in the morning of the 9<sup>th</sup> wet the soil, but the weather was hot (> 30C) and dry during planting and for the following two months.



**Figure 6. Site 2.**

Site 2 was surveyed on July 3, 2008. There was extensive mortality on the planted buffaloberry and sweet-vetch, with survival rates of approximately 5% on the buffaloberry and 8% on the sweet-vetch. Most likely this was at least partly due to the extremely hot dry weather that followed planting, but it is worth noting that the Lodgepole pine seedlings planted in spring 2006 suffered an equal or greater degree of mortality. There was considerable sign (scat and tracks) of animal presence, including cows, and this may well have contributed to the increased soil compaction. Rooting depth of established herbaceous vegetation was no more than 1-2 cm, suggesting that the soil was no longer able to absorb water.

**Site 3: PetroCanada wellsite access road (NW-12-23-06-W5)**

This site (Figure 7) is a small (0.12 ha) tilled section at the front of a 250m access road leading from the West Bragg Creek Road to Site 2 (Figure 7). Lodgepole pine seedlings had been planted in spring 2006 on the well site and access road but did not survive past 2007. The well site and access road had been planted with 1080 buffaloberry and 580 *Hedysarum* on July 9<sup>th</sup> and 10<sup>th</sup>, 2007. Mortality over the summer of 2007 was very high due to two months of extreme heat (> 30C) and drought conditions following planting. The tilled section at the front of the access road was planted again on July 3 and 4, 2008, with 495 buffaloberry and 400 sweet-vetch seedlings. The site was surveyed on June 12, 2009. Mortality on these plants was high due to compaction by cattle, and also competition from grass, clover, and dandelion. This section was planted a third time with 230 buffaloberry on July 4, 2009.



**Figure 7. Site 3, in 2006 before green-up.**

A survey was conducted on October 2, 2010. The site had been extensively and repeatedly trodden by cattle, leading to complete mortality of the planted buffaloberry and sweet-vetch seedlings. Note that the Lodgepole pine seedlings planted on this site in spring 2006 had also suffered complete mortality.

**Site 4: Interconnect pipeline (SW-3-23-6-W5)**

This portion of the Interconnect pipeline (1.3 ha) (Figure 8) was planted on July 3 and 4, 2009 with 4625 buffaloberry seedlings. The seedlings had been growing in Styroblock containers since Feb. 2009 and were in excellent condition (Figure 2). The soil was dry at the time of planting, but extensive thunderstorms on the evening of July 4, 2009 made it very likely that the plants were well-watered after planting.

A survey was conducted on October 2, 2010. The buffaloberry seedlings had suffered extensive mortality, in excess of 90%. The plants that had survived the winter were in poor condition (Figure 9), showing signs of desiccation and browse damage from ungulates (primarily deer).



**Figure 8. Site 4 in Sep. 2006.**



**Figure 9. Planted buffaloberry on Site 4 in October 2010.**

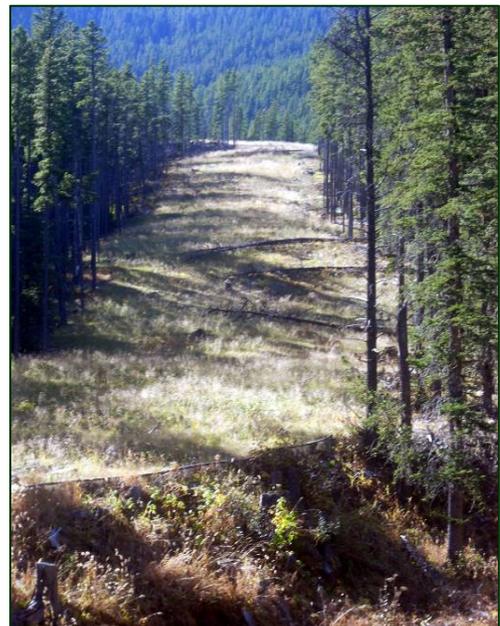


**Figure 10. Site 4 in October 2010. Grass up to 80 cm height.**

The poor performance of this plantation was likely due to a combination of ungulate damage and competition from other vegetation, primarily grass (Figure 10). A comparison of the site during initial reconnaissance in September 2006 (Figure 11a, below left) with conditions in October 2010 (Figure 11b, below right) shows the extensive spread of grasses on the site.



A



B

**Figure 11. Site 4 in 2006 (left), and in 2010 (right).**

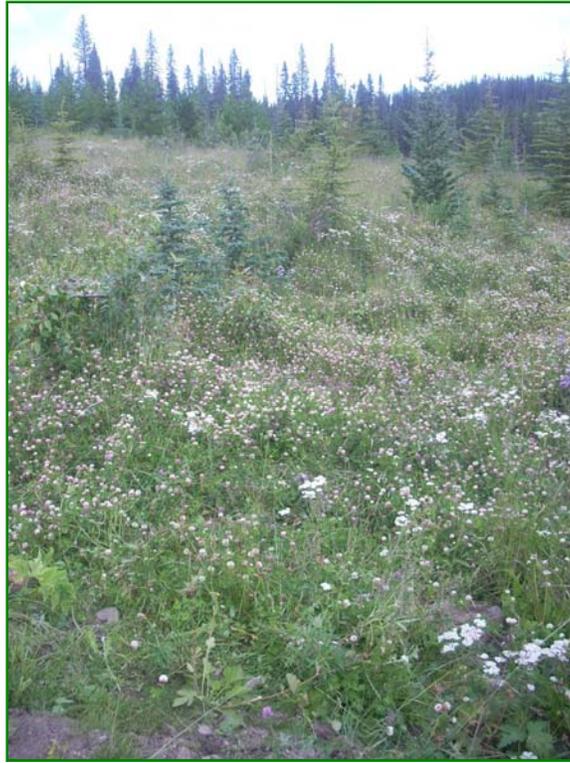
**Site 5: Burnt Timber 15 (NW-26-31-9-W5)**

This site was reclaimed in 2007 and extensive micro-siting and slash dispersal was employed (Figure 12).



**Figure 12. Reclamation of BT-15.**

This site was planted with 300 Buffaloberry seedlings on July 7, 2008; these showed good survival the following spring. The site was also planted on June 9<sup>th</sup> and 10<sup>th</sup>, 2009 with 4620 Buffaloberries, (including 1740 that came from 2007 seed and had overwintered in the nursery). A third planting treatment was carried out on August 18, 2009, with 490 sweet-vetch (Figure 15) and 190 buffaloberry (Figure 14) seedlings from Alberta Research Council. The site was very heavily vegetated at that time (Figure 13), and wild horses frequented the area. A total of 5600 seedlings were planted over 1.5 ha on BT-15.



**Figure 13.Revegetation of BT-15.**



**Figure 14.Planted Shepherdia.**



**Figure 15.**Planted *Hedysarum* on BT-15.

A survey was conducted on October 1, 2010. The seedlings had suffered extensive mortality, in excess of 90%. The plants that had survived the winter were in poor condition (Figure. 16a,b), showing signs of desiccation and browse damage from horses.



a)



b)

**Figure 16a and b. Planted Shepherdia, 2010.**

**Site 6:Burnt Timber 13 (SW-28-30-10-W5)**

This well site was reclaimed in 2008 and is flat, furrowed, and had considerable slash. Soil was soft and silty, and there was minimal competing vegetation at the time of planting. 2160 buffaloberry seedlings were planted on this 0.5 ha site on June 12, 2009.

A survey for this site was scheduled for October 1, 2010 but could not be completed as access to the site was blocked by a fence and locked gate.

**Site 7:Limestone East (SW-5-33-9-W5)**

This reclaimed well site had been planted about ten years previously with Lodgepole pine, which were about 2m tall by the summer of 2009. 1080 buffaloberry seedlings were planted on this 1.0 ha site on June 13, 2009. Most were planted on exposed mineral soil microsites adjacent to the pine saplings (Figure 17).



**Figure 17.Planted Shepherdia, 2010.**

A survey was conducted on October 1, 2010. As with BT-15, the mortality was very high, and the survivors showed signs of desiccation and browse damage (Figure18).



**Figure 18.Planted  
Shepherdia, 2010.**

## Conclusion

The objectives of the GBHET were to determine:

- i) whether grizzly bear foods such as buffaloberry (*Shepherdia canadensis*) and alpine sweet-vetch (*Hedysarum alpinum*) can be established on reclaimed oil and gas sites; and
- ii) once established, whether grizzlies will be attracted to these sites.

It is apparent from this trial that buffaloberry (*Shepherdia canadensis*) and alpine sweet-vetch (*Hedysarum alpinum*) cannot be established on reclaimed oil and gas sites without ensuring adequate protection from animal damage. The severe levels of disturbance on oil and gas sites, in which trees, duff, and organic topsoil is removed from a site, favours the subsequent colonization of the site by aggressive pioneer species such as grasses. The establishment of this vegetation complex in turn attracts ruminants such as deer, elk, and moose, which trample less resilient climax species (such as buffaloberry and sweet-vetch), thereby ensuring the dominance of grasses to the exclusion of other forage species.

It is possible that the installation of animal-proof fencing around sites undergoing reclamation treatment would enable planted forage species to be successfully established. Other silvicultural techniques that would favour the survival and performance of target species include planting larger and older nursery stock; fertilization of planted stock, and treatment of competing vegetation, either through mechanical or chemical means. It should be noted that all of the planted sites in this trial were higher-elevation (over 1470m), and had been severely disturbed, to the degree that the top organic LFH (duff) layer was removed, and seedlings were therefore planted in relatively nutrient-poor mineral soil from deeper soil horizons. It is recommended that the phenology of the target species be studied under controlled growth conditions, so that critical growth-limiting thresholds can be determined.

The second objective of the trial is predicated on the successful establishment of the target species, therefore no conclusions can be drawn. In terms of the implications for grizzly bear habitat supply, the reintroduction of late-seral forage species such as buffaloberry and alpine sweet-vetch, and even tree species such as Lodgepole pine, is problematic and such sites should be regarded as having been permanently converted to a non-forested condition, until such time as reforestation has been successfully demonstrated. Although the presence of ungulate species on these sites may afford predation opportunities for grizzly bears, the long-term implications for quality and quantity of grizzly bear habitat are uncertain.

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## CHAPTER 6: USING LINE TRANSECTS FOR RAPID ASSESSMENTS OF GRIZZLY BEAR FOODS

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### Introduction

The most commonly used approaches for sampling of grizzly bear foods in west-central Alberta have to date been based on short transects (20 m or 30 m long) whereby groundlayer cover is measured in five small (0.25-m<sup>2</sup> or 1-m<sup>2</sup>) quadrats and shrub cover and density measured in 2-m belt transects (Nielsen et al. 2004). Using this approach, the total area sampled per plot is quite small ( $\leq 5$  m<sup>2</sup> for groundlayer and 40 to 60 m<sup>2</sup> for shrubs) limiting accuracy and precision of estimates for the local stand. More recent field plots have been based on a 30 m transect length and have added a final meander survey within a 30 m x 30 m (900-m<sup>2</sup>) area to note the presence/absence of key grizzly bear foods and for the most important grizzly bear foods, such as alpine sweetvetch (*Hedysarum alpinum*), buffaloberry (*Shepherdia canadensis*), and cow parsnip (*Heracleum lanatum*), their density was recorded. Although this provides a good assessment of grizzly bear foods for a local area, it is quite time consuming (e.g., the layout of 30 m tape, the use of groundlayer quadrats, and flagging boundary edges for the 30 x 30 m area). This limits the number of sites and habitats covered in a day by field crews. It may also be sensitive to placement relative to stand heterogeneity. When assessing grizzly bear activities by visiting recent animal locations (Munro et al. 2006), limiting the extent of the plot is likely advantageous. However, when the goal is estimation of available habitat/foods across the entire landscape, a more efficient method is needed.

Here we explore the use of a more rapid inventory method for quantifying presence/absence and abundance of key grizzly bear foods in order to assist with food-based habitat modelling for grizzly bears (Nielsen et al. 2010). We demonstrate our method for two critically important grizzly bear foods that represent different vegetation strata and hence methodological challenges. The first species, alpine sweetvetch, is a perennial legume (groundlayer plant) that produces long, thick taproots belowground that grizzly bears favour in the spring and fall (Hamer & Herrero 1987, Hamer 1991, McLellan & Hovey 1995, Munro et al. 2006). The second species, buffaloberry, is a moderate-sized shrub that produces a large number of small single-seeded berries in late July and early August representing the primary source of calories during hyperphagia (Munro et al. 2006). Based on observations for these two species, we also relate their occurrence and abundance to common environmental factors to assess their applicability for use of landscape modelling of grizzly bear foods and nutrition (Nielsen et al. 2010).

### Methods

#### Study area

The study area encompasses 2,228 km<sup>2</sup> of the Canadian Rocky Mountains and Foothills of west-central Alberta (Figure 1). To stratify our sampling locations, we divided our study area into

three areas based on natural subregion type: Alpine (95-km<sup>2</sup>), Upper Foothills (1,262-km<sup>2</sup>), and Lower Foothills (932-km<sup>2</sup>). The Alpine study area, which was separated from the Upper and Lower Foothill study area, was located in southeast Jasper National Park (Figure 1). Vegetation in the foothills consisted of mixed forests of lodgepole pine (*Pinus contorta*), aspen (*Populus tremuloides*), and white spruce (*Picea glauca*) in upland sites and black spruce (*Picea mariana*) and tamarack (*Larix laricina*) in forested wetland sites. Open marshes and low gradient riparian areas were common in the lower foothills. In the upper foothills and alpine areas riparian areas were common, but often narrow in extent and dominated locally by willow (*Salix* spp.) and often surrounded by Engelmann spruce (*Picea engelmannii*). At the highest elevations, lodgepole pine and Engelmann spruce forests transitioned into patches of subalpine fir (*Abies lasiocarpa*) and alpine meadows below non-vegetated mountain peaks.

#### Line transect protocols

Presence and abundance (density) of alpine sweetvetch (*Hedysarum alpinum*), buffaloberry (*Shepherdia canadensis*), and several other important bear foods in west-central Alberta were recorded from late May to late August of 2010 using 500 metre long line (belt) transects. Locations of line transects were determined using a stratified random design for three natural sub-regions of Lower Foothills, Upper Foothills, and Alpine areas and the two broad habitat types of riparian or upland habitat. Random locations were selected in a GIS for upland habitat sites and the bearing of each transect assigned so that it was parallel with the direction of the nearest stream. Nodes were generated at 100 m intervals along each transect resulting in five line transect segments per plot. At the 500 m endpoint, the location of the nearest stream was determined based on the perpendicular distance to nearest streams in a GIS. This location was then assigned as the starting point of a second 500 m line transect (five 100 m segments) representing riparian habitat and using a back-bearing to return the observers to approximately the same area of the starting point for the first plot. This design thereby increased efficiency, while also ensuring that both upland and riparian habitats were sampled with equal effort (riparian habitats are often important for grizzly bears).

For each plot, two observers traversed on foot to the starting plot (waypoint) location using a handheld GPS. Once at the starting waypoint (the 0 m line transect location), the next 100 m node was selected from a list of GPS waypoints. One observer navigated to the next 100 m node (waypoint) using the handheld GPS while the other observer followed behind recording the density of alpine sweetvetch plants and buffaloberry shrubs within 1 m of either side of the transect (i.e., a 200 m<sup>2</sup> area; 2 m x 100 m). Along the same 100 m segment the presence and relative abundance (cover) of other fruiting species (*Empetrum nigrum*, *Shepherdia canadensis*, *Vaccinium myrtilloides*, *Vaccinium vitis-idaea*, *Vaccinium membranaceum*, and *Vaccinium scoparium*) were recorded, as well as the presence and relative abundance of fruit for each species, the density of cow parsnip (*Heracleum lanatum*), and general information on vegetation (habitat type, canopy cover, dominant tree species [AVI codes], etc.). This was repeated for each of the segments until reaching the 500 m end point.

A datasheet form used for recording site and species information is provided in Appendix A at the end of this chapter.

#### Predicting species occurrence and abundance using segment observations & GIS data

For each species we related the environmental variables from a GIS to species occurrence or abundance using logistic and either linear regression (sweetvetch) or zero-truncated Poisson

regression (buffaloberry). Linear regression was used to log transformed density counts of alpine sweetvetch given the large counts encountered for sweetvetch, while zero-truncated Poisson regression was used for buffaloberry (where present). In both models a random effect was used to account for the grouping of segments within transects (random effect was transect ID). All statistical analyses were performed in STATA (StataCorp 2005). Environmental predictors included surficial geology, bedrock geology (formation), climate normals (1961-1990), terrain (solar radiation, terrain wetness, elevation, and topographic position index), landcover, and stand characteristics (canopy cover). Surficial geology was limited to rock alpine geology (vs. blanket and veneer tills), while bedrock types included the Brazeau, Coalspur, Lower Mesozoic, Lower Palaeozoic, Upper Palaeozoic, Paskapoo, and Upper Paskapoo formations. For each species and response type (presence/absence or abundance), univariate models were fit for each variable to identify the importance of individual variables and the presence of non-linear responses. Multivariate models were then identified using the top uncorrelated ( $r < |0.7|$ ) factors.

Predictions of species occurrence for alpine sweetvetch (*Hedysarum alpinum*) were made in a GIS to illustrate mapping of predictions. Coefficients from the final multivariate occurrence (logistic regression) model for sweetvetch and GIS layers for those variables were calculated in ArcMap using the raster calculator function.

## Results

### Line (belt) transects

A total of 75 line transects (375 segments) totalling 37.5 km of length were completed in the summer of 2010. Alpine sweetvetch was found within belt transect segments (200-m<sup>2</sup> area) for 70% of the segments in the Alpine natural subregion, 41% of the segments in the Upper Foothills and 20% of the segments in the Lower Foothills. Buffaloberry, on the other hand, was found in 11.7% of the segments for the Alpine natural subregion, 38% of the segments for the Upper Foothills, and 74.5% of the segments for the Lower Foothills.

Average densities (per 200-m<sup>2</sup>) of alpine sweetvetch by natural subregion ranged from a high of 172.7 (SE = 20.2) individuals in the Alpine, 55.9 (SE = 8.1) individuals in the Upper Foothills, and a low of 3.6 (SE = 1.3) individuals in the Lower Foothills (Table 1). When examining maximum density across the natural subregions, similar patterns were observed with a maximum density reaching 1,193 individuals in the Alpine and only 43 individuals in the Lower Foothills (Table 1). In contrast to alpine sweetvetch plants, densities of buffaloberry shrubs were inversely related to elevation with average densities (per 200-m<sup>2</sup>) ranging from a low of 1.3 (SE = 0.44) shrubs in the Alpine, 11.6 (SE = 1.86) shrubs in the Upper Foothills, and a high of 33.4 (SE = 5.81) shrubs in the Lower Foothills (Table 1).

### Patterns of alpine sweetvetch (*Hedysarum alpinum*) occupancy & abundance

The final occurrence model for alpine sweetvetch included terms for surficial geology (rock alpine), terrain (compound topographic index and solar radiation), landcover (regenerating forest and areas of shrub classified within regenerating forests), and stand characteristics (canopy variation). Alpine sweetvetch was more likely to occur in the Rock alpine geological class (mountains), in areas of higher terrain wetness (CTI), in intermediate areas of solar radiation, in non-regenerating forested habitats, but when in regenerating forests in those areas classified as shrub, and finally in areas with greater canopy variation (Table 2).

Predicted patterns of alpine sweetvetch occurrence varied substantially among the study areas with sweetvetch occupancy lower overall in the Foothills and nearly always predicted within a 100-m segment outside of barren rocks in the Alpine region (Figure 2). Within the Foothills, areas of high occupancy appeared to occur most often in riparian habitat and wet areas consistent with areas of high terrain wetness (compound topographic index, CTI).

Abundance of alpine sweetvetch was explained by bedrock geology, climate (mean January minimum temperatures and mean growing season precipitation), terrain (global solar radiation), landcover (mixed forest and regenerating forest), and stand characteristics (canopy cover and canopy variation). Compared to the Alberta Group bedrock formation, sweetvetch densities were higher in the Lower Palaeozoic formation, while densities were lower in the Upper Paskapoo formation (Table 3). Densities of sweetvetch increased in areas of either low or high growing season precipitation, lower January minimum temperatures, and intermediate amounts of solar radiation. And finally, abundances were highest in forest stands with intermediate canopy cover and in areas with greater variation in canopy cover (Table 3).

#### Patterns of buffaloberry (*Shepherdia canadensis*) occupancy & abundance

Buffaloberry occurrence was explained best by regional environmental factors including bedrock geology (Brazeau formation), terrain (elevation, topographic position, and terrain wetness), and landcover (open conifer). The probability of occurrence for buffaloberry increased when off of the Brazeau bedrock formation, when at lower elevations and valley slope positions (topographic position index), when on drier terrain sites (inverse relationship with terrain wetness), and when outside of open conifer forests (Table 4).

Although occupancy was best described from broader-scale environmental factors, the abundance of buffaloberry was determined more by local stand characteristics. Specifically, buffaloberry shrub densities increased in deciduous forest stands, particularly when in sites with intermediate canopy cover which had low overall canopy variability (Table 5).

### **Discussion**

As an omnivore and a generalist species, grizzly bears consume a variety of foods across a variety of habitats (Nielsen et al. 2010). Due to their diverse diet and use of habitats, a major challenge is defining the quality of habitats available to grizzly bears. For the past decade we have been using small (20 m or 30 m) field plots to record information on habitat conditions and the presence and abundance (cover and for some food items density) of grizzly bear foods (e.g., Nielsen et al. 2004). Although these plots may be at an appropriate scale for assessing grizzly bear behaviours from GPS telemetry information (Munro et al. 2006), they are not efficient for characterizing the general availability of grizzly bear foods. The small plots are time consuming relative to the information collected thus limiting the number of sites and habitats covered in a day. Given the natural heterogeneity of stand conditions common to west-central Alberta, a large numbers of plots are required to estimate landscape variability in food resources.

Here we demonstrated a rapid method for characterizing the patterns of occurrence and abundance of grizzly bear foods using 500-m long line (belt) transects segmented into 100 m sections. Upland line transects are paired with riparian transects thus facilitating completion over a relatively short period of time (approximately 2 hours) a total transect length of 1 km (10 plots). Total area assessed in an outing when using the paired upland to riparian plot design is thus 2000-m<sup>2</sup> (0.2 ha) or 1000-m<sup>2</sup> (0.1 ha) per transect (200-m<sup>2</sup> per segment). This compares to

our prior methods that were limited in extent to  $\leq 5 \text{ m}^2$  for groundlayer surveys and  $\leq 60 \text{ m}^2$  areas for shrubs. Efficiencies in the longer line transects arise from the fact that the observer follows directly behind a navigator who is walking to 100 m waypoints using a GPS unit and counting the number of target food items encountered within 1 m (metre stick) of their path. The crew immediately begins their next transect segment and repeats the process until reaching the final 500 m endpoint. A second 500 m transect along riparian habitat is then within walking distance and leads the observers back to the nearby area where they first began.

By using this design in 2010 we recorded information on grizzly bear foods along 75 transects or 375 segments for a total transect length of 37.5 km (12 km in Alpine, 20 km in Upper Foothills, and 5.5 km in the Lower Foothills) and total sampled area of 75 hectares. We demonstrated the effectiveness of using information collected along 100-m transect segments for modelling species occurrence and abundance (density) based on common environmental GIS data and standard statistical methods.

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**Table 1. Summary statistics describing densities by natural subregion of alpine sweetvetch (*Hedysarum alpinum*) and buffaloberry (*Shepherdia canadensis*) shrubs encountered along 100-m long and 2-m wide belt transects (200-m<sup>2</sup> area) in west-central Alberta, Canada.**

Natural subregion	alpine sweetvetch			buffaloberry		
	Mean	S.E.	Maximum	Mean	S.E.	Maximum
Alpine (n = 120)	172.7	20.2	1193	1.3	0.44	30
Upper Foothills (n = 200)	55.9	8.1	720	11.6	1.86	132
Lower Foothills (n = 55)	3.6	1.3	43	33.4	5.81	204

**Table 2. Logistic regression coefficients describing probability of occurrence for alpine sweetvetch (*Hedysarum alpinum*) along 100-m long 2-m wide belt transects (200-m<sup>2</sup>) sampled in 2010 in west-central Alberta, Canada.**

Variable group	Variable	Coef.	Std. Err.	P value
<i>Surficial geology</i>				
	Rock alpine (surficial geology)	2.625	0.325	<0.001
<i>Terrain</i>				
	Terrain wetness (CTI in a 3x3 window)	0.194	0.058	0.001
	Solar radiation (Julian day 172)	0.011	0.006	0.062
	Solar radiation <sup>§</sup>	-0.185	0.098	0.059
<i>Landcover</i>				
	Regenerating forest	-1.444	0.797	0.070
	Regenerating forest classified as shrub	1.086	0.645	0.092
<i>Stand characteristics</i>				
	Canopy variation (StDev in a 3x3 window)	0.044	0.017	0.010
<i>Constant</i>	Constant (model intercept)	-166.0	88.1	0.060

§Coefficient and Standard Errors are 1,000,000 times their original value.

**Table 3. Regression coefficients used to describe the abundance (log transformed) of alpine sweetvetch (*Hedysarum alpinum*) along 100-m long 2-m wide belt transects in west-central Alberta, Canada.**

Variable group	Variable	Coef.	Std. Err.	P value
<i>Bedrock geology</i>				
	Brazeau formation	0.037	1.105	0.973
	Coalspur formation	1.320	1.308	0.313
	Lower Mesozoic	-0.406	0.805	0.614
	Lower Palaeozoic	2.245	0.906	0.013
	Paskapoo formation	-0.145	1.164	0.901
	Paskapoo formation upper	-2.615	1.301	0.045
	Upper Palaeozoic	1.182	0.967	0.222
<i>Climate normals (1961-1990)</i>				
	January minimum temperature	-176.7	79.4	0.026
	January minimum temperature <sup>2</sup>	-4.989	2.259	0.027
	Growing season precipitation	-0.343	0.161	0.033
	Growing season precipitation <sup>2</sup> <sup>†</sup>	0.036	0.017	0.036
<i>Terrain</i>				
	Solar radiation (Julian day 172)	0.005	0.006	0.335
	Solar radiation <sup>2</sup> <sup>§</sup>	-0.085	0.093	0.365
<i>Landcover</i>				
	Mixed forest (landcover)	-0.513	0.497	0.302
	Regenerating forest (landcover)	-1.214	0.768	0.114
<i>Stand characteristics</i>				
	Canopy cover	0.026	0.012	0.026
	Canopy cover <sup>2</sup>	-0.037	0.018	0.043
	Canopy variation (StDev in 3x3 window)	0.028	0.016	0.084
<i>Constant</i>	Constant (model intercept)	-1564.3	681.3	0.022

<sup>†</sup>Coefficient and Standard Errors are 100 times their original value.

<sup>§</sup>Coefficient and Standard Errors 1,000,000 times their original value.

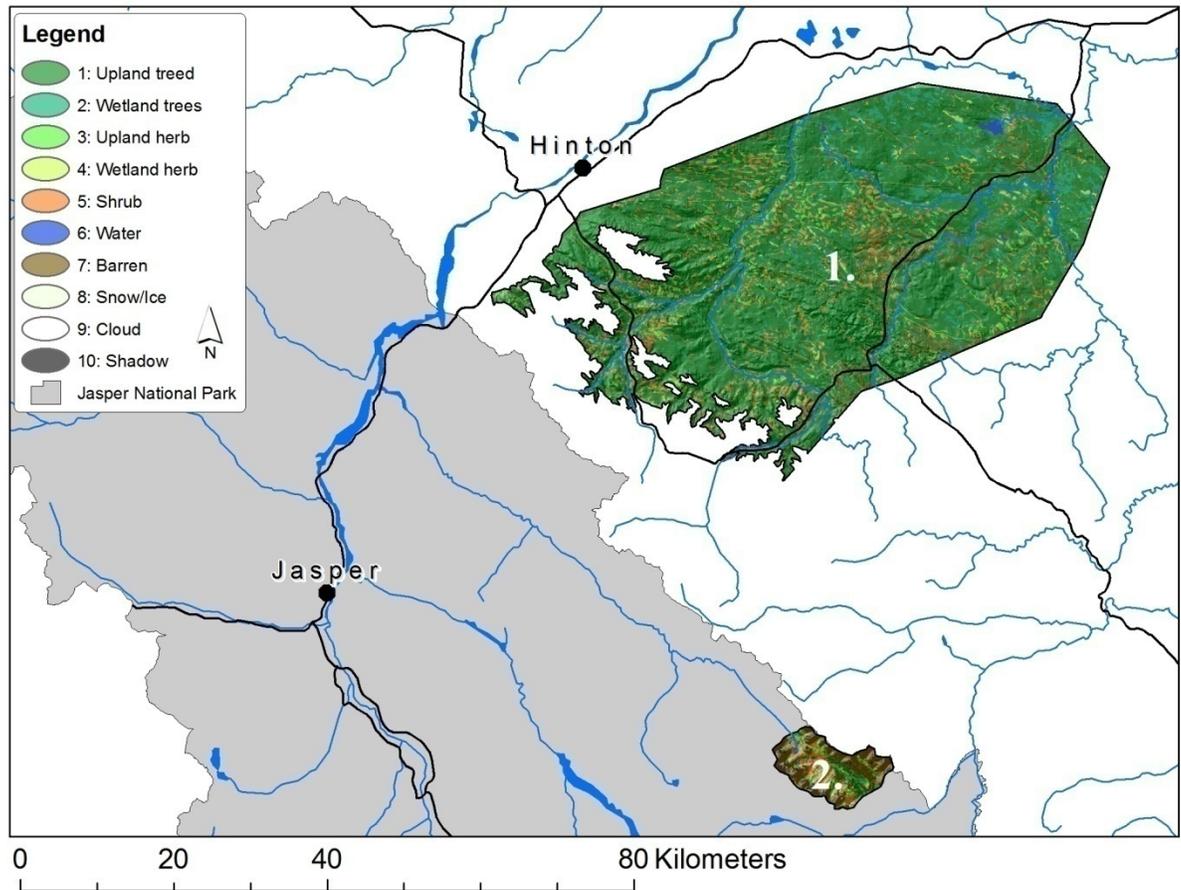
**Table 4. Logistic regression coefficients describing probability of occurrence for buffaloberry (*Shepherdia canadensis*) along 100-m long 2-m wide belt transects (200-m<sup>2</sup>) sampled in 2010 in west-central Alberta, Canada.**

Variable group	Variable	Coef.	Std. Err.	P value
<i>Bedrock geology</i>				
	Brazeau bedrock	-1.180	0.471	0.012
<i>Terrain</i>				
	Elevation (100 m increments)	-0.717	0.135	<0.001
	Topographic position index	-0.499	0.012	<0.001
	Terrain wetness (CTI in a 3x3 window)	-0.291	0.109	0.008
<i>Landcover</i>				
	Open conifer	-1.833	0.787	0.020
<i>Constant</i>	constant (model intercept)	10.81	2.218	<0.001

**Table 5. Zero-truncated Poisson Regression coefficients used to describe the abundance (log transformed) of buffaloberry (*Shepherdia canadensis*) where present within 100-m long 2-m wide belt transects in west-central Alberta, Canada.**

Variable group	Variable	Coef.	Std. Err.	P value
<i>Landcover</i>				
	Deciduous <sup>†</sup>	0.151	0.053	0.004
<i>Stand conditions</i>				
	Canopy cover	0.067	0.024	0.004
	Canopy cover <sup>2</sup>	-0.812	0.308	0.008
	Canopy variation (Std Dev in 3x3 window)	-0.039	0.020	0.058
<i>Constant</i>	Constant (model intercept)	1.987	0.262	<0.001

<sup>†</sup>Coefficients and Standard Errors are 1000 times their original value.



**Figure 1.** Area used to define locations of 500 m transects in west-central Alberta. Area labelled as 1 represents the upper and lower foothills, while the label 2 area represents the alpine study area within southeast Jasper National Park.

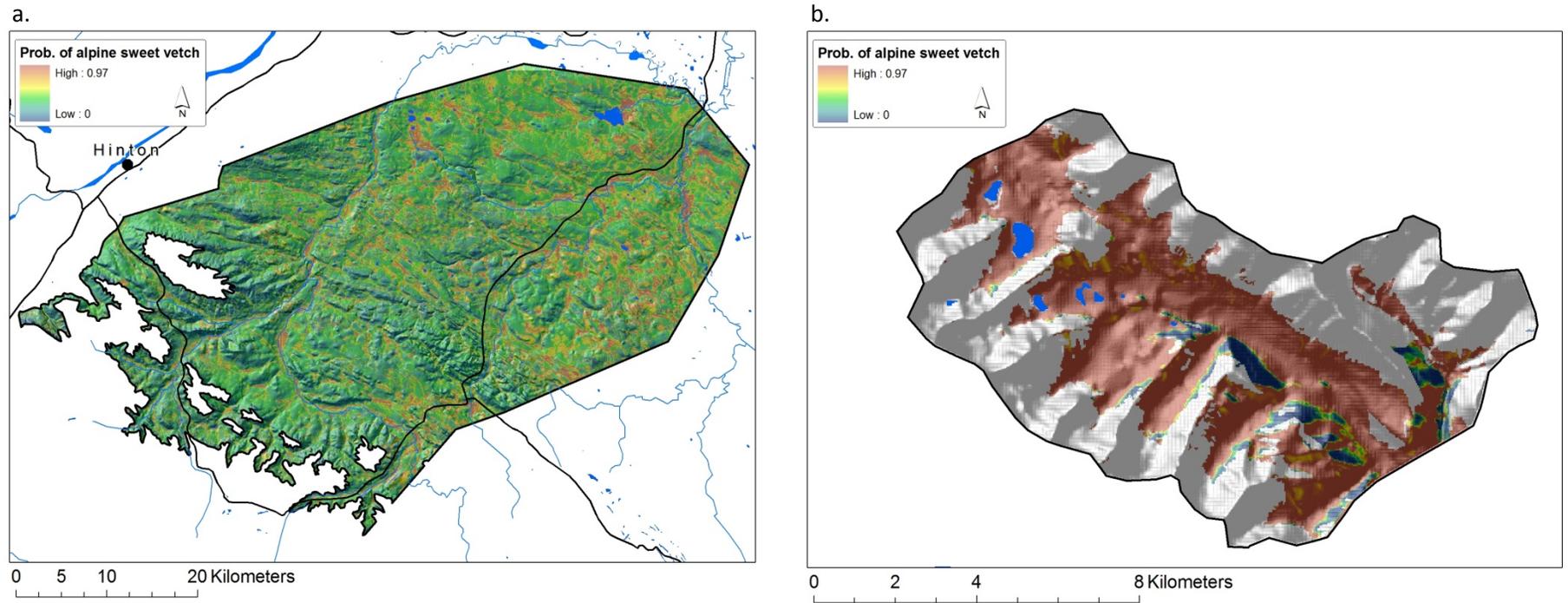


Figure 2. Predicted probability of occurrence for alpine sweetvetch (*Hedysarum alpinum*) in the Foothills (a.) and the Alpine (b.) study areas.

Appendix A. Field datasheet used for recording major grizzly bear foods on 500 metre line transects.

Line #: \_\_\_\_\_ Bearing (°): \_\_\_\_\_ Length (m): \_\_\_\_\_ Start time: \_\_\_\_:\_\_\_\_ AM/PM Month: June / Jul / Aug; Day: \_\_\_\_\_  
 Observer: \_\_\_\_\_ Recorder: \_\_\_\_\_ Stop time: \_\_\_\_:\_\_\_\_ AM/PM NSR: Low Foothl; Up Foothl; Alpine  
 UTM Locations (N83 Z11): Start (0m): X= \_\_\_\_\_ Y= \_\_\_\_\_ ; Stop (500m): X= \_\_\_\_\_ Y= \_\_\_\_\_

	0-100m		100-200m		200-300m		300-400m		400-500m		Notes:
Habitat											
Dom Spp											
Canopy											
Spp	% Cover	Fruit cls	% Cover	Fruit cls	% Cover	Fruit cls	% Cover	Fruit cls	% Cover	Fruit cls	
SheCan											
VacMyrt											
VacVit											
VacMem											
VacSco											
EmpNig											
2 m belt HedAlp (dot tally)											
H.A. total											
2 m belt SheCan (dot tally)											
S.C. total											

UTM locations of 100m nodes:			
Loc.	Xcoord	Ycoord	Acc. (m)
0m			
100m			
200m			
300m			
400m			
500m			

Fruit class definitions (where present):	Canopy classes:
0 = None	0 = 0%
1 = sparse (<1 berry/m <sup>2</sup> );	1 = 1-5%
2 = Few (1-5 berries/m <sup>2</sup> );	2 = 6-25%
3 = Low (6-10 berries/m <sup>2</sup> )	3 = 26-50%
4 = Moderate (11-25 berries/m <sup>2</sup> );	4 = 51-75%
5 = High (26-50 berries/m <sup>2</sup> );	5 = 76-95%
6 = Very high (>50 berries/m <sup>2</sup> )	6 = 95-100%

**Habitat:** uF= upland Forest; wF= wet Forest; uH= upland Herb; wH= wet Herb; S= Shrub; R = Riparian; yC = young Clearcut; oC= old clearcut; B = Barren

**Dominate species (AVI):** PI = lodgepole; Sw = w. spruce; Se = Engel. spruce; Sb = b. spruce; Fb = bals fir; Fs = sbalp fir; Aw = Aspen; Ab = bals poplr; T = tamarack; Sx = willow; H = herbaceous

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## CHAPTER 7: SPATIAL AND TEMPORAL VARIATION IN THE NUTRITIONAL QUALITY OF ALPINE SWEETVETCH IN WEST-CENTRAL ALBERTA

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### Introduction

The nutritional quality of edible plants is spatially and temporally heterogeneous. This spatial and temporal heterogeneity of plant food resources is often associated with plant phenology, as the nutritional quality of many plant species is dependent upon its current stage of growth. For example, in North America it is commonly known that grasses have higher protein and lower fibre content in the spring when they are young, and that this nutritional quality decreases through the summer and fall as the grasses age. The phenological stage of a plant species (i.e. budburst, flowering, and fruiting), however, is influenced by many factors, including age, photoperiod, nutrient availability, genetics, and the environment. This in turn influences the temporal patterns in nutrient quality of the plants which affects ecosystem processes and animal foraging behaviours. For instance, animals selectively forage on the most nutritious plant foods available (McNaughton 1979; Mysterud et al. 2001; Hebblewhite et al. 2008). As well as considering temporal dynamics (i.e., phenology), the nutritional quality of plant foods is affected by spatial variations in the environment (Mysterud et al. 2001).

Alpine sweetvetch (*Hedysarum alpinum*; Fabaceae), also known as pink sweetvetch, Eskimo potato, and liquorice root (Holloway and Alexander 1990; Moerman 1998), is a widely distributed perennial plant in the northern parts of North America, being found throughout the western boreal forest, Aspen parkland, Canadian Rocky Mountains and Foothills, as well as across the arctic tundra (Hamer 1985; Hamer and Herrero 1987; Johnson et al. 1995; McLellan and Hovey 1995; Treadwell and Clausen 2008). In Alberta, alpine sweetvetch is typically found in meadows, open moist woods, slopes, and disturbed areas, and can be found at both high and low elevations (Johnson et al. 1995; Munro et al. 2006; Nielsen et al. 2010). Alpine sweetvetch has an edible taproot and in fact was traditionally consumed by Native Americans (Johnson et al. 1995; Treadwell and Clausen 2008). Roots can be eaten raw, boiled, baked, or fried, and are harvested in the fall through to spring, when the root is considered to be the most palatable and nutritious (Johnson et al. 1995). During the summer the root becomes dry and woody and is therefore not consumed (Johnson et al. 1995). This is typical of many short stature plants, where above ground spring growth is dependent on resources that have been translocated to roots the previous winter (Clark 1977).

Alpine sweetvetch is also an important food resource for grizzly bears (*Ursus arctos*) where it is found (McCroly and Herrero 1981; McLellan and Hovey 1995, Munro et al. 2006). Similar to humans, the roots are typically consumed by bears during pre- and post-flowering stages (Holcroft and Herrero 1984; Hamer and Herrero 1987). In west-central Alberta, alpine sweetvetch root is especially critical during early spring after den-emergence, and in late fall

prior to den-entry, as it makes up the majority of their diet during these periods of low resource availability (Munro et al. 2006).

Given its importance to grizzly bears, alpine sweetvetch is an understudied resource. In fact, very little is known about root phenology in general (Jackson et al. 2001), which is surprising given that root production accounts for 50 – 90% of the primary production in temperate vegetation (Ruess et al. 2003; Steinaker 2006). Very little is also known about how environmental factors influence the nutritional quality of alpine sweetvetch and thus potentially affect spatial patterns in quality. An investigation into the temporal and spatial variation in nutritional quality of alpine sweetvetch would therefore be valuable in understanding grizzly bear habitat and foraging behaviours. This information would also be beneficial to current modelling efforts examining bottom-up perspectives of populations (e.g. Nielsen et al. 2010). My objectives here are therefore to: (1) describe the spatial and temporal variation of alpine sweetvetch nutritional quality; and (2) evaluate how grizzly bears respond to predicted variations in the quality of alpine sweetvetch based on temporal examinations in habitat selection using GPS radiotelemetry.

### Study Area

The study area is located in the Canadian Rocky Mountains and Foothills of west-central Alberta, Canada (53°15'N, 117°30'W). The foothills contain a diverse array of habitats, including black spruce (*Picea mariana*) and tamarack (*Larix laricina*) bogs; lodgepole pine (*Pinus contorta*) stands; open marshes; riparian areas; and mixed forests composed of lodgepole pine, aspen (*Populus tremuloides*), and white spruce (*Picea glauca*). Mountainous forests consist of spruce (*Picea engelmannii* x *glauca*), subalpine fir (*Abies lasiocarpa*), and lodgepole pine, with alpine meadows and rock outcrops occurring at higher elevations. There are numerous anthropogenic activities in the foothills including forestry, mining, oil and gas, hunting, outdoor recreation, and human settlements. Recreational use is extensive in the mountains, although human activity in high elevation alpine areas is less than in the foothills.

There is a great diversity of mammals in the study area including, moose (*Alces alces*), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), and beaver (*Castor canadensis*). In addition, hoary marmot (*Marmota caligata*), Columbian ground squirrels (*Spermophilus columbianus*), and bighorn sheep (*Ovis Canadensis*) occur in the mountains. Large carnivores in the area include American black bear (*Ursus americanus*), gray wolf (*Canis lupus*), cougar (*Puma concolour*), and grizzly bear (*Ursus arctos*).

### Methods

#### Sample collections and nutritional laboratory analyses

*Hedysarum alpinum* roots were collected at 14 sites in the montane, lower foothills, upper foothills, and subalpine zones over the spring, summer and fall of 2008-2010. Nutritional analyses were performed in the Proximate Laboratories of the Department of Agriculture, Food, and Nutritional Sciences at the University of Alberta. Samples were frozen, dried at 60°C for 48 hours and finely ground. Crude protein (N x 6.25) was determined using a LECO TruSpec N/C Analyzer (Leco Corporation, St. Joseph, Michigan, USA). All estimates were corrected to a 100% dry matter basis by drying a subsample at 105 °C or 110 °C.

### Phenological changes in nutrition (crude protein content)

Root samples were grouped into six phenological stages (pre-leaf, leaf, bud, flower, seed, dormant) based on the observed phenology of sweetvetch plants at the time of collection. For each phenological stage, mean and standard error of crude protein estimated and an ANOVA used to test for significant differences between groups (phenological stages). To determine whether assumptions were met for ANOVA, a histogram plot of residuals was used to assess normality, while heterogeneity of variances was assessed by examining a residual plot and performing a Bartlett test. Pair-wise one-way t-tests with adjustments (Holm's) for multiple inferences was used to test for significant differences between phenological classes.

### Nutritional landscape modelling

*A priori* hypotheses of factors affecting the nutritional quality of alpine sweetvetch (Table 1) were compared using a competing models approach and ranked using the Akaike Information Criterion (AIC). Candidate models included those that contained individual variables, multiple variables, and interaction terms believed to be relevant. Because samples were collected over multiple years, year of collection was used to test for annual variation in nutritional quality. Models were fit using generalized linear models (GLMs). The most supported model was checked for normality by examining a histogram of residuals followed by a Shapiro-Wilk test. All statistical analyses were conducted in the program R (R Core Development Team 2009).

Bi-weekly predictions of nutritional quality (crude protein) were combined with an existing presence/absence model of *H. alpinum* habitat from Nielsen (2010) to create bi-weekly maps illustrating patterns of crude protein content in roots from May to mid-October.

## **Results**

### Phenological changes in nutrition (crude protein content)

Phenological stage of alpine sweetvetch varied between mountain (elevation  $\geq 1700$  m) and foothills habitats (elevation  $< 1700$  m), with sweetvetch phenology in the mountains not surprisingly lagging behind that of the foothills (Table 2). Mean crude protein content of *Hedysarum alpinum* roots declined as phenology advanced from the pre-leaf stage, reaching its lowest point during flowering, after which crude protein content rose to pre-leaf levels in dormant plants (Figure 2). Significant seasonal differences in crude protein content were apparent (ANOVA,  $p < 0.001$ ), with roots from the pre-leaf period having higher crude protein content than both flowering ( $p < 0.05$ ) and seed bearing ( $p < 0.01$ ) stages. The roots of dormant plants also had significantly higher crude protein content than flowering ( $p < 0.05$ ) and seed bearing ( $p < 0.05$ ) plants.

### Nutritional landscape model for crude protein

The most supported crude protein model for alpine sweetvetch included factors for Julian day, Julian day squared (quadratic), terrain wetness (CTI), and 5 °C Growing Degree Day (GGD) with a three-way interaction between terrain wetness, degree days, and Julian day (Table 3). Figure 2 illustrates a nutritional landscape model of crude protein content for May 21. During this date, lower river valleys tended to have moderate crude protein content, while roots on average had higher levels of crude protein during this time in higher elevation valleys (Figure 2).

## Discussion

Our results suggest that both temporal and spatial factors are important determinants of crude protein content of alpine sweetvetch (*Hedysarum alpinum*) roots in west-central Alberta. We are currently evaluating habitat selection behaviours of grizzly bears to evaluate whether bears are responding to spatial and temporal changes in quality of roots.

## Acknowledgements

We thank Karen Graham, Tracy McKay, Sarah Rovang, Molly Penzes, Scott Nielsen, and Terrence Larsen for collecting roots in the field and providing samples and Gordon Stenhouse for support of this research.

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**Table 1. Hypothesized factors, variable names, and abbreviations of variables used in candidate models.**

Hypothesized Factor	Variable names (predictor variables)	Abbreviation
<i>Temporal</i>	Julian Day	JDAY
	Year	YEAR
<i>Soils</i>	Terrain wetness (Compound Topographic Index)	CTI
	Landcover category	LANCOV
	Bedrock formation	GEO
<i>Moisture</i>	Terrain wetness (Compound Topographic Index)	CTI
<i>Temperature</i>	Growing Degree Day (5 °C)	GGD
	Global solar radiation (on Julian day 172)	GLBL 172
	Crown Cover	CROWN
<i>Competition</i>	Landcover category	LANCOV
	Crown Cover	CROWN
	Global solar radiation (on Julian day 172)	GLBL 172

**Table 2. Range of dates and average crude protein content (based on % dry weight) of alpine sweetvetch (*Hedysarum alpinum*) by phenological stage for both mountain (elevation  $\geq 1700$  m) and foothills (elevation  $< 1700$  m) environments. Roots were sampled in 14 areas between 2008 and 2010.**

Elevation	Pre-Leaf	Leaf	Bud	Flower	Seed	Dormant
$\geq 1700$ m	26 May – 17 Jun	04 Jun <sup>†</sup>	30 Jun – 06 Jul	08 Jul – 29 Jul	04 Aug – 12 Sep	17 Sep – 13 Oct
$< 1700$ m	27 Apr – 17 Jun	28 May – 08 Jun	04 Jun – 06 Jul	24 Jun – 30 Jul	29 Jul – 29 Sep	17 Sep – 17 Oct
Average Crude Protein	17.0 <i>a</i> <sup>§</sup>	17.9 <i>ab</i>	15.8 <i>ab</i>	14.6 <i>b</i>	14.8 <i>b</i>	17.1 <i>a</i>
N	15	6	14	19	40	18
S.E.	0.51	1.50	0.51	0.54	0.40	0.59

<sup>†</sup>There was only one observation made of the Leaf phenological stage in mountain habitats.

<sup>§</sup>Unique lower case lettering indicates significant differences in crude protein content.

**Table 3. Hypothesized candidate models, AIC,  $\Delta$ AIC, and weight of the top 10 candidate models used to predict crude protein content of alpine sweetvetch (*Hedysarum alpinum*) in west-central Alberta, Canada. The final model (in bold) was selected based on the highest Akaike weight ( $w_i$ ).**

Candidate models (hypotheses)	Model structure	AIC	$\Delta$ AIC	$w_i$
<b>Soil + Moisture + Temperature</b>	<b>JDAY + JDAY2 + CTI * GDD * JDAY</b>	<b>528.65</b>	<b>0</b>	<b>0.70</b>
Soil + Moisture + Temperature	JDAY + JDAY2 + CTI * GDD * JDAY + YEAR	531.59	2.94	0.16
Moisture	JDAY+JDAY2+CTI	534.94	6.29	0.03
Soil	JDAY+JDAY2+CTI+GEO	535.70	7.05	0.02
Moisture	JDAY+JDAY2+CTI+CTI*JDAY	536.26	7.61	0.02
Temp + Moisture	JDAY+JDAY2+CTI+GDD	536.43	7.78	0.01
Soil	JDAY+JDAY2+CTI*GEO*JDAY	537.23	8.58	0.01
Soil + Moisture + Temperature	JDAY+JDAY2+CTI+GDD*JDAY	537.36	8.71	0.01
Soil	JDAY+JDAY2+CTI+GEO+LANCOV	537.70	9.05	0.01
Soil + Temp + Moisture	JDAY+JDAY2+CTI+GEO+GDD	537.70	9.05	0.01

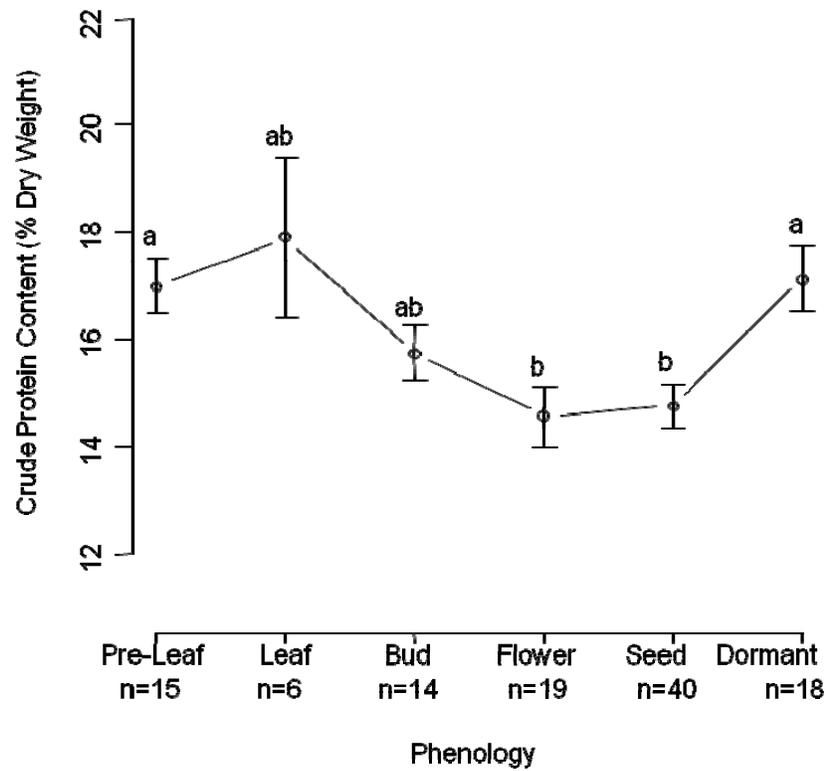
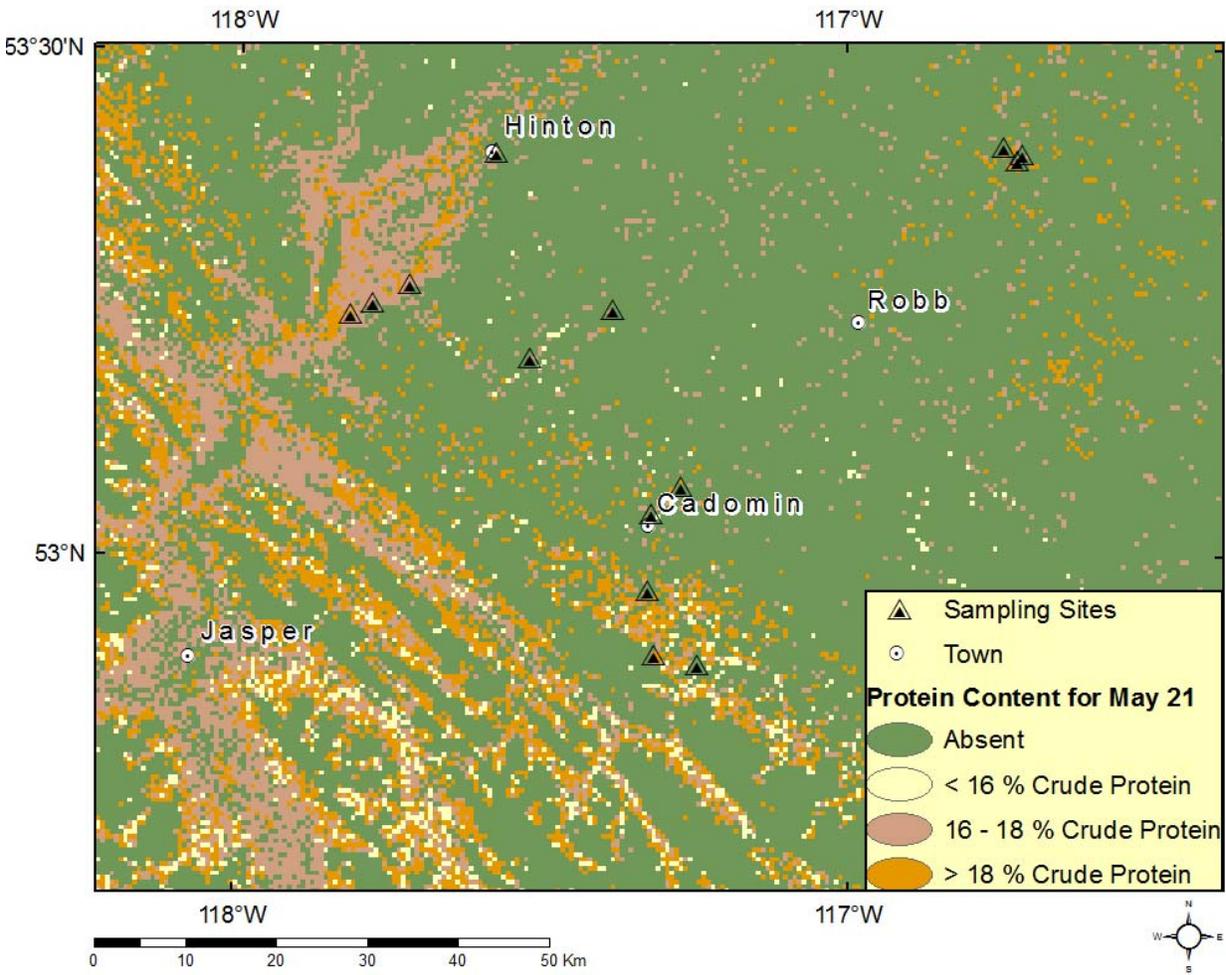


Figure 1. Crude protein content (% dry matter basis) of *Hedysarum alpinum* root at different phenological stages collected in the study area. Error bars are 1 standard error above and below the mean. Lower case letters indicate phenological stages that have significantly different levels of crude protein (pre-leaf & flower, pre-leaf and seed, seed and dead, flower and dormant).



**Figure 2. Nutritional landscape map predicting the average percent crude protein in alpine sweetvetch (*Hedysarum alpinum*) roots for May 21.**

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## CHAPTER 8: A BIOENERGETIC MODEL FOR GRIZZLY BEARS: LINKING LANDSCAPES TO POPULATIONS

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### Introduction

Understanding how sensitive species interact with their environment and how they respond to changes in their landscape is essential to their effective management and conservation. For grizzly bears this is particularly important given their naturally low densities and fecundity and their sensitivity to changes in survival. They also live in highly variable environments, often with short growing season that limits food availability. As well as having inherent spatial and temporal variations in food availability, there is also substantial seasonal and spatial variability in the nutritional quality of the foods (protein and energetic content).

Because bears have a hibernation phase, during their active period they must not only satisfy their maintenance and productive demands, but also accumulate enough reserves to be used in the inactive period. Pregnant females must also accumulate enough energy to satisfy not only their needs for hibernation, but also the needs of their cubs. Therefore food resource characteristics, such as nutritional values and their spatial-temporal distributions, influence the ability of an animal to accumulate body reserves (fat and lean) and therefore affect survival and reproductive success which ultimately affects population growth.

Nutritional ecology provides a framework from which to connect individual energetic demands, life history traits and the interactions of these factors with the environment to determine population processes (Barboza et al. 2009; Robbins 1994). Using this framework we consider the individual biochemical and biophysical demands that are critical to life and represent these as a bioenergetic model that simulates flow of energy between the animal and their habitat focusing on the principal mechanisms that are significant in individual fitness (Robbins 1994).

Grizzly bear populations in Alberta have recently been listed as a threatened species due to their small population size and low rates of population growth (slow recovery to population declines). Populations are limited to the western part of the province where they are associated with the foothills, mountains and western boreal forest. Not only do densities vary across their range in Alberta (4.8 to 18.1 bear/km<sup>2</sup>, ASRD & ACA, 2010), but also their home range size and individual body condition varies. These variations may be the consequence of two limiting factors. The first is the temporal and spatial availability (abundance) of critical resources of protein and total energy. In some cases this limits individual energy storage thereby affecting reproductive success (Stringham 1990). The second potential limiting factor relates to variations in survival. In Alberta the majority of bear mortalities are due to human-bear conflicts.

Over the past decade there have been a number of habitat studies completed which have increased our knowledge of grizzly bear-habitat interactions (Munro et al. 2006; Nielsen et al. 2002, 2004, 2006, 2008). Recent emphasis has been on assessing nutritional landscapes (Nielsen et al. 2010) and relating this to individual body condition (Nielsen et al. in prep) and its implications to reproduction success, carrying capacity and population dynamics.

The goal of this research is to provide a mechanistic understanding of how grizzly bear population dynamics emerge from individual behaviours and bioenergetic balances. More specifically, we are exploring how key elements in the biology of grizzly bears and spatial structure and dynamics of the landscape interact to determine body size, population density and demography of bears in Alberta. To achieve this goal, we are integrating landscape nutritional models predicting the spatial and temporal variation in food quality (protein and energy) with bear biology, nutritional physiology, and behaviours using simulation models. Linking bioenergetic, behavioural and movement models with the environment (landscape), we will examine different scales from landscape to individuals to populations.

This report summarizes the preliminary results of our first step in this process where we are building a mechanistic model simulating the bioenergetic budget of female grizzly bears under different diets. More specifically our objectives in this component are to:

- 1) Understand the mechanisms that influence lean and fat accumulation in bears thereby providing a link to understanding and predicting body condition;
- 2) Evaluate the impact of seasonal variability in nutritional components (protein and energy content) for different age/gender classes; and
- 3) Assess the effect that energetic and nutritional values of dominant food resources in Alberta on grizzly bear body condition.

## **Methods**

### The Bioenergetic Model

The purpose of our bioenergetic model is to simulate the dynamics of lean and fat body mass on grizzly bears under different diets (food resources). The model operates under daily time steps based on the active period. Food resources are represented as diets with different amounts of energy and protein, which themselves vary through time. Model inputs are different diets and their characteristic digestibility and metabolizable energy and protein. These factors are used to estimate intake and energy and protein budgets (see sub-model section below).

Depending on the daily diet, body fat and lean body mass accumulations are estimated in a simultaneous process. For this reason the model operates in two interconnected dimensions. One is the amount of energy ingested expressed in kilocalories/day. This affects lean and fat accumulation. The second is the amount of protein expressed in kilograms/day that has an effect on lean accumulation. Model outputs are lean body weight and body fat weight per day. Total body weight is estimated as the sum of these two components.

To estimate gain/loss of lean and fat mass, the bioenergetic model integrates different processes and components through mechanistic relationships. Processes are represented as sub-models (black rectangular boxes in Figure 1). The sub-models include:

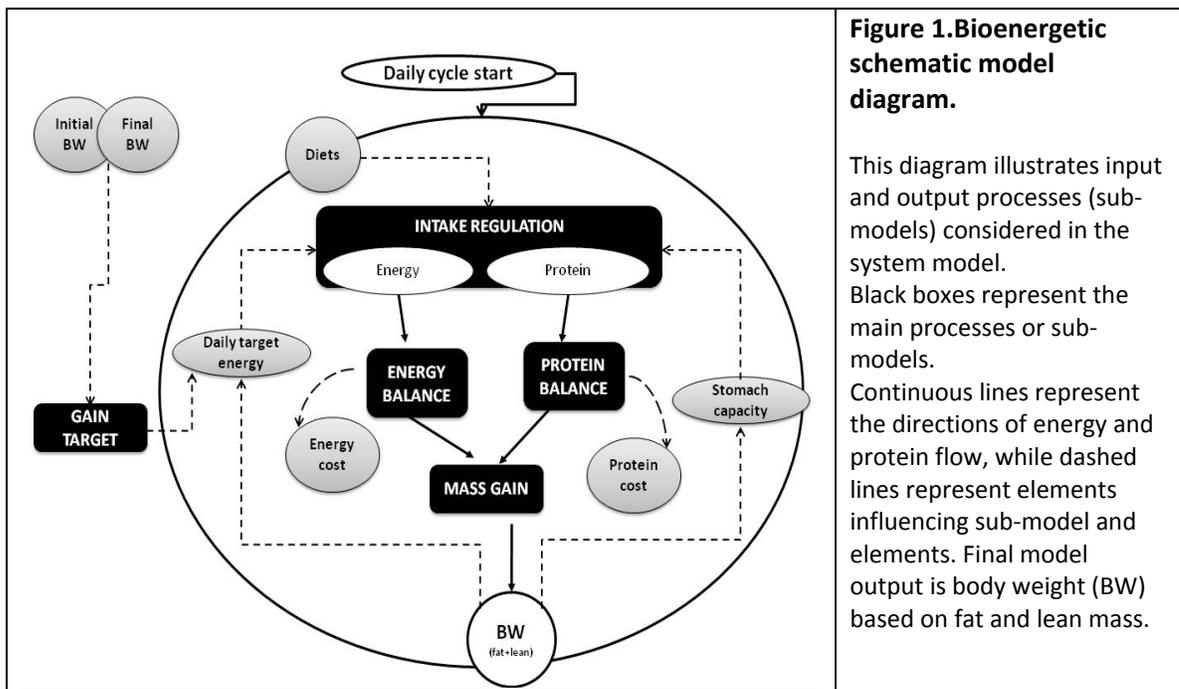
- Intake Regulation,
- Energy Budget,

- Protein Budget,
- Gain Target, and
- Mass Gain.

The main components of the model are on the other hand:

- Diet characteristics (e.g. dry matter, digestibility, metabolizable protein/ energy);
- Maintenance Cost (energy and protein); and
- Efficiencies of Lean and Fat Gain.

The main assumption of the model is that an individual satiates to a target weight (see processes). Fitness maximization therefore occurs inside the limits of the *Gain Target* parameter. Another assumption is that there is no external restriction on the amount of food that an individual can eat. This means that the individual eats until *Stomach Capacity* is reached or simply as much as it wants (i.e. an *Energy Target*). The limitations on growth are therefore the amount of energy and protein in an animal's diet.



#### Model Initialization and schedule

At the beginning of the simulation the initial and final body weight and the initial and final proportion of fat and lean mass are defined. These parameters define the potential body weight per day that is the *Gain Target* (see Gain Target sub-model). The duration of the active period (amounts of days) and the diet composition are also defined. Given those parameters, a daily cycle starts. In each day the total lean and fat mass accumulation is estimated through five processes described below as sub-models.

### Sub-models

#### *Gain Target*

This process determines the animals daily *Target Energy* based on the animal fat and lean weight goals in the annual season. Total *Body Weight* (BW, fat and lean) goals, during the active period, follows a sigmoid curve that describes the potential body weight per day. At lower levels of this curve is the *Initial BW*, while at the upper level of the curve is the *Final BW*. The specific shape of the curve is dominated by two parameters that represent when the early hyperphagia season starts and how fast the individual gains weight. The daily *Target Energy* is estimated by the difference of the potential body weight and the actual body weight. Kilograms of fat and lean targets are expressed in energy to represent the daily *Target Energy*. Because we assume that the 'goal' of the individual is to reach a predetermined body weight, daily *Target Energy* constrains individual intake.

#### *Intake regulation*

We acknowledge that *Intake Regulation* is a complex process guided by numerous interacting components including physical, hormonal and neurological factors (Robbins 1994). Rather than including all of this complexity, where knowledge is limiting, we assume a simplified structure to represent how much food the individual eats during a day. For this we consider two factors. First, a "*Stomach Constraint*" which represents the available space in the stomach and is defined as the difference between the stomach capacity and the stomach fill. We define stomach capacity as a function of the individual body weight and thus it increases during the active period (Robbins 1994). Stomach fill is then simply how much food is in the stomach. Second, is the *Gain Target* which represents the amount of energy that the animal is 'willing' to eat in order to reach the daily *Target Energy*. Depending on the dry matter content and total energy (fat and protein), intake is estimated as kilograms of food. The type of diet and the amount of intake define the amount of metabolizable energy and protein. These are included as inputs in the energy balance and protein balance sub-models.

#### *Energy balance*

*Energy Balance* determines the available energy for growth and is the difference between the metabolizable energy and the maintenance energetic cost. Metabolizable energy is obtained from the Intake regulation process. Energetic cost is represented as the sum of *Basal Metabolic Rate* (BMR), standing cost and protein metabolism. BMR is a function of the individual weight. Standing cost is assessed as an increment of 10% of the BMR (Robbins 1994). Protein metabolism is a function of the metabolic energy supply. In this first version of our bioenergetic model, there is no movement cost (i.e., we are assuming a stationary bear that is fed different diets). This allows for comparison of diets without confounding due to movement costs.

#### *Protein balance*

The *Protein Balance* determines the available protein for growth and is measured as the difference between the metabolizable protein and the maintenance protein cost. Metabolizable protein is obtained from the Intake regulation process. Maintenance requirements are the metabolic fecal nitrogen (MFN) and endogenous urinary nitrogen (EUN). MFN represents the minimal constant losses in feces and depends on the amount of feces and thus digestibility of foods. EUN is related with the protein metabolism and it is expressed as a function of metabolic body weight ( $BW^{0.75}$ ).

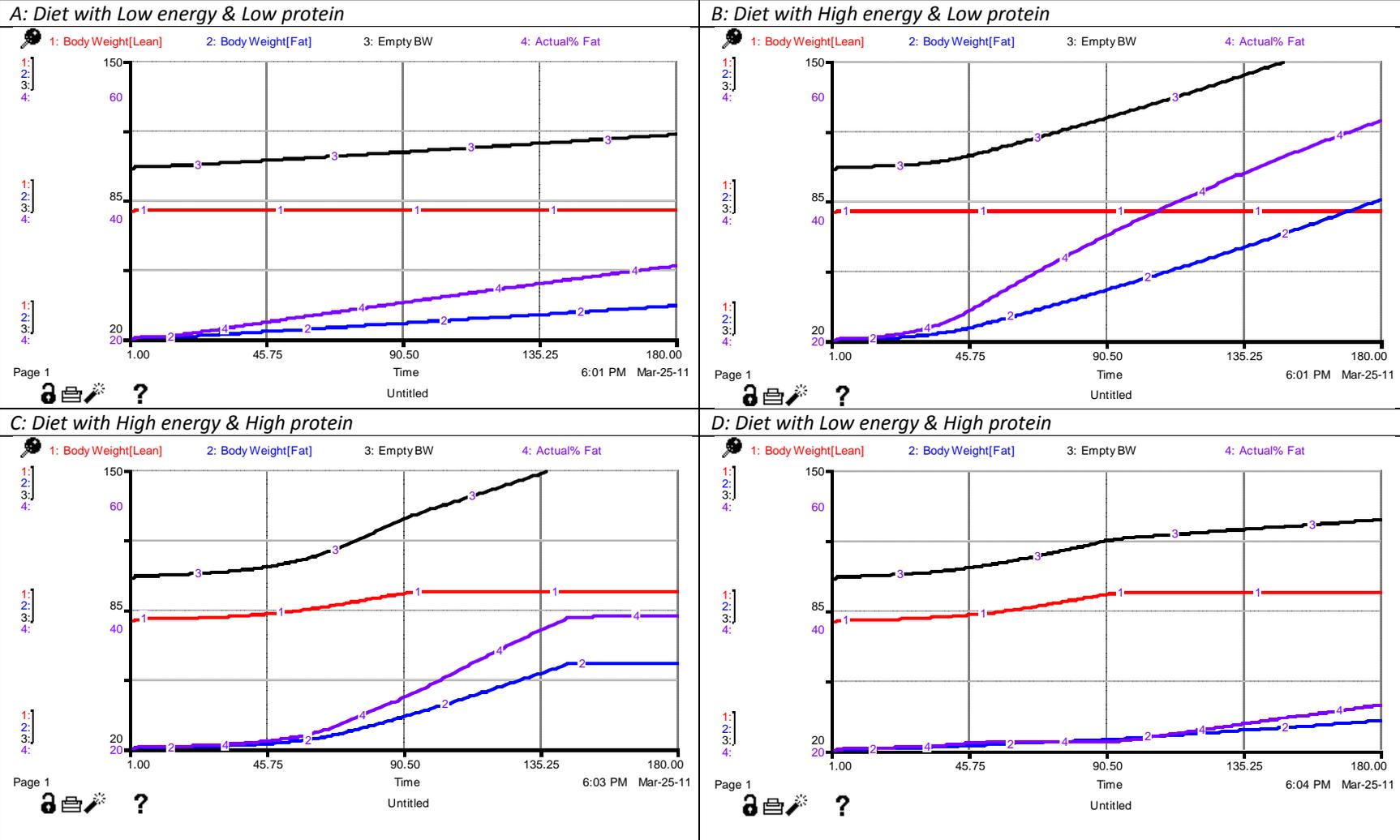
*Mass gain*

*Mass Gain* is the final process that determines how much lean and fat mass will be accumulated in the animal's body per day. This sub-model uses *Energy* and *Protein* balance outputs and daily *Target Energy* to define the kilocalories and protein available for growth after having met maintenance demands. The minimum amount between *Gain Target* and energy and protein available for growth is chosen to determine mass growth. This is because the model assumes that the individual will gain the minimum amount of mass necessary to reach the *Gain Target* even if there is more energy and protein available for growth. The model also assumes that the animal prioritizes the lean target over that of the fat target. Lean gain is determined by the amount of available protein for gain (*Protein Balance*) and energy for gain available (*Energy Balance*). A one kilogram gain in lean mass requires 0.222 kg of protein and 1200 Kcal (Robbins 1994). Fat gain is determined by the remaining energy available after lean gain with a one kilogram gain in fat requiring 9100 Kcal. When the individual is starved (food limited), body lean and body fat are used as an energy source. The animal therefore loses body weight.

**Preliminary Results And Discussion**

Figure 2 illustrates a set of preliminary model outputs demonstrating the effects of four different diet compositions (A. low energy & low protein, B. high energy & low protein; C. high energy & high protein; and D. low energy & high protein) on body mass dynamics over an active season (180 days; den emergence to denning). Impacts of energy and protein are not only in the mass accumulation (kilograms of lean and fat), but also in the time necessary to reach these goals. As expected, in diets with low available protein (scenarios A & B), animals do not develop their lean mass (line 1 [red]). However, they are able to accumulate fat (lines 2 [blue] & 4 [purple]) if energy is present. These model dynamics assume that the animal is an adult. In the case of immature animals, protein deficiencies would affect body size, since protein is the key element of structural growth.

**Figure 2. Preliminary results of the bioenergetic model for grizzly bears. Graphs show body mass accumulation under different diets. Body lean mass, body fat mass and body weight are in kilograms. Actual% Fat represents the proportion of fat in body weight in percentage. Time is in days. Diets are characterized by different amount of energy and proteins.**



### Future Developments (Bioenergetic model expansions and IBMs)

Future developments of the bioenergetic model include incorporation of a hibernation phase and reproduction costs. Given these components we will explore in more detail the effects of different diet compositions on fat accumulation and thus reproduction success in adult female bears.

Following the dietary limitation comparisons, which assume a stationary animal, we will develop a spatially-explicit Individual Based Model (IBM; also called an agent-based model) that links spatial and temporal variations in nutritional quality and availability of critical grizzly bear foods (Nielsen et al. 2010) with our bioenergetic model. The IBM will identify individual behaviours (movements, nutritional condition, etc.), the behaviours or interactions with other bears, and ultimately population processes (Wiegand et al. 1999; Kramer-Schadt et al. 2004; Revilla et al. 2004). The IBM thereby provides an approach for indentifying and predicting spatial and temporal (seasonal inter-annual) variations in such factors as body size, fat composition, reproductive success, density, and thus population dynamics. Traditional models often fail to recognize these individual variations, yet they are quite apparent (e.g., body size differences between females in the mountains of Jasper National Park and that of the adjacent foothills) and important for demographic effects in grizzly bears. Following the incorporation of the bioenergetic model with nutritional landscape models, future management actions, such as changes in forest harvesting and road density limits, or landscape simulations, such as climate change, insects (mountain pine beetle), or fires, can be evaluated for how they influence growth and dynamics of grizzly bear populations. Such information will be critical to assisting with identification of population recovery targets (population size and time horizons for recovery) for threatened grizzly bears in Alberta.

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## CHAPTER 9: ESTIMATED ENERGETIC EXPENDITURE OF GRIZZLY BEARS IN ALBERTA

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### Introduction

The carrying capacity of a landscape for a wildlife species depends on both resource availability and the energetic requirements of the animal. The need for food energy is a “fundamental property of life” (Nagy, 1994), and metabolic rate may be one of the most important variables in ecology (Brown et al., 2004). The balance between energy availability and energy requirements determines how many animals can be supported in a particular area. In the case of potential carrying capacity, an estimate can be made of how many animals the landscape could theoretically support. Our analysis provides an estimate of the energetic expenditure of individual grizzly bears in west central Alberta, using equations from the literature and rates of movement from GPS collar data. Along with data currently being collected regarding calories available on the landscape, this estimate will allow calculation of an energy balance and an approximation of the potential carrying capacity of grizzly bear habitat. A carrying capacity estimate could be used to set population targets for grizzly bear recovery in Alberta.

Basic daily energetic requirements for wildlife include baseline metabolism, thermoregulation and activity (Nagy, 1994). Long-term requirements include energy for growth, reproduction, and denning or hibernation. The published literature includes some direct measurements of the energy used by bears. Weight loss and metabolic rate during winter have been measured under simulated denning conditions for grizzly bears, black bears and polar bears (Watts & Jonkel, 1988; Watts, 1990). Maxwell et al. (1988) recorded the heat budget and weight loss over the winter in two denning black bears in Minnesota. Watts et al. (1991) measured the resting and walking metabolism of two sub-adult polar bears. However, the metabolism of grizzly bears in the non-denning period has not been directly measured.

Metabolic rates of wildlife can be impractical to measure, as animals must be captured and tested under specific conditions. In spite of this, basal metabolic rate (BMR<sup>3</sup>) has been previously measured for a number of species, with some consistent relationships reported, and a number of allometric equations<sup>4</sup> have been derived from the data (Table 1). Analyses in recent studies corroborate the results initially used to establish the equations (Koteja, 1991; Anderson & Jetz, 2005; Clarke et al., 2010). The baseline energy required by an organism can be

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<sup>3</sup> Basal metabolic rate (BMR) is defined as “a measure of the minimal cost of maintenance at a normal body temperature during the usual period of rest, when an adult is post absorptive” (McNab, 1989).

<sup>4</sup> Allometric equations relate a dependent variable (i.e. metabolism) to body mass, and include a mass-independent constant and an exponent, which vary with the species and/or group measured. In other words, metabolic rate = (constant) x (mass<sup>exponent</sup>), or  $y = aM^b$ , and this equation can be transformed into a straight line as  $\log y = \log a + b \log M$ .

estimated from an animal's body mass, across a range of species, in a fairly consistent manner. The energy cost per unit mass decreases with an increase in body mass; in other words, for basal metabolism, larger animals use more energy overall, but less energy per kg than smaller animals.

**Table 1. Published equations derived from measurements of basal metabolic rate.**

Source	Equation	Original Units	Estimate for 136kg animal (kcal/day)
Kleiber, 1932	$BMR = 74.13 * m^{(0.739)}$	kcal/day, weight in kg	2797
Kleiber, 1975	$BMR = 67.61 * m^{(0.756)}$	kcal/day, weight in kg	2773
Hayssen & Lacy, 1985	$BMR = 4.266 * m^{(-0.262)}$	mLO <sub>2</sub> /g/hr	3007
McNab, 1989	$BMR = 4.05 * m^{(-0.288)}$	mLO <sub>2</sub> /g/hr	2099
Munoz-Garcia, 2005	$BMR = 2.19 * m^{(0.70)}$	kJ/day, weight in g	2052
McNab, 2008	$BMR = 0.06 * m^{(0.752)}$	kJ/hr	2495

Based on the consistent relationships observed, published allometric equations have been commonly applied in ecology to estimate basal metabolism when direct metabolic measurements are not possible or practical (e.g. Best, 1982; Bradshaw et al., 1988; Aldama et al., 1991; Clarke et al., 2010) including for the energetics of grizzly bears (Sizemore, 1980; Mattson, 1997; Gau & Case, 1999). The BMR serves as a good approximation for the energetic expenditure of a resting mammal (Aldama et al., 1991), and as a minimum metabolic rate, the BMR provides a baseline to which additional energy expenditures can be added (Robbins, 1993).

Research on metabolism during movement (travel) also shows consistent relationships for animals across a wide range of sizes and body types, suggesting that underlying principles of metabolism during movement may apply over a range of species. Equations derived from direct measurements of the energetic cost of travel show that the energy used can be estimated from body mass, and that the energy consumed per kilogram of body mass decreases with increasing body mass, in a manner similar to BMR (Taylor et al., 1982; Parker et al., 1984; Full, 1989; Kram & Taylor, 1990; Blickhan & Full, 1993; Herr et al., 2002; Alexander, 2004). As with the equations derived for BMR, results obtained by different authors are very comparable (Table2). The metabolic rate per unit time is dependent upon the speed of travel, but the relationship between energy consumption and speed appears to be linear. The slope of the regression between the cost of horizontal movement (kcal/kg/hr) and speed (km/hr) is the net cost, expressed in energy consumed per unit mass per unit of distance moved, or kcal/kg/km

(Robbins, 1993). Because this relationship is linear (unchanging slope), the cost per unit distance is not dependent upon the velocity of movement (Schmidt-Neilsen, 1972, Karasov, 1992; Robbins, 1993). In other words, for most animals, it requires approximately the same number of kilocalories to travel a set distance, regardless of the speed of movement.

**Table 2. Published equations derived from measurements of metabolic rate during movement.**

Source	Order, Class, or group	Parameter	Equation	Original units	Estimate for 136kg animal (kcal/kg/km)
Cohen et al., 1978	Mammals	Net cost of horizontal locomotion	$E = 6.35 * m^{(-0.34)}$	mLO <sub>2</sub> /g/km	0.54
Fedak & Seeherman, 1979	Mammals, birds, and lizards.	Cost of running	$E = 3.89 * m^{(-0.28)}$	mLO <sub>2</sub> /g/km	0.67
Taylor et al., 1982	Mammals	Net cost of locomotion	$E = 10.7 * m^{(-0.316)}$	J/m/kg	0.54
Taylor et al., 1982	Carnivora	Net cost of locomotion	$E = 0.509 * m^{(-0.311)}$	mLO <sub>2</sub> /m/kg	0.52
Garland, 1983	Mammals	Net cost of locomotion	$E = 10.678 * m^{(0.70)}$	kJ/km	0.58
Parker et al., 1984	Elk and mule deer	Net cost of locomotion	$E = 2.97 * m^{(-0.34)}$	kcal/kg/km	0.56
Full, 1989	Mammals, birds, and lizards.	Minimum metabolic energy to move	$E = 10.8 * m^{(-0.32)}$	J/m/kg	0.54

The linear relationship between metabolic rate and walking speed has been directly observed in polar bears (Watts et al., 1991). As with BMR, allometric equations have been applied to estimate energetic cost of transport for a number of species when direct metabolic measurements were not possible (Best, 1982; Garland, 1983; Fancy & White, 1987; Aldama et al., 1991; Covell et al., 1996).

In addition to base metabolism and energy for movement during the active season, the annual energy requirements for bears include the extra calories required to sustain them during denning. The weight gained by bears during each active season provides the calories for metabolism throughout the denning period. A number of authors have measured the annual cycles of summer weight gain and winter weight loss in grizzly bears (Kingsley et al., 1983; Blanchard, 1987; Stringham, 1990; Farley & Robbins, 1995). Patterns of weight change and approximate percentages of weight gained and lost are similar between studies. There is evidence that weight gain by bears in the spring and early summer may be mostly lean body mass, while weight gain in the fall is mostly fat (Hilderbrand et al., 1999). Based on the calories

released by lean and fat tissue, the approximate caloric equivalent of changes in weight can be calculated, and the caloric equivalent of weight lost during denning has been estimated for black and grizzly bears (Maxwell et al., 1988; Watts, 1990; Farley & Robbins, 1995). Metabolism of bears during simulated denning has also been measured directly (Watts & Jonkel, 1988; Watts, 1990; Toien et al., 2011).

The minimum energy requirements for a non-reproductive adult grizzly bear without cubs include basal metabolism, the energetic cost of movement, and the energy required for the denning period. This work was undertaken to estimate the minimum amount of energy required for individual grizzly bears in our study area, in order to apply these energy requirements to an overall energy budget and theoretical carrying capacity for grizzly bear habitat in Alberta.

## **Methods**

### General methods

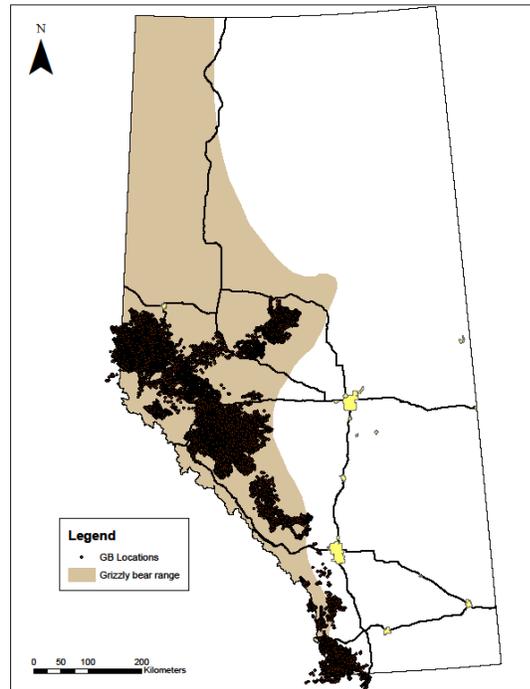
Direct measurements of metabolism in grizzly bears were not feasible for this study. Therefore, we estimated the energy used by bears, based on our available data and the best sources of information from the published literature. Available data for bears in our study included body mass (as measured at the time of capture), GPS collar locations, and approximate denning periods. The daily basal metabolic rate (BMR) of individual bears was estimated from the measured body mass of each bear as applied in an allometric equation. The energy cost per unit of distance (km) was estimated for each individual bear in this study based on body mass, as applied in an allometric equation. The daily energy used for movement was calculated from the distance traveled, as measured between consecutive GPS collar locations. The approximate daily energy used by each bear was estimated from the sum of the base metabolism plus energy used for travel each day. To estimate annual energy requirements, the energy equivalent of weight gained to sustain bears throughout the denning period was added to the sum of daily energy requirements during the active period.

### Study area, capture, and GPS dataset

Data for this analysis were obtained from bears captured in west-central and southern Alberta (Figure 1) between April and October during the years of 2000-2010. Grizzly bears were captured and collared using helicopter aerial darting, culvert traps or foot snares (Cattet et al., 2003a; Cattet et al., 2003b). All capture efforts followed procedures accepted by the Canadian Council on Animal Care (2003) for the safe handling of bears, and in accordance with the American Society of Mammalogists Animal Care and Use Committee (Gannon et al., 2007). Capture procedures were approved annually by the University of Saskatchewan's Committee on Animal Care and Supply and the Alberta Department of Sustainable Resource Development Animal Care Committee. Beginning in 2006, capture efforts focused primarily on the use of culvert traps and helicopter aerial darting, and the use of foot snares was phased out (Cattet et al., 2008). Over the course of the study period some bears were targeted for recapture to replace GPS collars, resulting in multiple capture and sampling events, and some bears were recaptured more than once due to chance.

Once captured and anesthetised, grizzly bears were weighed using a load scale (MSI-7200 Dynalink: Precision Systems Inc., Edmonton, Alberta, Canada). GPS radiocollars and a VHF ear tag transmitter were attached. Tattoos and a micro chip transponder were applied, body length was measured, and hair, blood, and tissue samples were collected. A premolar tooth was

removed for ageing purposes, and teeth were sent to Matson's Laboratory in Milltown, Montana for analysis. Based on counting the number of cementum annuli in extracted premolar teeth (Stoneberg & Jonkel, 1966), bears were aged, assigned a birth year, and classified as adult ( $\geq 5$  years old) or subadult.



**Figure 1. Grizzly bear location data used for this study.**

GPS location data from 2000-2010 were available for 91 adult bears. Several types of GPS collars were used, including Telonics (ARGOS), Televilt (Simplex, RC, TELLUS1, TELLUS2, TELLUS2UHF, and SatLink) and Advanced Telemetry Systems (ATS) collars. Programmed fix rates in the initial dataset ranged from 20 minute intervals to 12 hours between fixes. Among individual bears, the number of locations (successful GPS fixes) per day varied from 1 to 72, the total number of days with location data ranged from 2 to 788, the total number of locations varied from 4 to 9804, and the number of years of data for individual bears ranged from 1 to 4. These differences in location frequency and quantity between individual bears were accounted for in the final analysis, and are addressed in Data processing.

#### Body mass calculations

Data from bears without measured capture weights were not used for this analysis, as the accuracy of estimated weights is uncertain. Due to the nature of the capture season, almost all bears (78) in our study had a measured spring weight from at least one year, and some bears had more than one measured weight during the study period. However, relatively few bears had measured weights from the summer and fall, and none had measured weights from all three seasons within one year. Bears gain a significant amount of body mass during the summer and fall of each year, and using the spring weight for energetic calculations throughout the active seasons would likely result in a significant underestimation of energy use. Time periods relevant to resource selection and energy availability have been previously described for bears (see Nielsen et al., 2004), and these seasons were applied to patterns of weight change for bears

in our study.<sup>5</sup> Differences were estimated as mean changes across each season; therefore, weights were adjusted at the midpoints of the seasons (Tables 3 and 4). Changes in body mass were predicted based on our data and values reported in the literature (see Results and Discussion).

Where available, the measured body mass from the capture date closest in time to the location points was used for estimations. If a measured weight was not available from the appropriate season, an adjusted weight was applied for location points during that season, to reflect predicted changes in body mass. For example, measured spring weights were used from den emergence throughout the hypophagic season to the midpoint of early hyperphagia (July 12<sup>th</sup>), at which point the weight was adjusted, and another adjustment was applied at the midpoint of late hyperphagia (September 26<sup>th</sup>) through to den entry in the fall (see Tables 3 and 4). However, if a measured weight was available from the early or late hyperphagic seasons, the actual weight was used instead of the adjusted spring weight, and measured summer or fall weights were also used to estimate any missing weights for hypophagia or early hyperphagia. If no measured weights were available for the year of location data, values from the previous year were used. In this way, the most accurately known body weights were used for calculations, and all estimations were based on measurements or adjustments of measured weights from within two years of the location data. If measured weights were not available from within two years, the location data were not used in the analysis.

**Table 3. Seasonal adjustments of body mass in female bears.**

Date range	Body mass used for estimations
Den emergence to July 12 <sup>th</sup>	Spring (hypophagia) weight.
July 13 <sup>th</sup> to September 26 <sup>th</sup>	Summer (early hyperphagia) weight: spring weight increased by 13%.
September 27 <sup>th</sup> to den entry	Fall (late hyperphagia) weight: summer weight increased by 33%.

**Table 4. Seasonal adjustments of body mass in male bears.**

Date range	Body mass used for estimations
Den emergence to July 12 <sup>th</sup>	Spring (hypophagia) weight.
July 13 <sup>th</sup> to September 26 <sup>th</sup>	Summer (early hyperphagia) weight: spring weight decreased by 12%.
September 27 <sup>th</sup> to den entry	Fall (late hyperphagia) weight: summer weight increased by 32%.

#### Selection of equations for estimations

Using equations with exponents and constants derived from data collected on the same or similar species, genus, or family as the study animals increases the accuracy and usefulness of the estimations. To select an equation for estimation of the basal metabolic rate, we reviewed the literature to compile a list of equations derived from analysis of measured BMR values.

<sup>5</sup> Hypophagia: from den emergence to June 14<sup>th</sup>; early hyperphagia: from June 15<sup>th</sup> to August 7<sup>th</sup>; late hyperphagia: from August 8<sup>th</sup> to den entry.

Studies included new measurements and/or analysis of previously published data, and the list of equations was narrowed down to those specifically analyzing data from species of Carnivora. After review, the equation  $BMR = 2.19 * m^{(0.70)}$  as derived by Munoz-Garcia and Williams (2005) was selected, based on the following criteria:

1. The analysis was one of the most recently published derivations of BMR equations.
2. The dataset included Ursidae species, with data from grizzly bears, black bears, polar bears, and an additional Ursidae species (*Melursus ursinus*) not included in other studies.
3. Data included animals across the entire relevant range for mass (this addresses problems reported with scaling equations to larger masses).
4. The dataset included more species than other similar studies, and covered a wider range of food habits. A range of food habits is important in applying carnivore data to grizzly bears, due to their omnivorous nature.
5. Data included some larger carnivore species (cougar and wolf) that are found within grizzly bear habitat in Alberta; these species were not included in similar studies.
6. The analysis included the least number of aquatic mammals (two species of otter) as compared to other studies. Marine mammals may have a higher metabolism than terrestrial mammals (Lavigne et al., 1986; McNab, 1988).

We reviewed the literature and compiled a list of equations derived from analysis of measured metabolism during locomotion. Data are more limited for metabolism of movement than for BMR, and it was not appropriate to limit equations to those derived from carnivore data. After review, the equation  $E = 10.7 * m^{(-0.316)}$ , as derived by Taylor et al. (1982) was selected, based on the following criteria:

1. Data included animals across the relevant range of mass.
2. The dataset included more mammal species than other similar studies, and did not include birds or lizards, which were included in some other equations.
3. The species included covered a wider range of food habits.
4. Data included measurements on a wolf (*Canis lupus*).
5. This equation was previously applied for estimates in other carnivores (e.g. Aldama et al., 1991; Covell et al., 1996).

#### Data processing

Prior to analysis and estimation of energy values, data were reviewed, and some limitations were applied to the dataset to improve the quality of the results. All GPS data contain errors due to GPS accuracy and missed fixes, and data limits are usually applied to minimize error in the dataset. The removal of datapoints to reduce location errors must be balanced with the information lost and the potential bias created by reducing the size of the dataset.

Applying limits to the data based on the dilution of precision (DOP) value of GPS locations is a standard procedure to minimize inaccurate locations in the dataset. Lower DOP values reflect a higher accuracy, and GPS locations with DOP values greater than 6 are considered questionable (Ganksopp & Johnson, 2007). Locations with a DOP value of greater than 6 were excluded from the dataset in this analysis.

In the case of a stationary animal, small (false) movement distances may be measured between GPS fixes due to low GPS accuracy. As a result, travel distances could be overestimated. This error could be reduced by applying a minimum distance above which movement is considered “true” movement. However, it is problematic to determine a standard minimum distance, as the accuracy of each GPS collar location depends on the individual collar, the canopy cover, the body position of the bear, and other factors. The error in measured distance could also cause other travel distances to be underestimated. A certain amount of location error is inherent in GPS data, and because the error is considered random, a minimum distance was not applied in this analysis.

The number of GPS locations collected per day affects the measurement of distance traveled: as the time interval between GPS locations increases, there will be a greater difference between the straight line distance measured and the actual path traveled by the bear. Our dataset included a range of collar programs and fix rates. The initial dataset was reviewed in order to investigate how much the measured distances change with a change in the number of fixes. We calculated the average daily distance traveled for each bear, using days where the minimum number of successful GPS fixes was 1, 4, 6, 8, 10, 12, and 15. The average daily measured distance increased with an increase in number of fixes per day, with a small correlation ( $r = 0.25$ ) between the number of fixes and the measured distance. The largest increases in average measured daily distance occurred as the minimum number of fixes increased from 1 to 4, and 4 to 6, and the correlation factor also dropped slightly ( $r=0.21$ ). Above a minimum of 6 fixes per day, measured distances did not change significantly. In order to balance the accuracy of distance measured with maintaining sample size, 6 locations per day was chosen as the minimum criteria for inclusion in daily energy summary calculations. In addition, to minimize variation, daily overall averages were only calculated for bears with  $\geq 30$  days of locations within one year.

Movement rates of grizzly bears have been observed to decrease below normal for an average of 28 days following capture events (Cattet et al., 2008). In order to better reflect normal energy use, GPS locations were excluded from analysis until 28 days post-capture for each capture event.

The metabolism of sub-adults may be significantly higher than the BMR of adults (Corts & Lindzey, 1984; Lavigne et al., 1986; Watts et al., 1991; Robbins, 1993); therefore only data from adult bears (five years of age or older at time of capture) were used in the analysis.

Many studies report metabolism in  $mLO_2$  or  $LO_2$  consumed per minute or per second, based on measurements of respiration rate to determine energy use. When changing to direct energy units, conversion factors range from 4.69 – 5.05 kilocalories/ $LO_2$ , depending on the ratio of carbohydrates and fat burned. Most studies have applied an intermediate value of 4.8 kcal/ $LO_2$  (Parker et al., 1984; Hayssen & Lacy, 1985; McNab, 2008), and this value was used for converting equations in this study. Kilojoules were converted to kilocalories based on the standard conversion factor of  $1\text{kcal} = 4.185\text{kJ}$ .

### Analysis

Energy estimations for BMR and energy for movement were calculated during the “active” or non-denning period for each bear, as determined from estimated denning periods. The start and end dates of denning periods for each bear were estimated based on movement patterns,

movement distances, proximity of GPS locations to known dens, and changes in GPS fix rates. If denning periods were unknown, the average dates for start and end of denning (calculated separately for male and female bears) were applied for that year.

Basal metabolic rate in kilojoules per day (kJ/day) was estimated for each bear using the equation  $BMR = 2.19 * m^{(0.70)}$  (see Selection of equations for estimations). The mass used for calculations was either the most current measured weight or the weight adjusted by season (see Body mass calculations). Results were converted to kilocalories (kcal) per day and kcal/hr.

Measurements of distance traveled were selected as a more accurate representation of movement than velocity, as velocities<sup>6</sup> were likely to fluctuate widely during the time elapsed between GPS fixes, and net cost of locomotion has been shown to be independent of velocity (see Introduction). The energy required for movement in Joules/metre/kilogram (J/m/kg) was estimated for each bear using the equation  $E = 10.7 * m^{(-0.316)}$ . As for BMR estimations, the mass used for calculations was either the most current measured weight or the weight adjusted by season. Results were converted to kcal/km. For all location data, the distance between two consecutive GPS collar points was calculated, and location data from  $\geq 28$  days after a capture event were used for analysis (see Data processing). The energy in kcal/km was multiplied by the distance traveled (km) to estimate the total energy (kcal) used for movement between two collar points.

Using the sum of the energy used for movement between two points, the hourly BMR, and the time difference (hours) between two locations, an energy value was calculated for each GPS collar location. This energy value reflects the cost of maintaining basal metabolism for the time period between the two locations, plus the cost of movement from the last location point to the current point. A dataset was created in which each individual bear location has an associated energy value.

For days when there were  $\geq 6$  GPS fixes (see Data processing), daily energy summaries were calculated from the sum of the daily BMR plus the energy for movement for the total distance traveled that day. Daily energy averages were completed for individual bears if  $\geq 53$  days of data were available within the non-denning period (one quarter of the average non-denning period).

Spring weights and patterns of weight gain were available for bears in our study area (see Body mass calculations), and the caloric equivalent of measured or predicted summer/fall weight gain was calculated to estimate energy required for denning. In bears, stored fat contains approximately 9.11 kilocalories per gram, while lean tissue contains approximately 1.2 kcal/g (Robbins 1993; Farley and Robbins 1994). Based on the assumption that weight gain by bears in the spring and early summer is approximately 70% lean body mass, while weight gain in the fall is approximately 80% fat (Hilderbrand et al., 1999), the caloric equivalent of weight changes was calculated. For female bears, the weight gain from hypophagia to early hyperphagia (EH) was converted to calories as follows:

$$\text{Caloric equivalent} = (\text{weight gain} * 0.70 * 1.2\text{kcal/g}) + (\text{weight gain} * 0.30 * 9.11\text{kcal/g}).$$

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<sup>6</sup> Average velocity traveled was calculated from distance traveled divided by time between GPS fixes.

Similarly, the weight gain from EH to late hyperphagia was converted using a ratio of 80% fat to 20% lean tissue. For male bears, it was assumed that the initial mass lost in spring and early summer was regained as 70% lean tissue/30% fat, and the remaining weight gain from EH to LH was 80% fat to 20% lean tissue. For each bear, the total calories required for denning were divided by the number of days in the active season (as calculated from denning dates) to obtain the approximate number of kcal/day required during the active season to gain weight for denning.

Annual energy requirements include daily energy costs (BMR and movement) during the active season plus the extra calories required for denning. It was not possible to sum the daily energy values over the course of the active season, as the large number of days with missing data would result in an underestimation of annual requirements. To account for missing days, the average daily energy estimate for each bear was multiplied by the number of days in the active season, and this total was added to the calories for denning to estimate annual energy requirements.

After completion of landscape energy models, weekly, biweekly, monthly, and/or seasonal energy requirements will be estimated for each bear; the time periods will correspond with the timing of the changes in the energy model. Additional analyses will include a spatial component, such as the energy used within a seasonal home range, bear management unit, or bear conservation area.

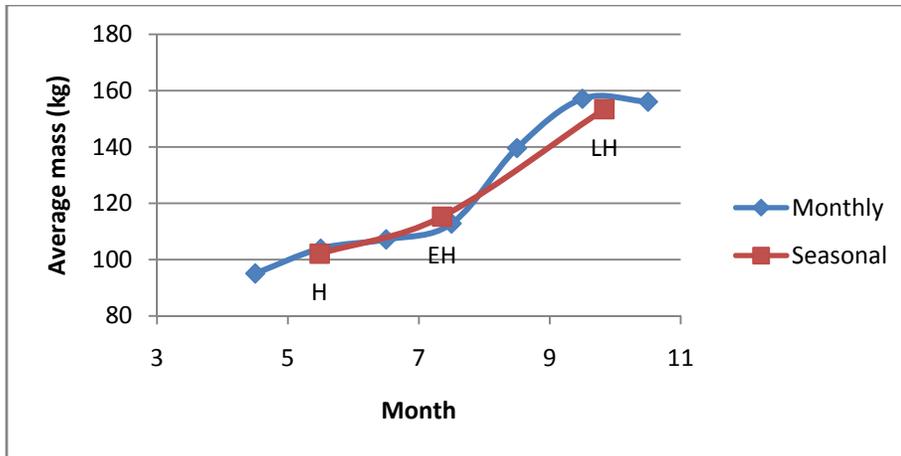
## Results

Fifty-two individual adult female bears had body mass data, with a total of ninety-five weight measurements across all bears, seasons and years. Average body mass across all females increased by 13% from hypophagia (H) to early hyperphagia (EH), and the mean weight in late hyperphagia (LH) was about 33% higher than the EH weight (Table 5). These average weight changes were applied to adjust seasonal weights for analysis of female bears (see Body mass calculations). Over the course of the entire active season (spring to fall, H to LH), the total average increase across all adult females was 50% of the spring (H) weight, and for six individual female bears with measured spring and fall weights from the same year, the average increase in body mass was 45%.

**Table 5. Seasonal changes in measured body mass of female bears. N=number of body mass measurements, rather than number of individual bears.**

Season	Mean weight (kg)	N	Mean change (%)	
H (spring)	102.12	59	LH to H	-33.4
EH (summer)	115.29	16	H to EH	+12.9
LH (fall)	153.43	20	EH to LH	+33.1

Similar patterns of change were observed when weights were summarized by month (Figure 2); however, monthly sample sizes were too small for a full analysis. For comparison, seasonal values are plotted at the midpoints of each season.



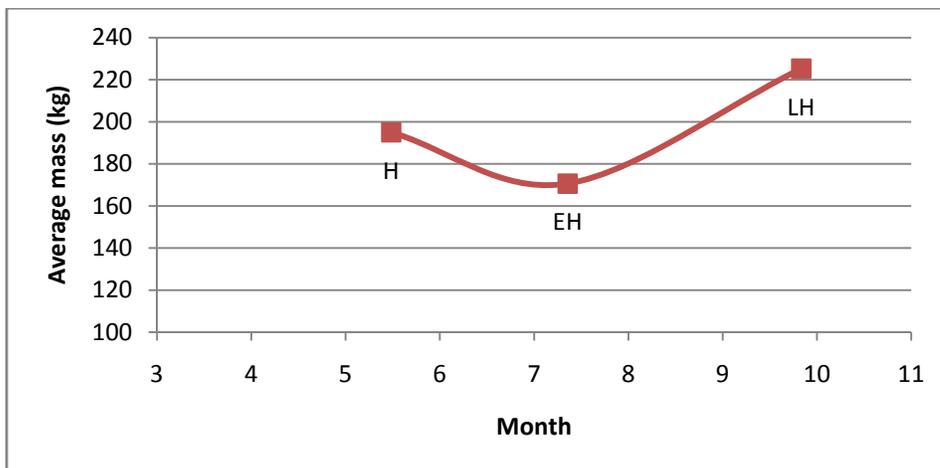
**Figure 2.** Mean seasonal and monthly measured capture weights in adult female bears.

For adult males, 41 individual bears had body mass data, with a total of 58 weight measurements across all seasons and years. Average body mass in males decreased by 12% from hypophagia (H) to early hyperphagia (EH), and the mean weight in late hyperphagia (LH) was about 32% higher than the EH weight (Table 6).

**Table 6.** Seasonal changes in measured body mass of male bears. N=number of body mass measurements, rather than number of individual bears.

Season	Mean weight (kg)	N	Mean change (%)
H	195.03	49	LH to H -13.44
EH	170.68	4	H to EH -12.49
LH	225.30	5	EH to LH 32.01

Over the course of the entire active season (spring to fall), the average total weight increase was 16% of the spring (H) weight. Weights were not summarized by month for male bears, due to the lack of data.



**Figure 3.** Seasonal averages of measured captured weights in male bears.

Both spring and fall weights from within the same year were available for six female bears and one male bear. An analysis of the measured fall weights versus values predicted by using adjustment values (predicted fall weight = spring weight plus 50%, see Body mass calculations) showed no significant difference between measured and predicted fall weights for the six females (paired t-test;  $p=0.53$ ). The measured (278kg) and predicted (255kg) values for the male bear also compared closely.

Location data were available for 91 adult bears across the years of 2000 to 2010. After applying criteria to ensure data quality (see Data processing), collar location data with measured weights from location years were available for 75 individual adult bears, including 47 females and 28 males.

Estimated BMR values for 47 female bears ranged from 1390 kcal/day to 2868 kcal/day across the active season, with a mean of 1921. Estimations of total daily energy (BMR plus energy for movement) were calculated for 22 individual female bears with  $\geq 53$  days of data (see Analysis). The mean estimate for total daily energy for individual females was 2285 kcal/day, with a range of 1926 to 3173 (Table 7).

For comparison of females with/without cubs, data for females with young of different ages were grouped due to small sample sizes. Average total daily energy use estimated for females without young (or reproduction status unknown) was kcal, and females known to be with young (cubs of the year, yearlings, or two year olds) averaged kcal/day. These estimates do not take into account the energetic cost of lactation.

**Table 7. Daily summary results for individual females across all seasons (N=22).**

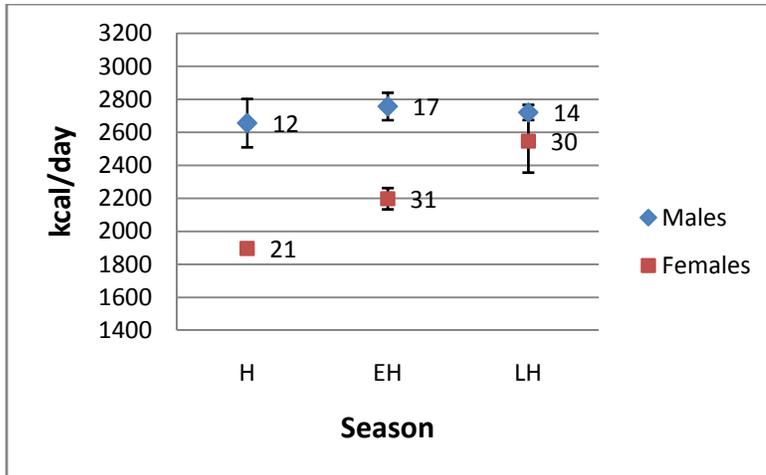
Females	Average BMR (kcal/day)	Average daily distance traveled (m)	Average energy for movement (kcal/day)	Average total daily energy (kcal/day)
Mean	1881	5969	405	2285
Minimum	1598	3638	238	1603
Maximum	2460	11872	950	2926

Estimated BMR values for 28 male bears ranged from 1390 kcal/day to 3436 kcal/day across the active season, with a mean of 2397. Estimations of total daily energy for 11 individual male bears with  $\geq 53$  days of data ranged from 2003kcal/day to 3527kcal/day, with a mean of 2819kcal (Table 8).

**Table 8. Daily summary results for individual males across all seasons (N=11).**

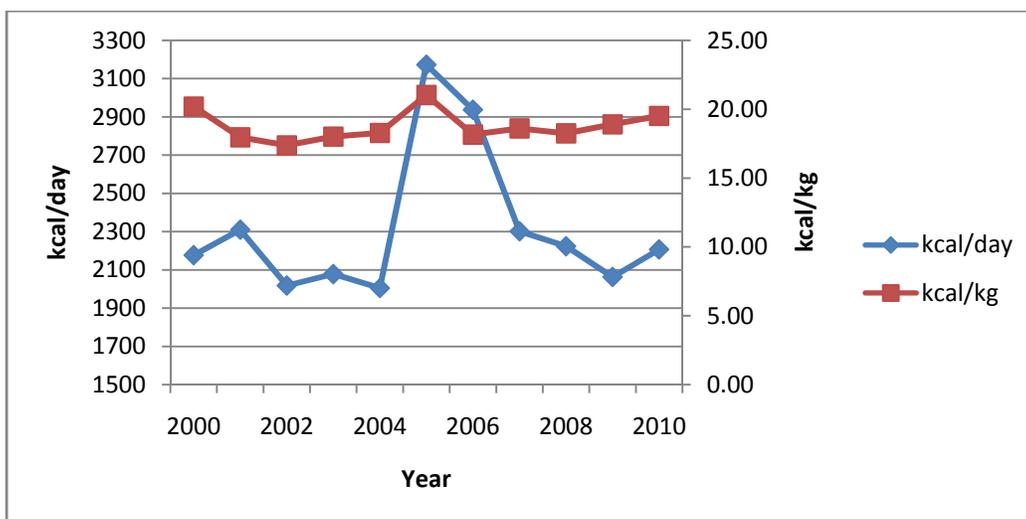
Males	Average BMR (kcal/day)	Average daily distance traveled (m)	Average energy for movement (kcal/day)	Average total daily energy (kcal/day)
Mean	2258	6937	561	2819
Minimum	1673	4609	317	2003
Maximum	2946	9290	744	3527

Seasonally, there appeared to be a steady increase in estimated energy requirements for females from spring to fall, while average seasonal energy estimates for males did not change significantly (Figure 4). Averages for each season were calculated across all individuals for all years (2000-2010).

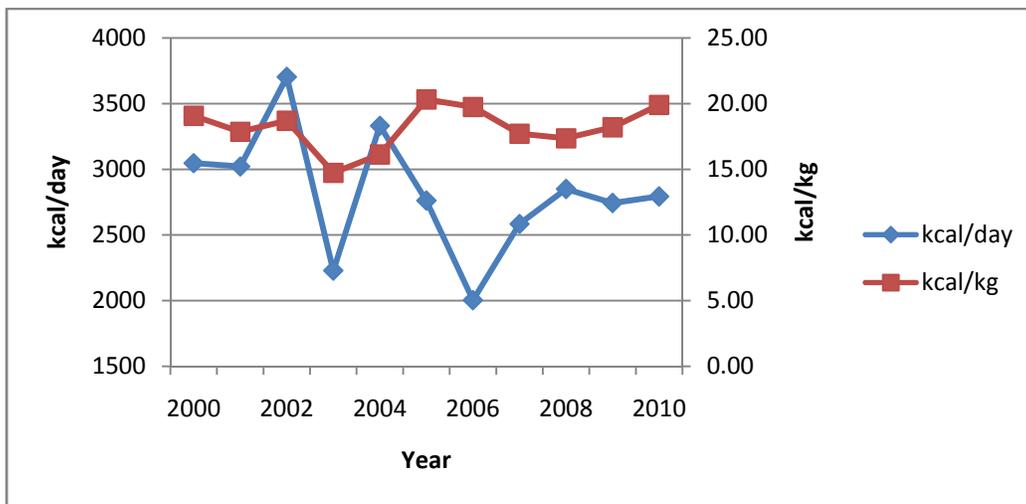


**Figure 4. Seasonal averages of total daily energy requirements across all years. Values next to points indicate the number of individual bears in each dataset.**

From year to year, the average daily energy requirement appeared to fluctuate (Figures 5 and 6). However, data from different years were often from different bears. Therefore, results must be interpreted in the context of random differences in body mass of individual animals captured each year. When total daily energy use (kcal/day) values were standardized to kilocalories per kilogram (kcal/kg), inter-annual variation was greatly reduced.



**Figure 5. Average daily energy use by year for female bears.**



**Figure 6. Average daily energy use by year for male bears.**

The average estimated caloric equivalent of weight gained for denning was 380,265 kilocalories for females. This amounts to a requirement for an extra 1811kcal/day during the active season, or 3092kcal/day if it is assumed that all weight gain takes place during early and late hyperphagia. Based on the average denning period for females (166 days), the average weight gain would provide for a metabolic rate of 2290 kcal/day during denning. For male bears, the average calories required for weight gain were estimated at 365,554 kcal, the equivalent of an extra 1584 kcal/day across the entire active season, or 2972 kcal/day during hyperphagia alone. Applying the average denning period for male bears in our study (154 days), this predicted weight gain would provide an average of 2358 kcal/day during denning.

Annually, we estimated that female bears would require an average of 859,181 kcal in total. Over the course of the active season, this annual requirement translates to an average of 4048 kcal/day for the costs of BMR, movement, and weight gain for denning. For males, the average total annual requirement was 972,317 kcal, or 4217 kcal/day.

Estimates from this study for an individual bear (G251) weighing 136kg were compared with previously published measurements for similarly sized bears (Table 9). Previously published methods were also applied to calculate the equivalent estimate for a 136kg bear. The BMR estimate for a 136kg bear in our study was 2053 kcal/day, and BMR plus movement was 2621 kcal/day. Caloric requirement for estimated weight gain for denning was 328,738 kcal, or an extra 1558 kcal/day during the active season, bringing total daily requirements up to 4179 kcal/day. The predicted weight gain would provide calories for a metabolic rate of 1980 kcal/day over the course of an average denning period.

**Table 9. Comparison of previously published measurements and estimation methods with results from this study.**

Source	Species	Body mass (kg)	Method	Parameter	Value	Units
This study	Grizzly bear	136	Estimation using allometric equation.	BMR	2053	kcal/day
Mattson, 1997	Grizzly	136	Equivalent estimation using allometric equation.	BMR	2266	kcal/day
Gau and Case, 1998	Grizzly	136	Equivalent estimation using allometric equation.	BMR	4982	kcal/day
Watts & Jonkel, 1988	Grizzly	135	Measurement during simulated denning.	Least observed metabolic rate	1209	kcal/day
Watts & Jonkel, 1988	Grizzly	135	Calculated from metabolic measurements during simulated denning.	Standard metabolic rate	1958	kcal/day
Watts et al., 1991	Polar bear	125	Measurement during rest.	Resting metabolic rate	2626	kcal/day
This study	Grizzly	136	Estimation using allometric equation.	Energy for movement	74	kcal/km
Hurst et al., 1982	Polar	154	Measurement during walking on treadmill.	Energy for movement	184	kcal/km
Watts et al., 1991	Polar	125	Measurement during walking on treadmill.	Energy for movement	160	kcal/km
This study	Grizzly	136	Estimation from equation.	BMR plus movement	2621	kcal/day
This study	Grizzly	136	Caloric equivalent of estimated weight gain.	Extra calories required for denning	1558	kcal/day
This study	Grizzly	136	Calories supplied by weight gain divided by the denning period (days).	Calories available per day during denning.	1980	kcal/day
This study	Grizzly	136	Estimation (see above).	Total daily requirement: BMR, movement, and calories for denning	4179	kcal/day
Sizemore, 1980	Grizzly	136	Equivalent estimation using multiple of BMR.	Daily maintenance energy	3903	kcal/day
Mattson, 1997	Grizzly	136	Equivalent estimation using a multiple of BMR.	Daily energy	3172	kcal/day
Gau and Case, 1998	Grizzly	136	Equivalent estimation using multiple of BMR.	Daily energy requirements	9964	kcal/day

## Discussion

Body mass was the major determinant of BMR in our study; therefore, careful consideration of body mass data was required. For the majority of bears in our study, measured weights were only available from the spring, but using the spring weight for calculations throughout the summer and fall would likely result in an underestimation of energy use. The use of seasonally adjusted weights prevents this underestimation, but using predicted (rather than measured) weights also introduces another source of error. Therefore, it is important that methods used to adjust weights are well supported. For female bears, the values used for weight adjustments checked well in internal data reviews. Sample sizes for seasonal weights were considerably smaller for male bears, and average weight changes were compared to previously published results before being applied to adjust body mass values in the analysis.

The average increase in body mass from spring to fall for all females across all years in our study (50%) was very close to the mean weight increase (45%) observed in a direct comparison of measured spring and fall weights (from within the same year) for six individual female bears. In an analysis of measured fall weights versus predicted fall weights for these six individuals, there was no significant difference between actual measured and predicted values. For males, only one bear had both a spring and fall weight from the same year; the predicted and measured values were very close but an analysis was not possible.

Our body mass data show changes in weights from between seasons that are consistent with patterns previously reported in the literature. Adult female grizzly bears in the Yukon and Northwest Territories gained between 40-70% of their spring weight from spring to fall, depending on age (Kingsley et al., 1983). For three different bear populations in the Yukon, average fall weights of females were 22-60% greater than average spring weights (Stringham, 1990). Over three years of data collection, Hilderbrand et al. (1999) observed average weight increases of approximately 17% from spring to summer and 36% from summer to fall for female brown bears on the Kenai Peninsula in Alaska. These results compare well with the values of 13% and 33% that were observed in this study and subsequently applied in seasonal body mass adjustments

For male bears, Kingsley et al. (1983) reported an increase of 28% from spring to fall, and average fall weights reported by Stringham (1990) were 19 to 42% greater than average spring weights. These values compare well with the 32% increase from spring to fall observed in this study. Our data indicated that in contrast to the weight gained by females from spring to summer, male bears lost about 12% of their spring weight from den emergence to early hyperphagia, and this value was applied to adjust male weights by season. Male black bears in Minnesota lost about 11% of their spring weight between den emergence and early summer (Noyce & Garshelis, 1998). Blanchard (1986) also reported that adult bears lost weight from den emergence through July, regaining emergence weight by August.

There are some limitations to applying BMR equations, since data are based on laboratory measurements with specific criteria not met in the field.<sup>7</sup> In spite of the strong relationships observed between BMR and body mass, many authors report that a considerable amount of the variation in metabolic rate is not explained by mass alone, and other factors must be considered including food habits, taxonomic affiliation or phylogeny, climate or temperature, habitat,

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<sup>7</sup> BMR equations assume a thermoneutral environment and a post-absorptive state.

behaviour, food availability, and home range size (Nagy, 1994; McNab, 2000; Anderson & Jetz, 2005; Munoz-Garcia & Williams, 2005; Bozinovic, 2007; Clarke et al., 2010). However, separating species into related groups often improves both the significance of the derived equations and the amount of variation explained by body mass (Hayssen & Lacy, 1985; Nagy, 2005). Other authors have expressed concerns with applying allometric equations for large species (Packard & Birchard, 2008). Applying established equations for estimating BMR is likely most appropriate when based on data from species with ecological characteristics similar to that of the species in question, and many of the problems described above were addressed during the selection of the particular allometric equations used for estimations. Previously measured metabolic rates from black bears and grizzly bears (Maxwell et al., 1988; Watts & Jonkel, 1988) were not directly applied to estimate BMR for this study, as measurements were taken during simulated denning, rather than during the active (non-denning) period. Metabolic measurements from resting and active polar bears (Watts et al., 1991) were also not directly applied, based on the small amount of data available (measurements on two sub-adult polar bears) and because of the potential for differences between grizzly bears and polar bears (diet, climate, and habitat) to impact metabolic rates. The use of equations provides estimations rather than actual measured values for metabolism, but it is a widely accepted method for metabolic estimations, and measured values often compare well to predicted metabolic rates. When compared with values predicted by previously published equations, measured BMR values for cougars were within 10-20% of the predicted BMR (Corts & Lindzey, 1984), and BMR measurements in polar bears were within 7% of predicted values (Watts et al., 1991).

The estimate of BMR from a 136kg bear in our study is close to the standard metabolic rate reported by Watts and Jonkel (1988) for a similar (135kg) grizzly bear measured during simulated denning, and higher than the lowest metabolic rate measured during denning. However, BMR values from this study are significantly lower than some previously published BMR estimates. To estimate the BMR for grizzly bears in the Northwest Territories, Gau and Case (1998) used the formula from McNab (1988) for vertebrate-eating carnivores, and Mattson (1997) estimated total energy expenditures of adult grizzly bears in Yellowstone using the equation for carnivore basal metabolism from McNab (1989). Animals with a vertebrate-eating habit diet are reported to have higher metabolic rates than omnivores and herbivores (McNab, 2000), and BMR estimations for vertebrate-eaters are probably not appropriate for the omnivorous grizzly bear population in our study area. Recently, Toien et al. (2011) measured the BMR in three black bears one month after denning, and reported a mean value of 0.276mLO<sub>2</sub>/g/hour, which translates to a value of 4324kcal/day for a 136kg bear. This value is considerably higher than that calculated in this study. Metabolic rate per unit mass is known to decrease with increasing mass, and the weight range in the above study of black bears (34 to 104kg) was considerably lower than the bears in our study. BMR has not been measured on non-denning grizzly bears, or on bears within the weight range of those in our study, so the expected range of BMR is unknown. Regardless, these results suggest that BMR may have been underestimated in this study.

Estimates of energy for movement in this study are also significantly lower than those reported for sub-adult polar bears. However, it may be inappropriate to directly compare results from this study with polar bear results; polar bears are reported to be relatively costly walkers compared to other large quadrupeds (Best, 1982; Hurst et al., 1982), and differences in thermoregulation requirements and food habits suggest that metabolic rates of grizzly bears may not be comparable to polar bears. In addition, data used for analysis in this study were

from adult bears only ( $\geq 5$  years of age), and sub-adult animals are known to have a higher metabolism than adults. Unfortunately, there are no previously published measurements of grizzly bear metabolism during movement; therefore, it is unknown how estimated values in this study may compare with the actual energy used for travel. To account for the energy used for activity and movement, some studies apply a factor to the BMR, with the assumption that the daily energy expenditure is a relatively constant multiple of the BMR (Sizemore, 1980; Mattson, 1997; Gau and Case, 1999; Brown et al., 2004). A multiplier is usually applied in the absence of movement or activity data, but it is often arbitrary, and it does not take into account specific movement rates, travel distances, or activity levels. In this study, the availability of measured travel distances provides an opportunity to more accurately estimate the energy used for movement, and the extensive evidence in the literature supporting the use of allometric equations does suggest that these estimates are an appropriate method of approximating energy use. Aldama et al. (1991) applied measured travel distances and the equation from Taylor et al. (1982) to estimate the energetic cost of movement in Iberian lynx, and Covell et al. (1996) used similar methods to estimate the energy cost of movement in swift foxes. In their study of cougars, Corts and Lindzey (1984) reported that the average measured metabolism during walking was within 3% of that predicted by an allometric equation published by Taylor et al. (1970).

Metabolism has been measured on grizzly bears during simulated denning (Watts & Jonkel, 1988); however, data were limited ( $N=2$ ), and it is difficult to extrapolate these results to our dataset. Toien et al. (2011) recently measured the metabolism of five black bears during simulated denning; results were published after this study was completed, and therefore were not incorporated into this analysis. Other authors have estimated the metabolic rate of denning bears by calculating the caloric equivalent of the mass lost over the course of the winter, rather than the mass gained during the active season. Fall weights were not available for the majority of bears in this study, but spring weights were measured at least once for most of the bears. Calories used for metabolism during denning are entirely provided by energy consumed during the active season. Therefore, the extra calories required for the weight gain relate directly to energy availability on the landscape, and to the overall energy budget. In addition, weight gain in females during the summer is not affected by gestation, while weight loss in females can be highly variable during denning, depending on gestation and lactation requirements. For these reasons, the caloric equivalent of mass gained was used to estimate energy requirements for denning. The estimated calories required for a 136kg female bear to gain weight for denning translates to an average daily metabolism of 1980 kcal/day during the denning period. This value is in excellent agreement with the standard metabolic rate (1958 kcal/day) reported by Watts and Jonkel (1988) for a 136kg bear in a simulated den. Based on the caloric equivalent of mass lost during denning, Farley and Robbins (1995) reported a metabolic rate of 51 kcal/kg<sup>0.75</sup>/day, equivalent to 2031 kcal/day for a 136kg bear. Toien et al. (2011) observed values in black bears ranging from 0.07 to 0.35 mL O<sub>2</sub>/g/hour during denning, equivalent to 1097-5484 kcal/day (for a 136kg bear), with metabolism at the equivalent of around 2334 kcal/day on emergence from the den. Surprisingly, denning metabolism as estimated from weight gain in this study is not significantly lower than values predicted for basal metabolic rate during the active season. It has been reported that metabolic rate is significantly lower for denning bears (Maxwell et al., 1988; Watts & Jonkel, 1988; Farley & Robbins, 1995). Toien et al. (2011) reported that metabolism went to as low as 25% of BMR during denning, although metabolic rate also fluctuated frequently during observations, sometimes rising to levels above BMR. Although calculations for energy requirements for denning in this study are not

significantly lower than BMR estimations, energy estimates for denning are in the range of those previously reported.

Measured distances used for estimation of the energy required for movement can be assumed as minimum distances of travel only, as the straight line distance between two consecutive collar points is likely less than the actual distance traveled. Other studies have accounted for this discrepancy by multiplying the distance by a correction factor (Aldama et al., 1991), however, this would introduce more uncertainty to our results. Data were not available to estimate energy expended for other behaviours in this study (e.g. digging, foraging) or for thermoregulation requirements. The energy estimated for movement does not take into account changes in elevation, such as the additional energy required to go uphill, and the energy recovered while moving downhill. Therefore, energy estimates from this study should be interpreted as minimum values. However, the application of measured body weights (versus population averages) and measured travel distances (rather than applying an arbitrary factor) may improve upon previously published energy estimates for grizzly bears.

Adding in the energy costs of weight gain for denning nearly doubles the daily energy requirements, from 2621kcal/day to 4179kcal/day. With the cost of denning, BMR and movement combined, estimates from this study are much closer to the range of those previously reported (Table 7). Nelson et al. (1983) reported that captive black bears eat 5000 to 8000kcal/day during normal activity; during hyperphagia, daily intake increased to 15,000-20,000kcal/day, and grizzly bears in the wild may consume up to 20,000 kcal/day. Assuming that more calories are consumed in early and late hyperphagia, the average daily values we determined for total energy requirements are consistent with these observations.

In the absence of direct metabolic measurements of active (non-denning) grizzly bears, estimations based on body mass and movement data provide the best information available at this time regarding energy requirements of bears in this study. Upon final completion of the food model in 2011, energy requirement estimations will be analyzed with energy availability on the landscape to calculate an energy balance. The dataset created during this analysis may also be used for future investigations, including review of seasonal movement rates, analysis of energy used by relocated bears, differences in energy use between females with and without young, energy use by home range, and investigation of other parameters potentially related to seasonal and annual energy requirements of grizzly bears in Alberta.

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## CHAPTER 10:FOOTHILLS RESEARCH INSTITUTE GRIZZLY BEAR PROGRAM DATABASE

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### **Introduction**

A program of this scale and magnitude requires efficient data handling procedures in order to maintain the integrity and accuracy of all the collected data. With such a system in place, it facilitates spatial analysis, querying and reporting. It can be very difficult to conduct any kind of analysis when data are not centrally managed and when the data sources are in various formats and inconsistent with each other.

To address these issues, a centrally-managed relational database was created that proved to be functional, with minimal to no duplication, easy to access and most importantly – easier to query and analyze. The first version of the database was created in 1999 and used until the end of 2010. The second version (2011+) was created to accommodate current data and user needs and to also increase the flexibility to incorporate data from other sources.

### **Improved database design**

Data collaboration opportunities with other agencies collecting grizzly bear data exist in Alberta, British Columbia and in neighbouring states in the US. Keeping a consistent data structure that would eventually allow synchronization of portions of the databases would be beneficial in tracking contiguous grizzly bear populations. Maintaining a centralized provincial database would also be an asset to the long-term conservation of grizzly bears. With this in mind, in 2008, a new design concept was adopted by referencing a schema presented by the Northern Divide Grizzly Bear Project in Montana.

In the new database design, everything is centered on events which usually contain a bear ID and a date. An event, for example, can include a capture, conflict, relocation, mortality, DNA census, tracking or GPS collar data upload. Field data is also associated with events, these include: locations, biological samples, measurements, tags and telemetry, and reproductive info. Field data applies to any type of event, where applicable.

This database version is more powerful. It allows the user to query out the history of any bear based on events. Field data has been normalized and is more universal. For example, location data are all stored in one table, instead of being included in each event table. Forms are being designed to provide more detailed information on a bear's history. The database design is also more flexible in allowing integration of data from other agencies.

Following the data integrity strategy of the previous version, the new database is set up with a back-end 'master' database and front-end 'user' databases. The user databases are further managed by linking to tables from a 'copy of the master' which is periodically updated as required. All front-end user databases contain linked tables. This prevents users from making

design changes to the tables. It also allows them to keep their own set of queries, forms and reports without cluttering the master database.

### **Managing genetics data**

All samples collected over the years, DNA lab results and resulting genetics information were tracked using multiple spreadsheets, shapefiles, and in some cases, manual recording of information written on sample bags sent to our program from other organizations. The biologists at FRI kept their own set of spreadsheets to help keep track of all the incoming reports and samples. The data originated from various sources and has proven to be a challenge when trying to incorporate it into a relational database. To date, the import process is almost completed. Some records require further quality checking, editing and in some cases, awaiting more detailed information.

Now that most of the samples and genetic information has been loaded and integrated within the database, genetics information for a particular grizzly bear will be tied to a biological sample which in turn, is part of an event. From the event, it can be associated with all available information to that event, including date and location (if such data originally existed). The genetics data will also be used to determine family trees and population distribution and diversity. VBA tools within MS Access are currently being built to help in determining these relationships.

Additional attributes for the biological samples table include information on which lab the sample has gone to, dates processed, and current storage location (if applicable). Not all samples have this level of detail recorded, however, future samples will be tracked more efficiently.

### **Current and forecasted benefits**

The new database has already improved efficiencies. Project staff were able to query out the the best hair sample left over from the 2004-2008 hair snag DNA censuses for a hair cortisol stress analysis. Hair samples that were collected in the early spring with guard hairs remaining were preferred and this information was easily queried out with the new database. Such a query from earlier sources and formats would have been tedious and would have taken much longer to do.

Having samples linked to events with a known location will make it possible to spatially visualize the bear's historical whereabouts on a map. Adding any known GPS locations and locations from other events for that same bear will help give a better picture of its home range. In absence of any GPS locations (from telemetry/GPS collars), knowing the locations of where samples such as hair from a DNA hair snag census were collected for an individual bear can provide an estimated home range for that bear. Such queries in the new database can easily be done.

### **Summary**

As the Foothills Research Institute Grizzly Bear Program continues to grow, spatial and non-spatial datasets will continue to evolve to meet research requirements. These multi-user datasets are being managed to be flexible and functional and to allow efficient GIS analysis. The database design changes will be beneficial in supporting multiple types of users, ensuring that everyone has the most recent information available.

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## CHAPTER 11: AN UPDATE ON GRIZZLY BEAR HEALTH RESEARCH

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### Introduction

Grizzly bear health research for the FRIGBP was in a transitional phase during 2010. In part, we collected similar measurements and samples to evaluate the health status of grizzly bears as in previous years. However, this field-based research was conducted largely to ensure continuity in our annual health evaluations. Instead, emphasis was placed toward (i) the analysis of environment, health, and stress data collected in conjunction with research support received from 2006-2010 through the Collaborative Research and Development (CRD) Grants Program of the Natural Sciences and Engineering Research Council (NSERC) of Canada, and (ii) the identification of key health-related research activities and knowledge gaps that need to be addressed to support the recovery of provincial grizzly bear populations over the next 5 years. The following update summarizes activities in each of these areas.

### Grizzly Bear Health Evaluation in 2010

We gathered complete health information from 14 grizzly bears captured in Alberta in 2010 as part of FRIGBP research activities and partial health information from another seven grizzly bears captured by Alberta Sustainable Resource Development staff. The data from these 23 bears include physical and physiological measurements recorded at capture as well as results from subsequent laboratory analyses of blood serum, skin, and hair. All health data for 2010 are now entered into our project health database bringing the total number of health records for the project to 357 cases representing 210 unique animals of which 78 have multiple (2-8) records over intervals ranging from 1 month to 8 years.

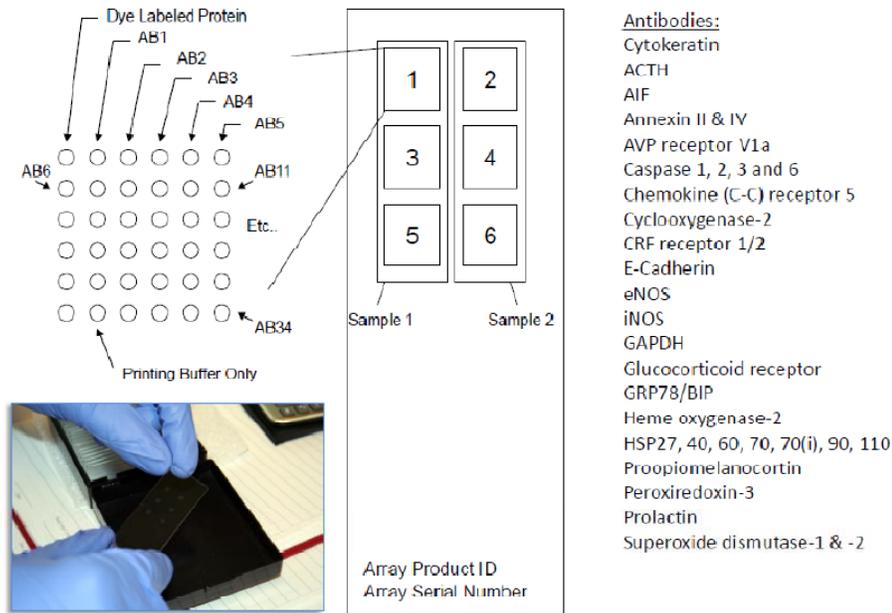
### Accomplishments from NSERC-CRD Supported Research (2006-2010)

#### 1) Development of a protein microarray to detect long-term stress<sup>8</sup>

From 2006-10, we developed a protein microarray to detect patterns of physiological stress with accuracy and precision in small samples of grizzly bear skin. The microarray consists of thirty-one commercially-available antibodies that we have validated for their sensitivity and reactivity to “stress-related” proteins in grizzly bears (Figure 1). These antibodies essentially recognize and bind to proteins associated with different aspects of the vertebrate stress response, including the hypothalamic-pituitary-adrenal axis, apoptosis/cell cycle, cellular stress, and oxidative stress and inflammation.

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<sup>8</sup> Information in this section adapted from Carlson 2011.



**Figure 1. Schematic illustration of the stress protein microarray developed for the detection of long-term stress in grizzly bears, as well as in other wild or domestic vertebrates. Each block numbered 1-6 consists of an array of 36 spots of which 31 are occupied by “stress protein”-specific antibodies and five are used for quality control. Three blocks are used for the test sample (i.e., the sample of interest), allowing triplicate analysis to ensure accuracy. The remaining three blocks are used for a reference sample against which test sample is compared, and relative protein expression values are calculated. The inset image shows that the stress protein microarray appears no different than a standard microscope slide.**

We selected skin as the ideal tissue for analysis for several reasons. First, in the capture and handling of bears for research or management, a small plug of skin is routinely collected from the ear in conjunction with the placement of ear tags for identification. Second, through the use of biopsy darts, we have determined that it is possible to remotely target a grizzly bear (by using a dart rifle), and collect a skin sample without capturing and handling it. We have also confirmed that the mass of skin (50-200 mg) collected by these means yields sufficient protein to accurately evaluate protein expression in grizzly bears based on duplicate or triplicate analyses of 80 µg quantities.

Other laboratory validation steps included: (i) determining that skin samples must be frozen ( $\leq 20^{\circ}\text{C}$ ) within 24 hours of collection, and ideally within a few hours, to avoid the degradation of stress-related proteins, and (ii) confirmation that stress protein expression profiles are not influenced by sex, age, capture method, or the location on the body from where the sample is collected.

To date, we have used the microarray to determine stress protein profiles for 139 grizzly bears. Analysis of these data is providing insight to relationships between the environment (landscape and climate) and stress, and between stress and health, in grizzly bears. We have also used the protein microarray to determine stress profiles in moose, ringed seal, polar bear, horse, and rat which demonstrates the potential for broad application of this tool. The development of “Phase

II” of the protein microarray is currently underway; its advantages over “Phase I” include technical improvements in the printing of arrays, as well as measurement of a larger suite of proteins, i.e., as many as fifty.

Outcomes:

Carlson, R.I. (2011). Development and application of an antibody-based protein microarray to assess stress in grizzly bears (*Ursus arctos*). Ph.D. Thesis, University of Saskatchewan, Saskatoon, Saskatchewan.

**2) Development of a hair cortisol assay to detect long-term stress<sup>9</sup>**

Hair cortisol concentration has recently been validated as a biomarker of long-term stress in humans and domestic animals. However, limited work has examined factors which may affect the measurement or interpretation of hair cortisol concentration in different species. In free-ranging wildlife, the use of non-invasive or opportunistic collection techniques presents additional challenges as these methods may be subject to a suite of confounding factors associated with sampling protocols and the quantity or quality of hair available for analysis. We have developed a technique to measure hair cortisol concentration in free-ranging grizzly bears. The technique is precise and accurate in  $\geq 5$  mg of hair (5-10 guard hairs). To date, hair cortisol concentration (range 0.62-43.33 pg/mg) has been measured in 205 grizzly bears and factors influencing hair cortisol concentration have been identified. We found that hair cortisol concentration varies with hair type, body region, and with capture method. However, it is not influenced by colour, age, sex class, environmental exposure (18 days) or prolonged laboratory storage (>1 year) and does not vary along the length of the hair shaft.

As with the microarray data, we are also analyzing the grizzly bear hair cortisol concentration data to gain insight to relationships between the environment (landscape and climate) and stress, and between stress and health, in grizzly bears. We have also modified the hair cortisol assay for application in polar bear, mule deer, and caribou (as well as reindeer) to support other wildlife research projects, which again demonstrates the potential for broad application of this tool.

Outcomes:

Ashley, N.T., Barboza, P.S., MacBeth, B.J., Janz, D.M., Cattet, M., Booth, R.K., Wasser, S.K. (2011). Glucocorticosteroid concentrations in feces and hair of captive caribou and reindeer following adrenocorticotrophic hormone challenge. *General and Comparative Endocrinology*, (in press)  
Macbeth, B.J., Cattet, M., Stenhouse, G.B., Gibeau, M.L., Janz, D.M. (2010). Hair cortisol concentration as a non-invasive measure of long-term stress in free-ranging grizzly bears (*Ursus arctos*): considerations with implications for other wildlife. *Canadian Journal of Zoology*, 88: 935-949.

**3) Development of an assay to measure corticosteroid binding globulin in blood serum of grizzly bears as a potential marker of long-term stress<sup>10</sup>**

Serum corticosteroid levels (primarily cortisol and corticosterone) are routinely measured as markers of stress in wild animals. However, corticosteroid levels rise rapidly in response to the acute stress of capture and restraint for sampling, limiting its use as an indicator of long-term

<sup>9</sup> Information in this section adapted from Macbeth et al. 2010.

<sup>10</sup> Information in this section adapted from Chow et al. 2010.

stress. We hypothesized that serum corticosteroid binding globulin (CBG), the primary transport protein for corticosteroids in circulation, may be a better marker of the stress status prior to capture in grizzly bears. To test this, a full-length CBG cDNA was cloned and sequenced from grizzly bear testis and polyclonal antibodies were generated for detection of this protein in bear sera. The deduced nucleotide and protein sequences were 1218 bp and 405 amino acids, respectively. Multiple sequence alignments showed that grizzly bear CBG (gbCBG) was 90% and 83% identical to the dog CBG nucleotide and amino acid sequences, respectively. The affinity purified rabbit gbCBG antiserum detected grizzly bear but not human CBG. There were no sex differences in serum total cortisol concentration, while CBG expression was significantly higher in adult females compared to males. Serum cortisol levels were significantly higher in bears captured by leg-hold snare compared to those captured by remote drug delivery from helicopter. However, serum CBG expression between these two groups did not differ significantly. Overall, serum CBG levels may be a better marker of long-term stress, especially because this protein is not modulated by the stress of capture and restraint in grizzly bears. We have now developed an enzyme-linked immunosorbent assay (ELISA) which permits rapid, high throughput analysis of grizzly bear serum samples, and has enabled us to determine CBG levels for 256 archived frozen samples that have been collected from grizzly bears captured for the FRIGBP since 1999. These data are also being used in our ongoing analyses to gain insight to relationships between the environment (landscape and climate) and stress, and between stress and health, in grizzly bears.

#### Outcomes:

Chow, B.A., Hamilton, J., Cattet, M., Stenhouse, G., Obbard, M.E., Vijayan, M.M. (2011). Serum corticosteroid binding globulin expression is modulated by fasting in polar bears (*Ursus maritimus*). *Comparative Biochemistry and Physiology Part A*, 158: 111-115.

Chow, B.A., Hamilton, J., Alsop, D., Cattet, M., Stenhouse, G., Vijayan, M.M. (2010). Grizzly bear corticosteroid binding globulin: Cloning and serum protein expression. *General and Comparative Endocrinology*, 167: 317-325.

#### **Next Steps in Grizzly Bear Health Research**

Over the next 5 years, we propose to integrate grizzly bear health research with other ongoing research efforts concerning the environment, habitat, energetics and population dynamics of grizzly bears to allow the assessment and monitoring of Alberta grizzly bears during recovery. Specifically, we will address the following health-related topics for grizzly bears:

- 1) Integration of stress and health assessment as a component of long-term population trend monitoring during recovery;
- 2) Development and coordination of a provincial program for the collection of biological samples and recording of standard measurements required to assess the health of grizzly bear populations and recovery progress, for all departments and jurisdictions in Alberta where bears are handled;
- 3) Development of biomarkers for the assessment of reproductive function;
- 4) Research to better understand how reproduction is linked with stress, growth and immune function, food (energy) availability and use, and population performance;
- 5) Application of multi-state models to identify dynamic relationships between demographic metrics (e.g., survival), stress, health, and environmental covariates (e.g., human activity);

- 6) Development of spatial analysis tools to identify and map spatial scales for grizzly bear stress and health responses to environmental covariates, this information will then be linked to the development of future scenario software for decision support;
- 7) Investigation of stress-induced compromises between immune function and reproduction / growth in grizzly bears over multiple generations.

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## CHAPTER 12: REMOTE SENSING REPORT ON MOUNTAIN PINE BEETLE/GRIZZLY BEAR PROJECT 2010/2011

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**Team: Thomas Hilker (UBC), Chris Bater (UBC), Trisalyn Nelson (UVic), Ben Stewart (UVic),**  
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### Executive Summary

The accurate and timely mapping of anthropogenic and natural disturbance patterns is critical to improve our understanding of grizzly bear habitat and movements. We have taken high-spatial (30 m) and -temporal (weekly or bi-weekly) resolution geo-spatial predictions of disturbance generated by the Spatial Temporal Adaptive Algorithm for mapping Reflectance Change (STAARCH) and applied them in three ways. First we generated a disturbance characterisation of the region from 2000 – 2008; secondly, we used the predictions to generate a disturbance type map; and thirdly, linked bear home range size to disturbance patterns. Results indicated that disturbance levels in the region increase later in the growing season, with most disturbances occurring in late August and September. Individual events are generally small in area (<10 ha) except in the case of wildfires, with, on average, 0.4% of the total area disturbed each year. When predicting the type of disturbance event, the overall classification accuracy was 86.2 % with misclassification errors ranged between 20-30 % for cutblocks, fires, and well sites, whereas roads – often subpixel in width – were misclassified more often (60% accuracy). The most important metrics for classifying the disturbances was the month of disturbance as identified from the STAARCH algorithm, followed by the core (interior) area of the disturbed patch and the disturbance size. Core Area Index and Contiguity both describe the shape of disturbance by comparing the disturbed core area to the disturbance perimeter. For the home range analysis we found that female grizzly bears use habitat less than expected when that habitat was disturbed in the same year. Use also becomes more variable for older disturbances. Male bears in spring and summer also use same-year disturbed habitat less than expected, but show increased use of same-year disturbed habitat in autumn. The response of male bears in summer indicates increased use of disturbed habitat with increasing disturbance age.

Research continued into the monitoring of habitat at the fine spatial scale. We again deployed a small network of cameras over the growing season of 2009 along an elevation gradient in western Alberta, Canada, with the dual purpose of: (a) developing a more comprehensive understanding of seasonal phenophases and the reproductive timing of understory forest vegetation, and (b) to support modelling efforts to validate phenological properties derived from satellite-based remote sensing systems. Results indicated excellent relationships between the field and camera data with 61 % ( $r^2 = 0.61$ ,  $p = 0.0043$ ) of the variance observed in the field measures of phenological phases captured by the cameras for the start of the growing season, and 72 % ( $r^2 = 0.72$ ,  $p = 0.0009$ ) of the variance in length of growing season. The mean absolute differences between predicted and observed start of growing season and length of growing season were 4 and 6 days, respectively. Lastly, research has continued into the development of base layers to support scenario-based modelling of the region. A spatial database of land cover,

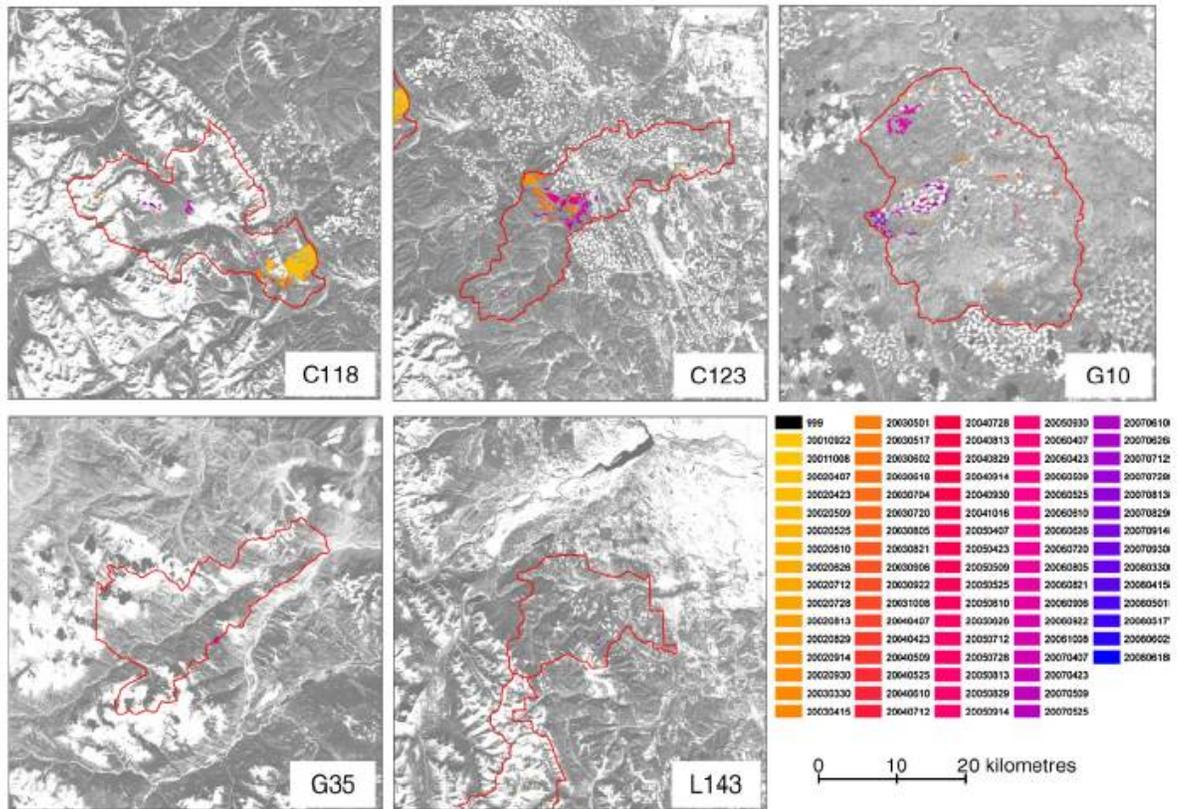
canopy closure and disturbances by type are being integrated from existing map products and STAARCH outputs. We have begun to parameterize the LANDIS model which is a simulation model that is spatially explicit and enables modelling of forest succession, disturbance (including fire, wind, harvesting, insects, global change), and seed dispersal across large (>1 million ha) landscapes.

Additionally, we have developed new methods for analyzing spatial-temporal patterns in telemetry data. Spatial Temporal Analysis of Moving Polygons (STAMP) has been extended to also include statistically significant change in utilization distributions between two time periods. As such we can detect subtle changes in site characteristics and in the intensity of habitat use. For female bears, drivers of space-time patterns of habitat use are found to change seasonally. In all seasons cub status is a key predictor of habitat use patterns; presence of parks, male habitat quality (male resource selection function (RSF), and resource availability are also important predictors. Methods based on conditional randomization have also been developed for the spatially explicit accuracy assessment of RSF models.

### **TOPIC 1 - IMPLEMENTATION OF STAARCH OVER MPB / GRIZZLY BEAR STUDY AREA AND IMPLEMENTATION OF THE STARFM COMPONENT (PHENOLOGY) OVER MPB/ GRIZZLY BEAR STUDY AREA**

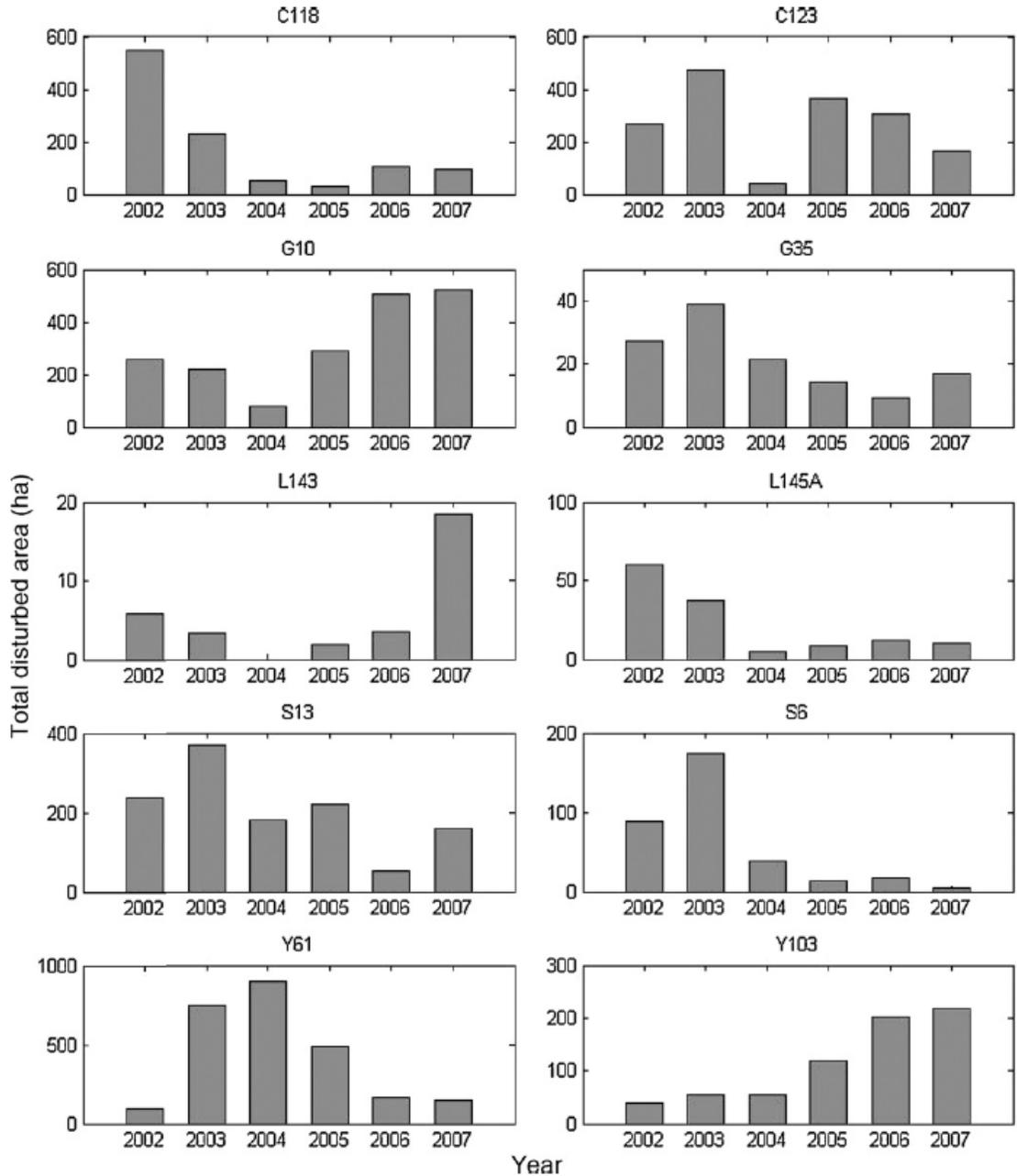
Timely and accurate mapping of anthropogenic and natural disturbance patterns can be used to better understand the nature of wildlife habitats, distributions, and movements. One common approach to map forest disturbance is by using high spatial resolution satellite imagery, such as Landsat-5 Thematic Mapper (TM) or Landsat-7 Enhanced Thematic Mapper plus (ETM+) imagery acquired at a 30 m spatial resolution. However, the 16 day revisit rate combined with interference of cloud and shadow to obtaining a usable image acts to limit the capability to accurately determine dates for a frequent sequence of disturbance events. As wildlife habitat use can vary significantly seasonally, annual patterns of disturbance are often insufficient in assessing relationships between disturbance and foraging behaviour or movement patterns.

The Spatial Temporal Adaptive Algorithm for mapping Reflectance Change (STAARCH) allows the generation of high-spatial (30 m) and -temporal (weekly or bi-weekly) resolution disturbance sequences using fusion of Landsat TM or ETM+ and Moderate Resolution Imaging Spectroradiometer (MODIS) imagery. The STAARCH algorithm is applied here to generate a disturbance sequence representing stand-replacing events (disturbances over 1 ha in area) for the period 2001 to 2008, over almost 6 million ha of grizzly bear habitat along the eastern slopes of the Rocky Mountains in Alberta. The STAARCH algorithm incorporates pairs of Landsat images to detect the spatial extent of disturbances; information from the bi-weekly MODIS composites is used to assign a date of disturbance (DoD) to each detected disturbed area (Figure ). Dates of estimated disturbances with areas over 5 ha are validated by comparison with a yearly Landsat-based change sequence, with producer's accuracies ranging between 15 – 85 % (average overall accuracy 62 %, kappa statistic of 0.54) depending on the size of the disturbance event. The spatial and temporal patterns of disturbances within the entire region and in smaller subsets, representative of the size of a grizzly bear annual home range, are then explored.



**Figure 1.** Pattern of disturbance from STAARCH for a subset of the selected grizzly bear habitat areas. Red lines represent habitat area boundaries.

Disturbance levels are shown to increase later in the growing season, with most disturbances occurring in late August and September. Individual events are generally small in area (less than 10 ha) except in the case of wildfires, with, on average, 0.4 % of the total area disturbed each year (Figure 2).



**Figure 2. Distribution of disturbance by year (2002-2007) for selected core and secondary habitat areas.**

The application of STAARCH provides unique high temporal and spatial resolution disturbance information over an extensive area, with significant potential for improving understanding of wildlife habitat use.

### **1.1. Integrating high temporal resolution disturbance data with wildlife movement: a case study in west-central Alberta**

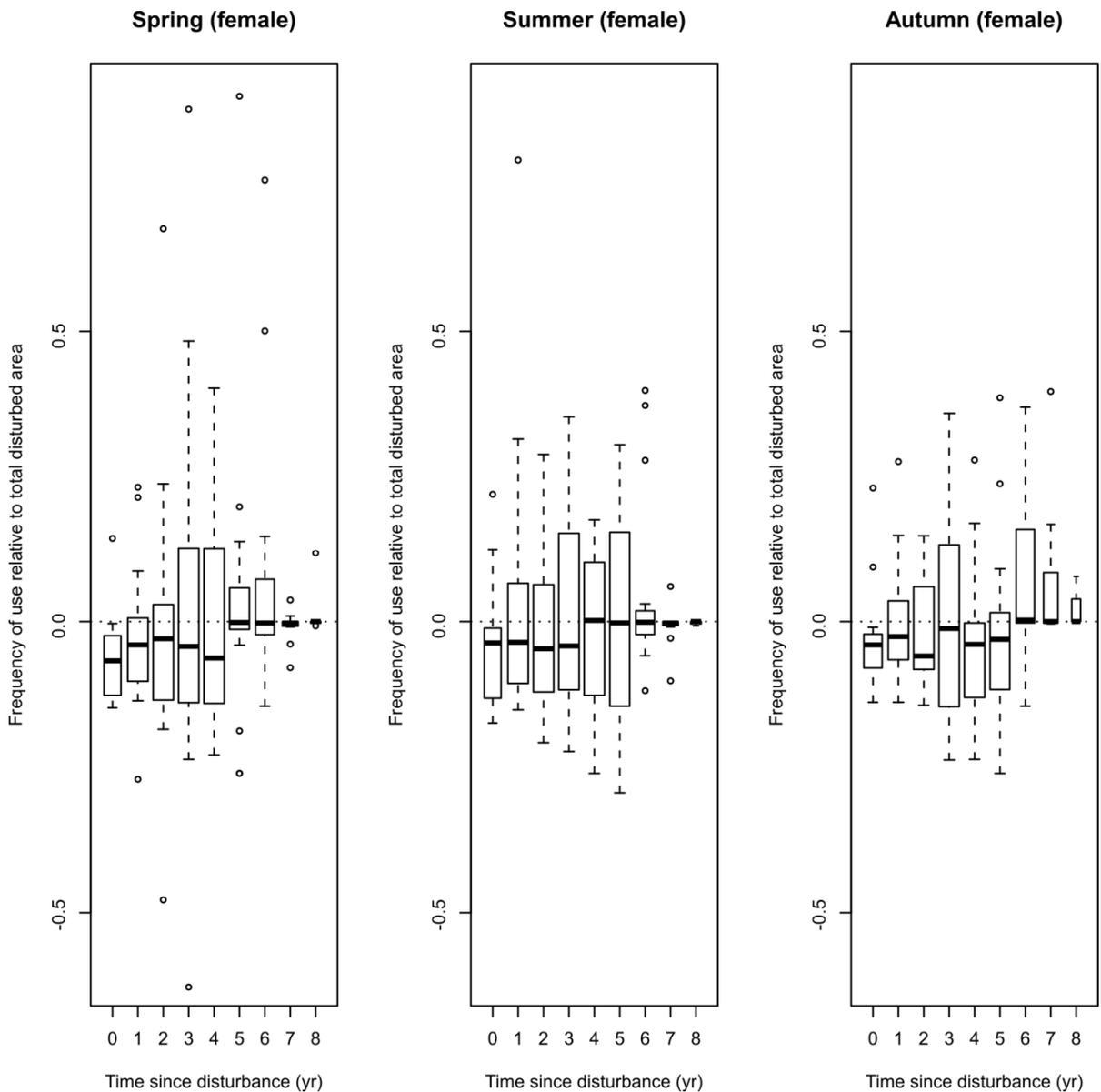
A thorough understanding of wildlife response to disturbance is necessary to ensure effective and informed conservation strategies. Unfortunately, the temporal scale of forest disturbance data is typically orders of magnitude less than that of wildlife movement data. Consequently, it is difficult to evaluate short-order responses to forest disturbance. However, recent research into data fusion techniques has provided a technique, the Spatial Temporal Adaptive Algorithm for Monitoring Reflectance Change (STAARCH), which is capable of generating disturbance maps with a 16-day temporal resolution and 30m spatial resolution.

The goals of this research were twofold: to examine the difficulties and opportunities associated with the integration of high temporal resolution disturbance data with wildlife telemetry data; and to evaluate what relationship, if any, exists between disturbance age and grizzly bear movement in west-central Alberta.

We demonstrate the utility of STAARCH for wildlife research by analyzing the response of grizzly bears to anthropogenic forest disturbance in west-central Alberta. Intra-annual seasonal analyses were conducted to capture differences in habitat use. It was found that for all seasons, female bears use habitat less than expected when that habitat was disturbed in the same year (Figure 3). Use also becomes more variable for older disturbances. Male bears in spring and summer also use same-year disturbed habitat less than expected, but show increased use of same-year disturbed habitat in autumn (Figure 4). The response of male bears in summer indicates increased use of disturbed habitat with disturbance age.

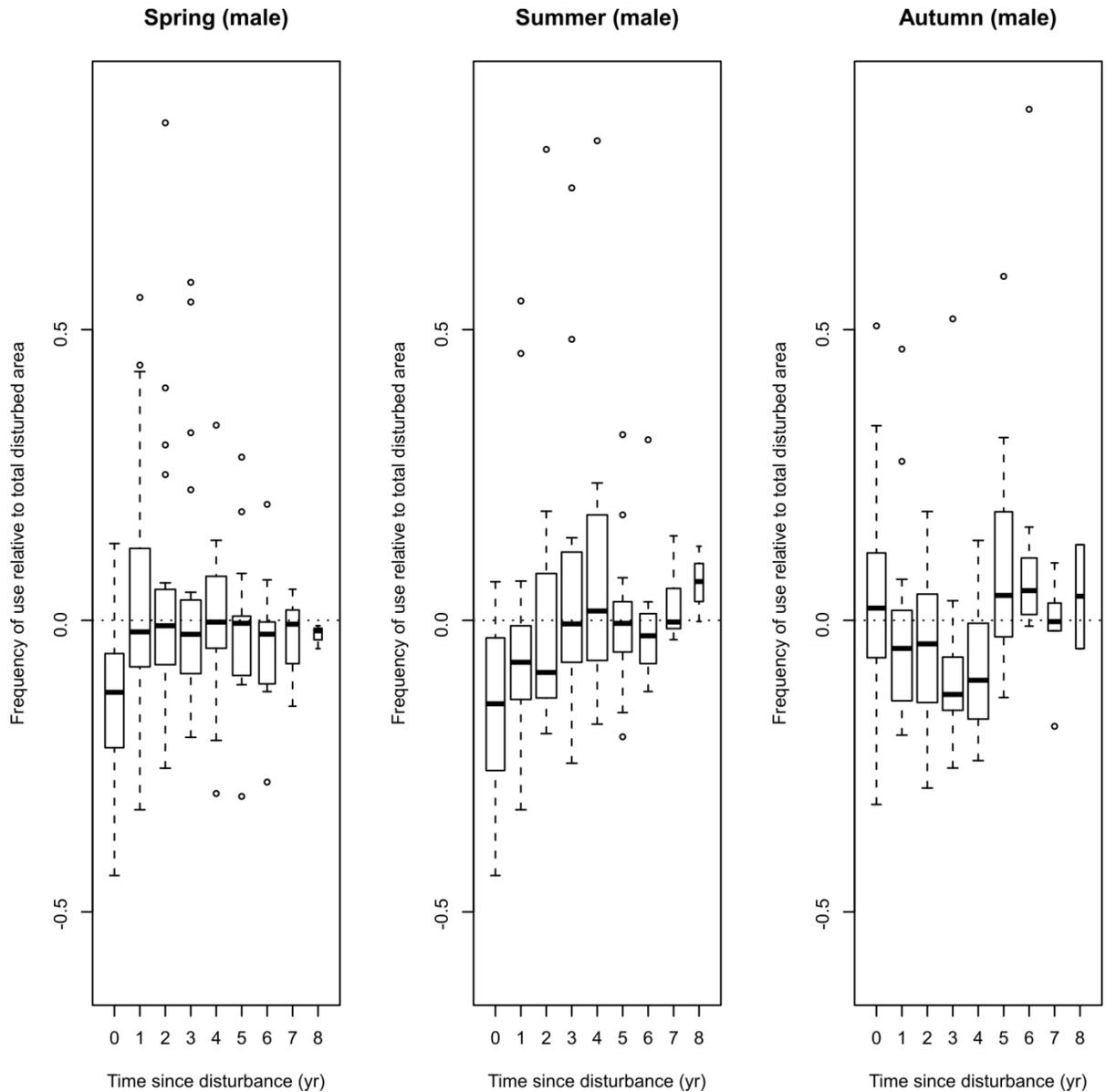
A difficulty inherent in this analysis was the sparse nature of the data relative to the size of the study area. For instance, the total disturbed area in a 16-day time period represents less than six percent of a bear's approximate home range, and less than one tenth of a percent of the total study area. Furthermore, grizzly bears often visit a disturbance site only once per year, making direct, causal relationships impossible to ascertain.

The ability to discern grizzly bear response to same-year disturbance is one of the key advantages to using high temporal resolution disturbance data. If annual disturbance maps are used, it is impossible to determine whether or not forest disturbance took place before or after a bear was observed. To quantify this effect, we downsampled the disturbance data to a one-year resolution and repeated the experiment for same-year disturbance. For all seasons, observed use of disturbed area increased. This suggests that previous research may have underestimated the impact of forest disturbance on grizzly bears.



**Figure 3. Response of female grizzly bears to disturbance. Positive values represent use of disturbed habitat; negative values represent disuse.**

This research demonstrates the utility of high temporal resolution disturbance data for characterizing grizzly bear movement relative to disturbance age, particularly when trying to understand bear response to same-year disturbance.



**Figure 4. Response of male grizzly bears to disturbance. Positive values represent use of disturbed habitat; negative values represent disuse.**

**Outcomes:**

Gaulton, R., Hilker, T., Wulder, M.A., Coops, N.C., Stenhouse, G. (2011). Characterising Stand Replacing Disturbance In Western Alberta Grizzly Bear Habitat, Using A Satellite-Derived High Temporal And Spatial Resolution Change Sequence. *Forest Ecology and Management* 261(4): 865-877

Brown, N.D.A., Nelson, T.A., Bater, C.W., Coops, N.C., Hilker, T., Wulder, M.A., Gaulton, R., and Stenhouse, G.B. (In review). Integrating high temporal resolution disturbance data with wildlife movement: a case study in west-central Alberta. *Journal of Applied Remote Sensing*. (Submitted on Feb 16, 2011).

## TOPIC 2 - ATTRIBUTION OF CHANGE – DEMONSTRATION OF METHODS

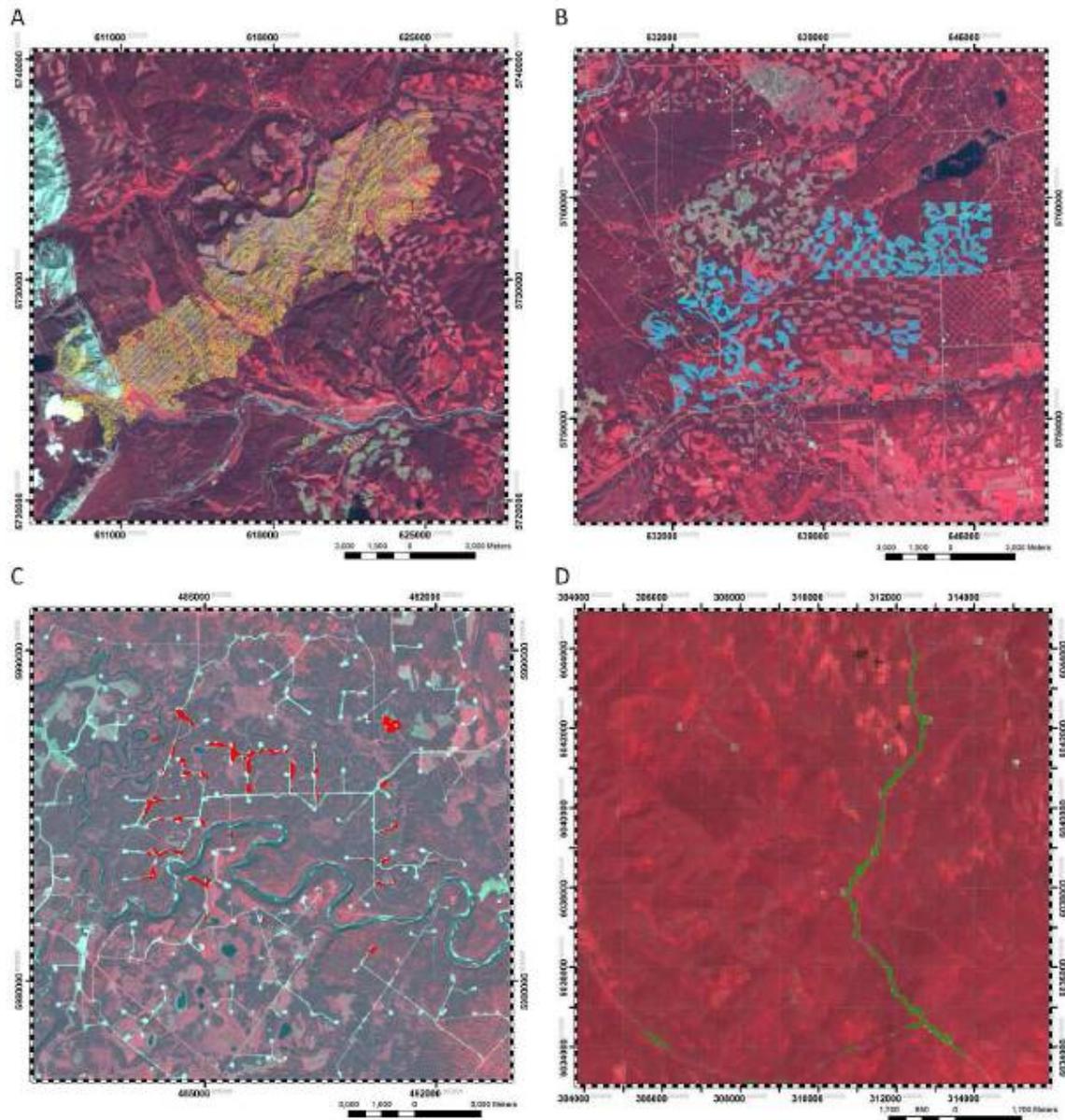
An increasing number of studies have demonstrated the impact of landscape disturbance on ecosystem health, and in particular, wildlife habitats. To support ecological studies, knowledge of change location, date, and type is often required. Satellite remote sensing has been demonstrated as reliable and operational for mapping landscape disturbance over large areas. However, in order to obtain sufficiently frequent observations at a high spatial resolution, it is desired to integrate the favourable qualities of differing satellite sensors, such as the high spatial resolution of Landsat with the temporal frequency of the MODerate-resolution Imaging Spectrometer (MODIS). Additionally, in an ecological context, the disturbance type is often required to inform upon different impacts on the quality of wildlife habitats and food resources. In this case study we demonstrate an approach for capturing landscape change with a high spatial resolution and frequency followed by a change typing protocol. Landscape level change is characterized on a near bi-weekly basis through application of a data fusion approach (Spatial Temporal Adaptive Algorithm for Mapping Reflectance Change (STAARCH)) and a number of spatial and temporal characteristics of the predicted disturbance patches are computed. Our results show that spatial and temporal disturbance characteristics can be used to classify disturbance events with an overall accuracy of 86 %. The date of disturbance (DOD) was found to be the most powerful predictor of disturbance types together with the patch core area, patch size, and contiguity.

The aim of this analysis was to determine the type of disturbance from the spatial characteristics of the individual disturbance events identified by STAARCH. Landscape pattern indices can be grouped into categories of size, shape index (edge-to-area ratio), isolation/proximity and contagion/interspersion). Critical indices in forested environments undergoing disturbance, based on a previous review include the number of patches per unit area, size class, and area-weighted mean patch size. In concert with edge density, these indices provide an indication of the degree of fragmentation associated with the different disturbance events. Conversely, area-weighted mean fractal dimension, mean proximity index, and interspersion/juxtaposition index provide a means to characterize patch shape, patch isolation/proximity, and contagion/interspersion, respectively.

Patch analysis of the disturbed areas was undertaken using Fragstats, a software tool designed to compute a wide variety of landscape metrics for categorical maps. The resulting disturbance characteristics were then validated against a disturbance type map derived from visual interpretation undertaken by a trained aerial photographic analyst familiar with the region. Air photo interpretation was based on maps of fire history, harvesting records and road coverages. For the purposes of this study, we distinguished between the most common disturbance types: cutblocks, fires, roads, and well sites.

The disturbance characteristics, which best predicted the type of disturbance were identified using decision tree analysis. The technique serves to automatically separate the dependent variables (spatial and temporal disturbance characteristics) into a series of choices that not only identifies the importance of each constraining variable but also identifies thresholds that best separate one species from another and best explain the predictor variable (here: disturbance type). One advantage of using decision trees over

conventional regression techniques is its capacity to deal with collinear datasets, to exclude insignificant variables and its independence of dataset distributions such as asymmetrical distribution of samples. Decision Tree Regression (DTREG) software was used to develop a classification tree for each disturbance type using a 10 -fold cross validation technique where the total dataset is partitioned randomly into 10 equally sized groups, a model is developed on nine of the groups, and then tested against the remaining 10% of the data not used in model development.



**Figure 5. Illustrative examples of different types of disturbances occurring in the study area.**

In Figure 5, panel A, we show the impact of the Dogrib Creek Fire, which burned from September to October, 2001 in an area of 787.8 ha. Burns were primarily characterized by large, contiguous patch sizes (> 4.5 ha). An example of cut blocks is provided in B. The blue areas in the image show harvesting activities since 2001, the other patches are disturbances that have occurred previous to this date and have been ignored in this study. Cut blocks were characterized by regular shape and “checkerboard” configuration, typically around 25-50ha in size. Well sites (Figure C) were characterized by attachment to short access roads and smaller, rectangular disturbance patches, whereas roads were determined mainly by their long and comparatively narrow shapes (Figure D).

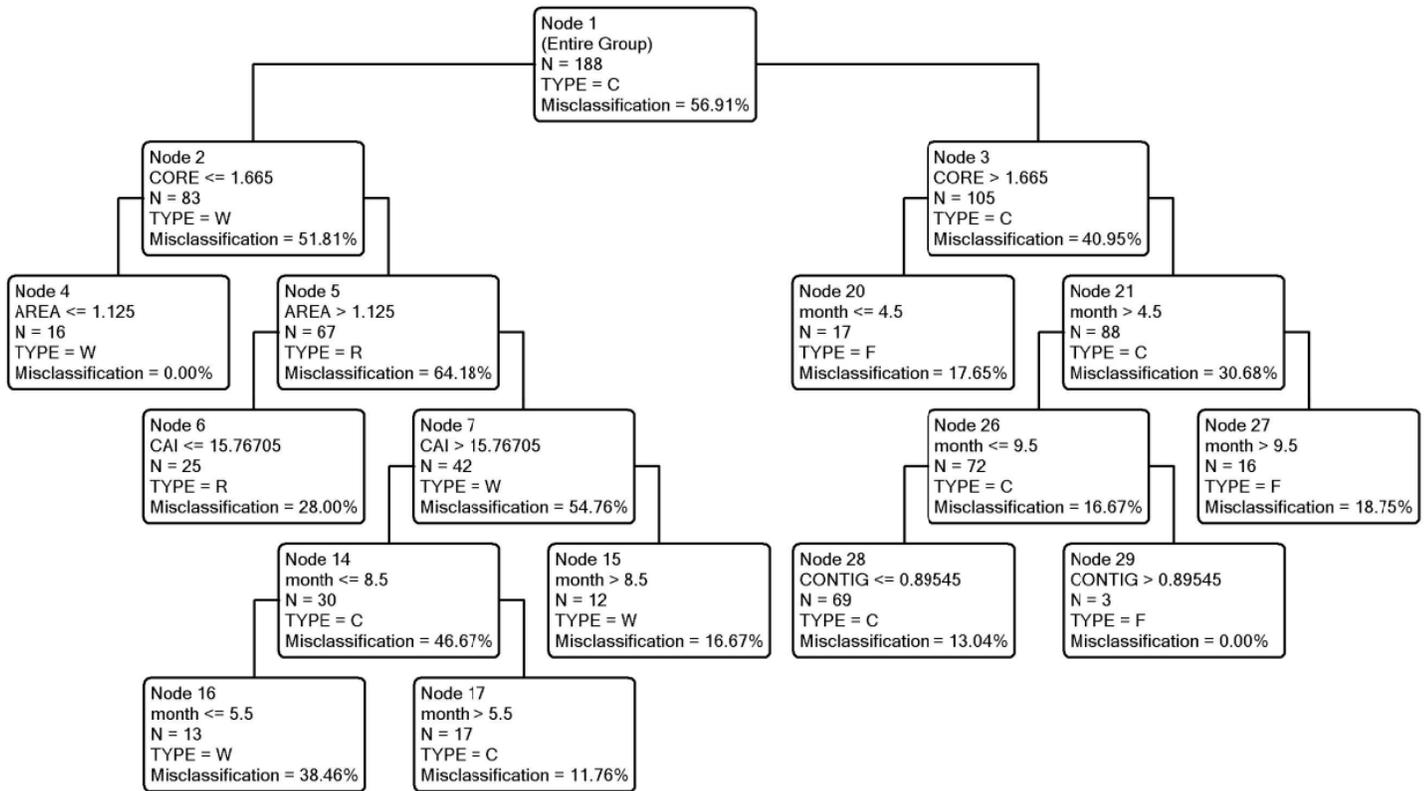


Figure 6. Regression tree for classifying the type of disturbance from spatial area metrics of the disturbed areas derived from Fragstats (see Table 1 for legend and explanation).

Table 1. Spatial disturbance attributes (Fragstats) and their predictive power derived from regression tree analysis.

Metrics name	Importance	Description
DoD	100.00	<b>Date of Disturbance:</b> STAARCH derived bi-monthly disturbance interval
Core (m <sup>2</sup> )	70.12	<b>Core Area: Area (m<sup>2</sup>):</b> area within the patch that is further than the specified depth-of-edge distance (here 30m) from the patch perimeter
Area (m <sup>2</sup> )	22.58	<b>Patch area:</b> The area of the patch in m <sup>2</sup>
CAI	22.17	<b>Core Area Index.</b> Patch core area (m <sup>2</sup> ) divided by total patch area (m <sup>2</sup> ), multiplied by 100 (to convert to a percentage); in other words, CAI equals the percentage of a patch that is core area.
Contig	12.46	<b>Contiguity Index:</b> The average contiguity value for the cells in a patch (i.e., sum of the cell values (=1 for the binary disturbance mask) divided by the total number of pixels in the patch) minus 1, divided by the sum of the template values (=1) minus 1. Note, 1 is subtracted from both the numerator and denominator to confine the index to a range of 1.

The regression tree resulting from fitting the different disturbance types to the patch metrics derived from Fragstats is presented in Figure 6. The tree depth was restricted to 6 levels and the tree was pruned to its minimum cross validation error. The overall classification accuracy was 86.17%. The misclassification errors ranged between 20-30% for cutblocks, fires and well sites, whereas roads were misclassified more often (60%). The accuracies for the individual disturbance types ranged between 83 and 89%, while the

precision ranged between 58 and 82%. Lowest precision values were found for roads, which also showed the highest rate of misclassification.

Most common misclassifications occurred between fires and cutblocks and between roads and well sites. A ranking of the most important shape metrics and disturbance characteristics that were used to characterize the different types of disturbance is presented in Table 1. The importance values are scaled between 100 (most important) and 0 (not important). The most important metrics for classifying the disturbances was the month of disturbance as identified from the STAARCH algorithm, followed by the core (interior) area of the disturbed patch and the disturbance size. Core Area Index and Contiguity both describe the shape of disturbance by comparing the disturbed core area to the disturbance perimeter. It should be noted that no STAARCH predictions were made outside the growing season due to possible snow contamination, and as a result, disturbance events occurring after October 15th were assigned the disturbance date of the first prediction of the following year (March 15th).

**Outcome:**

Hilker, T., Coops, N.C., Gaulton, R., Wulder, M.A., Cranston, J., Stenhouse, G. (2011). Automated bi-weekly disturbance capture and attribution: A case study in western Alberta grizzly bear habitat. *International Journal of GIS* (in review).

### **TOPIC 3 - ROLE OF UNDERSTORY AS A DRIVER OF CONIFER CANOPY SPECTRAL REFLECTANCE, INFLUENCE ON 'PHENOLOGICAL CAMERAS' AND ROLE OF UNDERSTORY AS A DRIVER OF CONIFER CANOPY SPECTRAL REFLECTANCE, INFLUENCE ON CAPTURE OF PHENOLOGY**

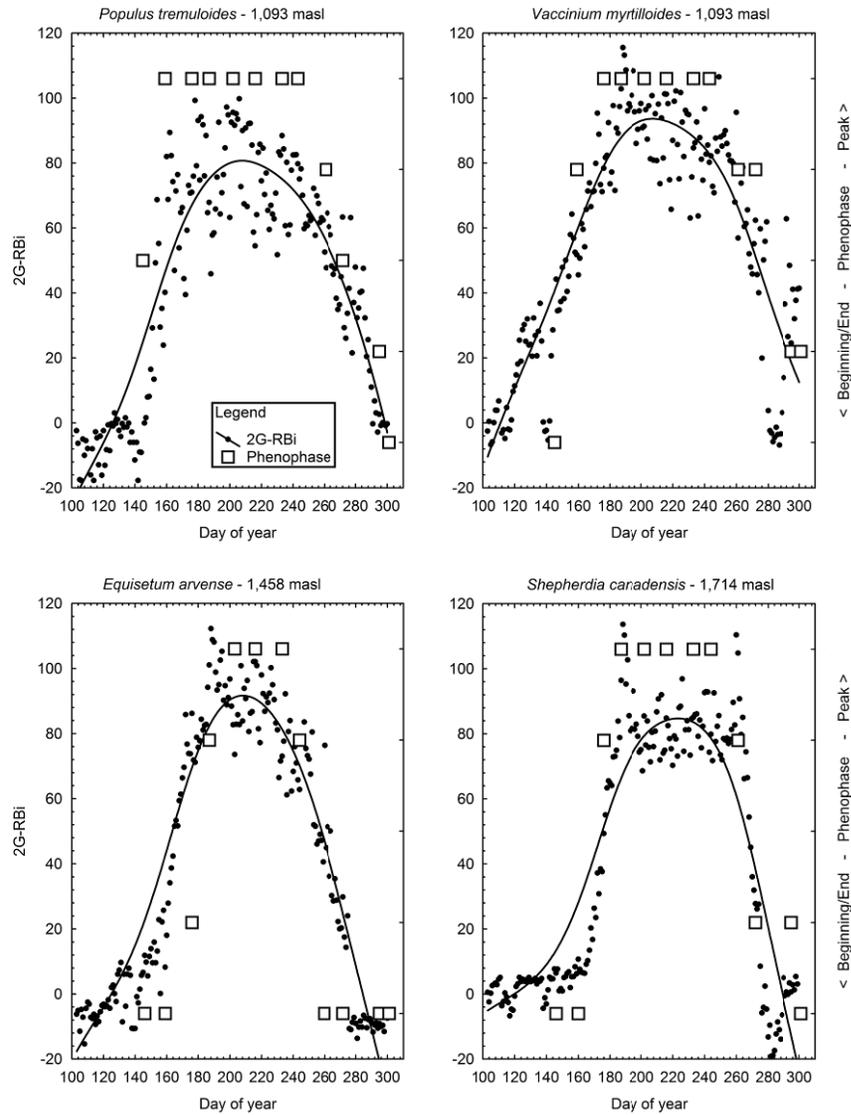
Developments in distributed sensing, web camera image databases, and automated data visualisation and analysis, among other emerging opportunities, have resulted in a suite of new techniques for monitoring habitat at many different scales. Data from these networks can provide important information on the timing of plant phenology, with implications on monitoring and assessment of habitat status and condition. Of more broad global relevance, information on phenology is also useful to better understand the relationship between canopy structure and seasonal dynamics of CO<sub>2</sub> uptake by forests, especially under changing climatic conditions.

In three recent papers we describe the design and deployment of a small network of cameras established during the growing season of 2009 along an elevation gradient in western Alberta, Canada, with the dual purpose of: (a) developing a more comprehensive understanding of seasonal phenophases and the reproductive timing of understory forest vegetation, and (b) to support modelling efforts to validate phenological properties derived from satellite-based remote sensing systems, principally Landsat and MODIS.

We have demonstrated the potential for imagery collected from ground-based cameras to be used to derive phenological patterns from food species commonly used by grizzly bears, including lingonberry (*Vaccinium vitis-idaea*), hillside blueberry (*Vaccinium myrtilloides*), buffaloberry (*Shepherdia canadensis*), horsetails (*Equisetum* spp.), and trembling aspen (*Populus tremuloides*). By focusing on specific “regions of interest” within the ground-based images delineating under- and overstory species (Figure 7), we assessed the capacity of the network to detect changes in phenological phases and correlate these indicators with field observations (Figure ). Relationship between the field and camera data indicates that 61 % ( $r^2 = 0.61$ ,  $df = 1$ ,  $F = 14.3$ ,  $p = 0.0043$ ) of the variance observed in the field measures of phenological phases were captured by the cameras for the start of the growing season, and 72 % ( $r^2 = 0.72$ ,  $df = 1$ ,  $F = 23.09$ ,  $p = 0.0009$ ) of the variance in length of growing season. The mean absolute differences between predicted and observed start of growing season and length of growing season were 4 and 6 days, respectively.



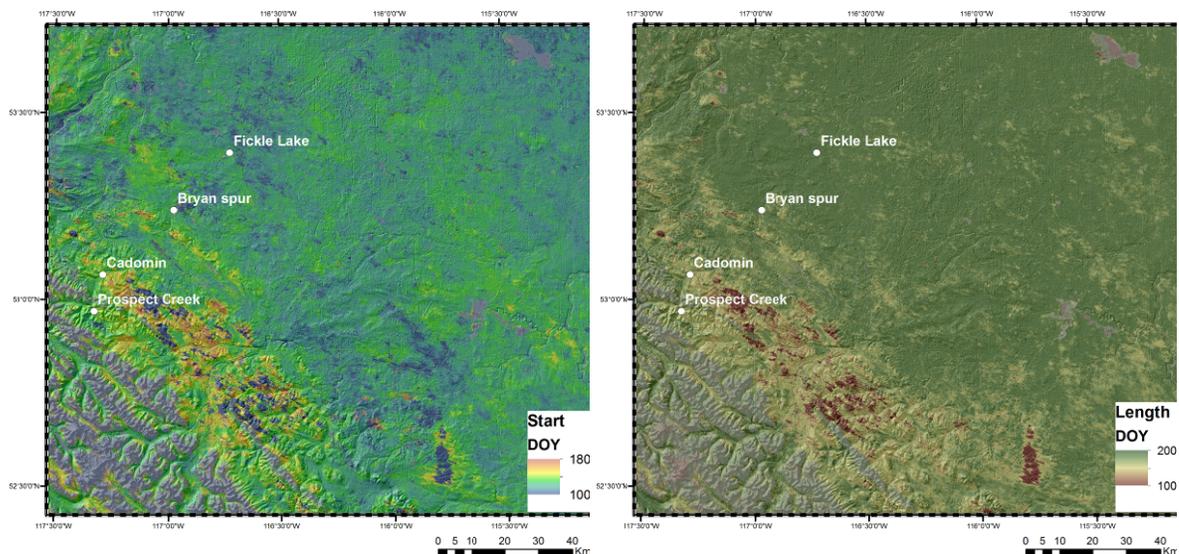
**Figure 7.**Black-and-white example of a digital image acquired at the Bryan Spur mixed site, and size and positions of species-specific regions of interest which were analyzed.



**Figure 8.** Temporal sequences of a camera-based vegetation index (2G-RBi) and traditional phenocode values for four species-specific regions of interest at three vegetation sites.

Although start and length of growing season were effectively captured for multiple species across a range of conditions, subtle changes between phenological phases, such as the development of fruiting bodies, were not distinguishable at the typical distances separating the targeted plants and the cameras. In order to refine our ability to detect these changes, the cameras were redeployed during the 2010 growing season with a new configuration. Three plots were established, and at each a camera was mounted overlooking the site. A second camera was then deployed within a few metres of an individual sweetvetch plant (*Hedysarum alpinum*) for daily captures at close range. The three sites were then visited several times each month. The phenological status of the sweetvetch plants were recorded, and roots were collected from surrounding plants for nutritional analysis. Currently, work is underway to develop refined camera-based indices for the detection of subtle changes in the phenology of the sweetvetch plants, with an emphasis on greening and flowering, seed set, and senescence.

A number of remote sensing-based vegetation monitoring techniques have recently been developed at a satellite scale, including those employing high temporal frequency AVHRR NOAA and MODIS imagery. A fundamental challenge with using satellite data to track plant phenology, however, is the trade-off between the level of spatial detail and the revisit time provided by the sensor, as well as the ability to verify interpretations of phenological activity. One way to address this challenge is to integrate remotely sensed observations obtained at different spatial and temporal scales to provide information that contain both high temporal density and fine spatial resolution observations. We compared measures of vegetation phenology observed from the ground-based camera network with satellite derived measures of greenness derived from a fused broad (MODIS) and fine spatial (Landsat) scale satellite dataset. We derived and compared start date of green-up, start-date of senescence, and length of growing season from both the ground-based camera network and 30 m spatial resolution synthetic Landsat scenes (Figure 9). Results indicate that although field-based estimates generally predicted an earlier start and end of the vegetation season than the fused satellite observations, highly significant relationships were found for the prediction of the start ( $R^2=0.65$ ), end ( $R^2=0.72$ ) and length ( $R^2=0.70$ ) of the growing season across all sites. This approach may be of value in understanding and tracking impacts of climate change on phenological activity and habitat use by wildlife species.



**Figure 9. Synthetic Landsat-based estimates of start and length of the growing season. The displayed area corresponds to Landsat path/row 44/23; the locations of the field sites are provided for orientation.**

#### **Outcomes:**

Bater, C.W., Coops, N.C., Wulder, M.A., Hilker, T., Nielsen, S.E., McDermid, G., Stenhouse, G.B. (2010). Using digital time-lapse cameras to monitor species-specific understory and overstorey phenology in support of wildlife habitat assessment. *Environmental Monitoring and Assessment*. doi: 10.1016/j.cageo.2008.09.001

Bater, C.W., Coops, N.C., Wulder, M.A., Nielsen, S.E., McDermid, G., Stenhouse, G.B. (In Press). Design and installation of a camera network across an elevation gradient for habitat assessment. *Instrumentation Science and Technology*.

Coops, N.C., Hilker, T., Bater, C.W., Wulder, M.A., Nielsen, S.E., McDermid, G., Stenhouse, G. (In Press). Linking ground-based to satellite-derived phenological metrics in support of habitat assessment. *Remote Sensing Letters*.

## TOPIC 4 - INTEGRATION WITH RSF MODELS

### 4.1. Living On The Edge: Grizzly Bear Habitat Selection In Forested Landscapes Of Alberta

Understanding grizzly bear (*Ursus arctos L.*) habitat selection is critical for managing threatened populations. With their seasonal diets and diurnal feeding patterns, grizzly bears often find food at transitions between homogenous land cover types. Edges are the boundaries separating distinct habitat patches and can be either natural landscape features, such as the transition between a forest and meadow, or anthropogenic disturbances, such as roads or forest harvests. While these transitions provide important food sources not always available in either adjacent patch, they may also put a bear at risk of increased mortality. It is of interest to examine the selection or avoidance of edges by grizzly bears to better understand habitat use.

The goal of this research was to examine grizzly bear use of edge habitat, both natural and anthropogenic, with respect to landscape-level measures of habitat edges. To achieve this goal we identified three main objectives: 1) quantify edge density by edge type in available grizzly bear habitat (area within home range); 2) quantify frequency of edge use, distance to nearest edge, and edge density in available grizzly bear habitat; 3) evaluate use of edge types.

We defined edges as transitions between land cover types or interruptions in land cover (anthropogenic disturbances). GPS telemetry data from 26 grizzly bears were collected from 2005 to 2009 in the foothills of the Rocky Mountains in west-central Alberta, Canada. The locations were compared to a series of landscape transitions extracted from satellite-derived land cover data and linear features, such as streams, roads, and pipelines.

For each grizzly bear telemetry point, distance to nearest edge was calculated and edge type recorded. By enumerating the nearest edge we were able to calculate frequency of nearest edge type and distance to nearest edge for each bear location. These were summarized by individual bears, sex, and season. Comparison of edge characteristics between sex and seasons were conducted using the Mann-Whitney U-test. The values were compared to randomized points created through a conditionalized randomization, based on a resource selection function (RSF). The RSF evaluates third-order habitat selection for grizzly bears based on a series of underlying land cover datasets. The RSF explicitly removes edges from its calculation, so it accounts for all non-edge biological phenomena. The observed distance to edge and frequency of selection was compared to the expected (from the randomized points) to determine significant differences between sexes and between seasons.

The analysis of grizzly bear home range edge density indicates that females (Figure 10) use habitats with pipelines and roads more than males (Figure 11). Anthropogenic edges are less common in grizzly bear home ranges than shrub-conifer edges, which are the most common in every season for both sexes, with females having significantly higher density of these edges in the spring. The wetland transitions appear to be much less common than any of the other transitions in bear home ranges, but this reflects the relative frequency of wetlands in the study area (~2 %). Females are also found significantly closer to streams in the spring than males.

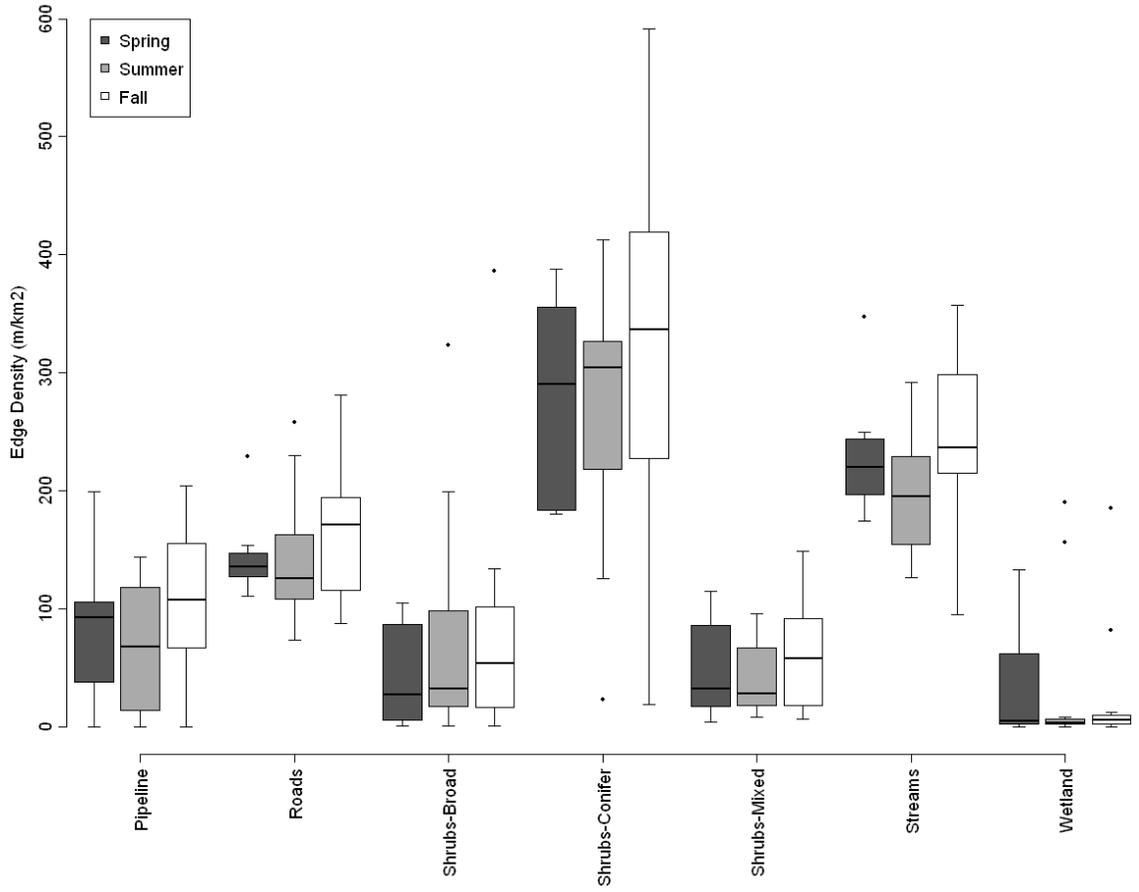
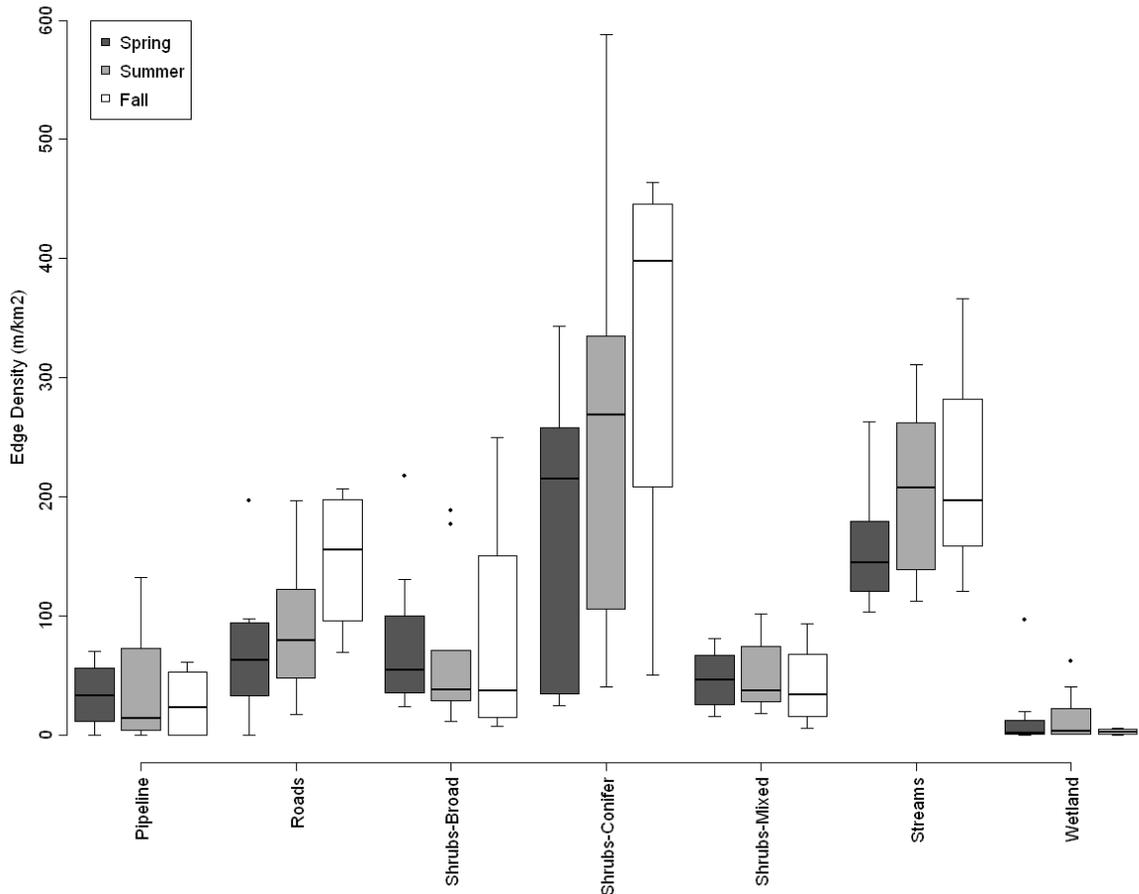


Figure 10. Boxplots showing the seasonal use of edge habitats for female grizzly bears.



**Figure 11. Boxplots showing the seasonal use of edge habitat by male grizzly bears.**

The analysis of frequency of edge and distance to edge selection shows a number of interesting results (Tables 2 & 3). Females select for wetlands more than expected, 5.38 %, 6.71 %, and 3.93 % for spring, summer, and autumn respectively even though wetland edges make up only 0.74 % of edges in their habitat. Males select for shrub-conifer transitions more than expected in autumn, using these edges 46.41 % of the time, while making up only 34.5 % of the habitat; conversely females use this transition approximately as expected throughout the year. Males preferentially select for the shrub-mixed transition in every season: 10.53 %, 11.16 %, and 10.16 % for spring, summer, and autumn, compared to an availability of 6.65 %. Males are found close to the shrub-broad transition often in the spring (21.48 %), but that selection decreases throughout the year (11.48 % in summer and 8.3 % in autumn). Males select for streams only in the summer (36.38 % versus 27.82 % availability). Females appear to select for anthropogenic edges (pipelines and roads), whereas males avoid them in all seasons.

**Table 2. Summary of frequency of edge use for male and female grizzly bears reported by season. The first two rows indicate the percentage of total edge available for males and females. \* indicates that the edge is used significantly more than expected at random.**

		Wetland	Shr-Con	Shr-Mix	Shr-Broad	Streams	Pipelines	Roads
Available	Male	1.7	34.5	6.65	10.62	27.82	5.08	13.58
	Female	0.74	33.42	5.64	7.68	25.44	9.85	17.23
Spring	Male	0.95*	36.98	10.53	21.48	23.14	1.56	5.36*
	Female	5.38*	31.82	7.84*	6.1	24.85*	7.43*	16.6*
Summer	Male	3.1	30.57*	11.16	11.48	36.38	1.55*	5.75
	Female	6.71*	27.01	6.95	9.2	23.63*	7.85*	18.92
Autumn	Male	0.54	46.41	10.16	8.3	25.02*	0.5*	9.09
	Female	3.93*	34.09	8.64*	6.28*	26.13	6.75	14.18

**Table 3. Summary of average and variation in distance to edge for male and female bears separated by season. The data is summarized as mean (standard deviation). \* indicates that the bears are significantly closer to the edge than expected at random.**

		Wetland	Shr-Con	Shr-Mix	Shr-Broad	Streams	Pipelines	Roads
Spring	Male	36 (140)	28 (131)*	40 (116)	32 (145)*	39 (157)*	29 (146)	14 (83)*
	Female	23 (146)	17 (108)	32 (83)*	19 (72)*	23 (109)	13 (57)	11 (73)*
Summer	Male	62 (199)	17 (135)	34 (106)	29 (115)*	23 (117)	76 (38)	29 (143)
	Female	18 (105)	15 (103)	25 (81)	18 (85)	19 (99)*	10 (64)	9 (61)*
Autumn	Male	57 (45)	17 (97)*	25 (102)*	29 (69)*	21 (108)*	22 (156)*	24 (92)
	Female	19 (87)	13 (103)*	18 (93)	29 (102)*	19 (93)*	11 (55)*	13 (85)

The identification of edges as key grizzly bear habitat extends beyond anthropogenic disturbances. While many studies have focused on grizzly bear attraction to anthropogenic disturbances, our work highlights natural edges as well. The variation in edge effects between natural and anthropogenic edges has not been well-studied in grizzly bears. For instance, females select for wetland edges much more than their availability making them important for conservation and management consideration. Our results also show that natural transitions have substantial variation in selection by season. Knowledge of the shrub-conifer edge preference by males in autumn could be used to manage access to forest harvests seasonally, allowing grizzly bears access to otherwise unavailable resources while avoiding human confrontations.

While the major focus of grizzly bear management is on anthropogenic disturbances, maintaining a balance of natural land cover and natural land cover transitions should also be considered when designing management plans. The current paradigm of fire suppression causes fewer natural clearings in grizzly bear habitat. Clearings created through forest harvesting may act as surrogates for natural clearings containing important food stuffs. However, they are not

perfect replacements as they expose bears to increased threats of human interaction. Maintaining a balance between natural and anthropogenic edges and focusing on retaining a matrix of all land cover types should be priorities in managing grizzly bear habitat in this area.

**Outcome:**

Stewart, B.P., Nelson, T. A., Wulder, M.A., Nielsen, S., and Stenhouse, G. (Submitted). The effects of edges on grizzly bear habitat selection. *Forest Ecology and Management*. (Submitted January 2011).

#### **4.2.A Spatially Explicit Method For Evaluating Accuracy Of Species Distribution Models**

Models predicting the spatial distribution of wildlife such as grizzly bears (*Ursus arctos*) are increasingly used in management and conservation planning. Species distribution models (SDMs) combine observed occurrences with geographic environmental data to predict species distribution and are often used as a key conservation tool, applied across a range of biogeographical scales. Given the diverse application and influence in conservation decisions of SDMs, understanding their accuracy, and particularly the variation in their accuracy across the study area, is critical. When model errors exhibit spatial patterning, characterizing the spatial nature of error can provide information on variables to be added or applied differently. The conditions at locations that are poorly modeled can be assessed and integrated with additional data to enhance model performance.

Current methods of spatial SDM assessment focus on applying local measures of spatial autocorrelation to SDM residuals, which require quantitative model outputs. However, SDM outputs are often probabilistic (relative probability of species occurrence) or categorical (species present or absent). The goal of this project was to develop a new method, using a conditional randomization technique, which can be applied directly to spatially evaluate probabilistic and categorical SDMs.

Using seasonal grizzly bear resource selection function (RSF) models, we have demonstrated a spatially explicit approach to quantify and map spatial variability in predictive success of categorical SDMs. Local test statistics computed from bear telemetry locations were used to identify areas where bears were located more frequently than predicted. We evaluated the spatial pattern of model inaccuracies using a measure of spatial autocorrelation, local Moran's I. (Figure 13).

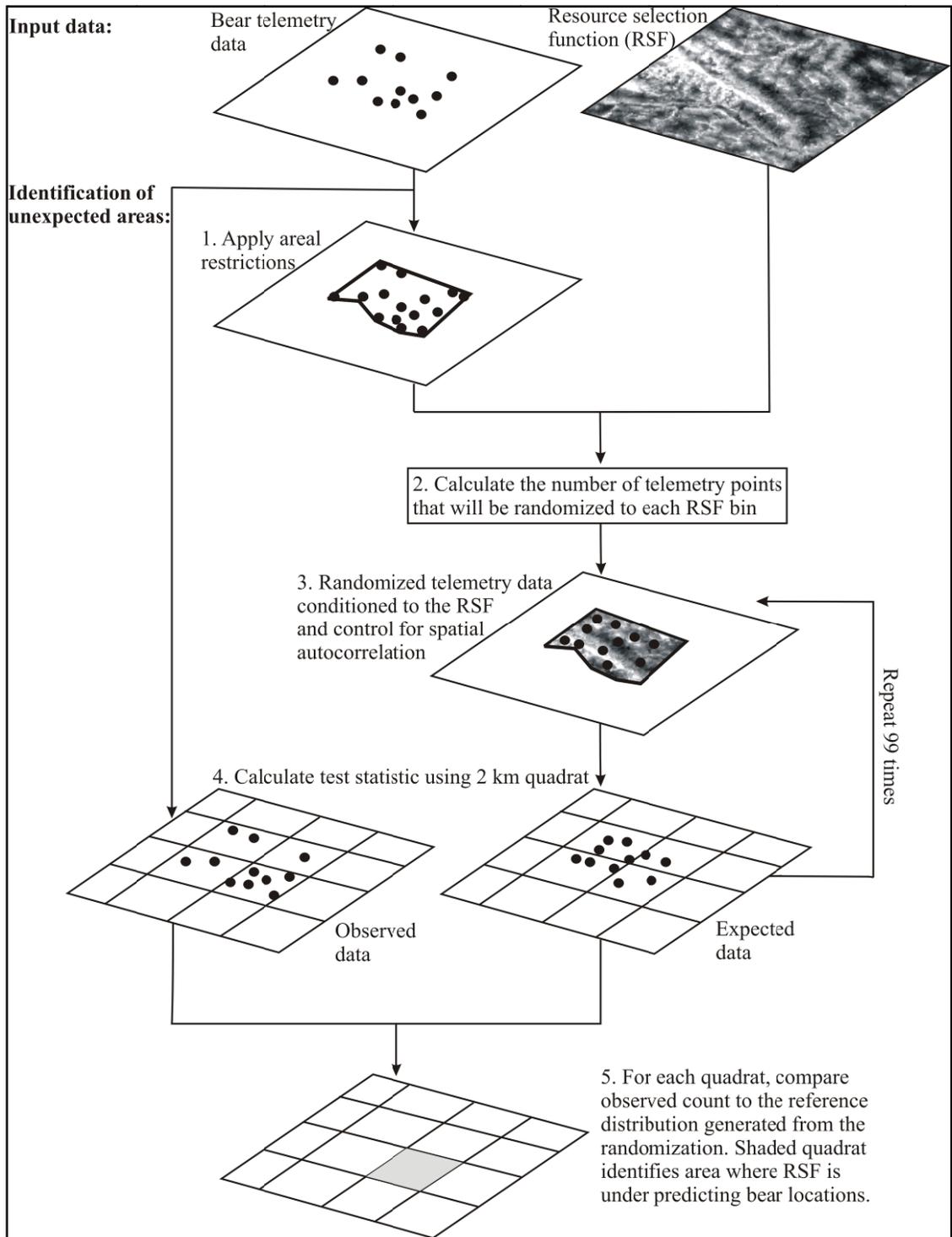
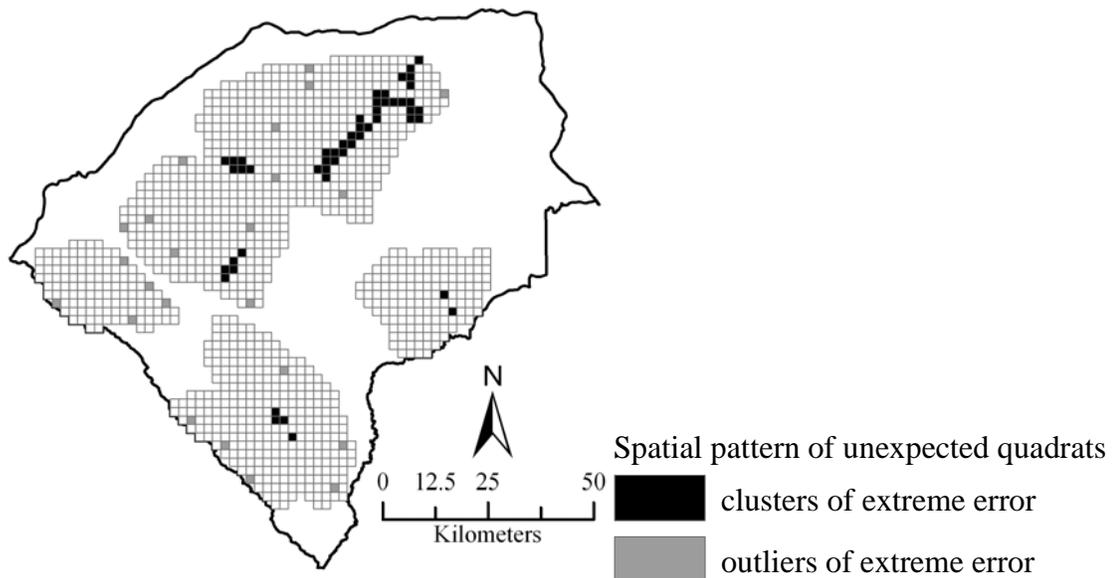


Figure12. An overview of the approach used to identify unexpected locations.

The results of our model validation method show that the RSF models predict bear occurrence well, as only approximately 5% of the study area was identified as under predicting bear occurrence. Further, we found the model to have non-stationary patterns in accuracy, with clusters of inaccuracies located in central habitat areas (Figure ). Model inaccuracies varied seasonally, with the summer model performing the best and the least error in areas with high RSF values.



**Figure 13. Spatial pattern of statistically unexpected quadrats identified by local Moran's I.**

By identifying locations of model inaccuracy, one can recognize and map errors. Furthermore, one can examine landscape characteristics at these locations that may be causing their deviation from the model's prediction. We demonstrated this examination of characteristics with two variables, elevation and distance to water; both of which were not included in the creation of the RSF model, but were shown to be relevant in other grizzly bear RSF models.

This method complements existing spatial approaches to model error assessment as it can be used with probabilistic and categorical model output, which is typical for SDMs. While our model validation method is based on a presence/available RSF model, it can be applied to all types of SDMs. We recommend that species distribution model accuracy assessments be done spatially and resulting accuracy maps included in model metadata.

**Outcome:**

Smulders, M., Nelson, T.A., Jelinski, D.E., Nielsen, S.E., and Stenhouse, G.B. (2010). A spatially explicit method for evaluating accuracy of species distribution models. *Diversity and Distributions* 16: 996–1008.

### 4.3. Drivers Of Grizzly Bear Space-Time Habitat Use

It is of vital importance in conservation planning to understand a grizzly bear's (*Ursus arctos*) use of habitat. Understanding this use for females is even more critical as they have been shown to routinely face an energetics crisis as they balance the demands of security and sufficient calories. In contrast to their coastal counterparts who have more abundant sources of high-protein food, habitat use for interior female grizzly bears has a more profound effect on their fecundity and, as such, the vigour of the population. Previous research has suggested that habitat use by female grizzly bears varies by foraging season and is affected by males, humans, food availability, and age of offspring. For instance, mothers with cub-of-the-year (COY) have been shown in previous studies to occupy a much-reduced habitat. We were interested in examining what factors drive female habitat use and the variation in use between seasons and across offspring status.

The goal of this project was to assess the patterns and drivers of patterns in spatial-temporal grizzly bear habitat use. In order to meet our goal we quantified space-time habitat use and related patterns of habitat use to covariates on environmental conditions and maternal status.

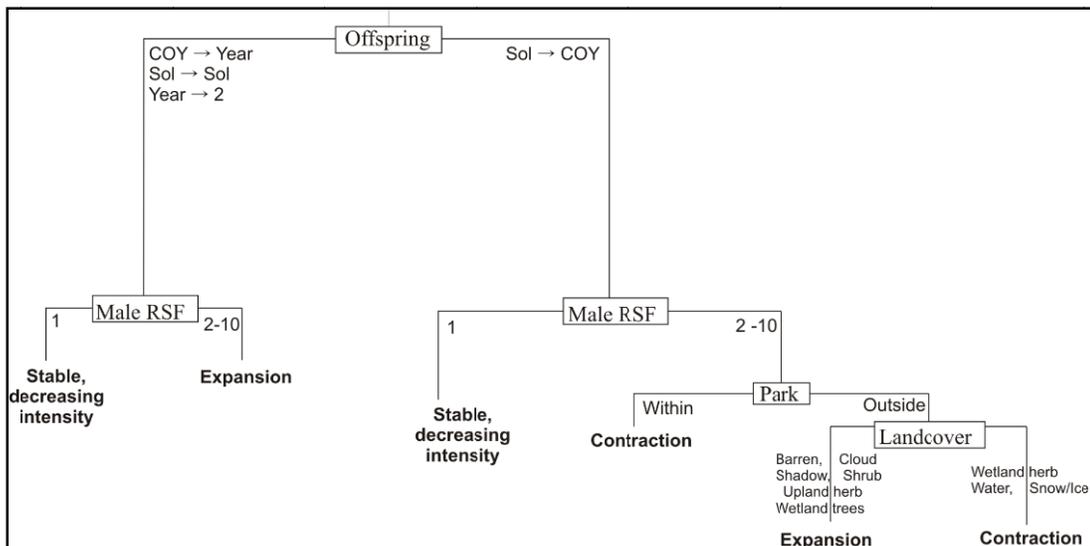
We categorized the spatial-temporal pattern of habitat use by considering both the temporal overlap of home ranges and change in intensity of utilization distributions through time using Spatial Temporal Analysis of Moving Polygons (STAMP). STAMP employs topological relationships of polygons to characterize spatial-temporal patterns of home range change between two time periods ( $t$  and  $t+1$ ). Five categories of spatial-temporal habitat were identified: stable, stable increasing intensity, stable decreasing intensity, expansion, and contraction. Stable patterns are locations where the home range is present in  $t$  and  $t+1$ . Contraction patterns indicate that a location is part of a home range in  $t$  but not  $t+1$ . Expansion patterns indicate that a location was not part of a home range in  $t$  but became part of a home range in  $t+1$ .

The purpose for quantifying spatial and spatial-temporal patterns is to make inferences about processes that cannot be directly measured. Using regression trees, we related the five space-time patterns of habitat use to: offspring status, land cover, male resource selection function (RSF), human caused risk, and parks. Regression tree analysis determined the hierarchy of drivers of space-time habitat use by females. Based on the order of breaks in the regression tree, the influence of variables on spatial-temporal patterns of habitat use was ranked and the nature of the impact of independent variables quantified.

The methods we present with this work for categorizing space-time habitat use are novel, combining statistically significant change in utilization distribution with patterns of home range overlap. Categories of space-time habitat use can be related to ecological concepts such as site fidelity and drift as well as changes in intensity of habitat utilization by wildlife. We found the space-time patterns of habitat use to vary by cub status and season. Females transitioning from solitary to having COY, showed a tendency to use smaller home ranges but some were observed to intensify use of previously known locations. It is possible that female with the youngest cubs seek refuge in familiar habitat as they are best able to protect vulnerable young. For the COY to Yearling class, expansion is common suggesting that female cubs with bears one year or older use a larger habitat range. These bears expand most in the spring and may reflect the compactness of home ranges used in the previous spring. Increased intensity of previously used

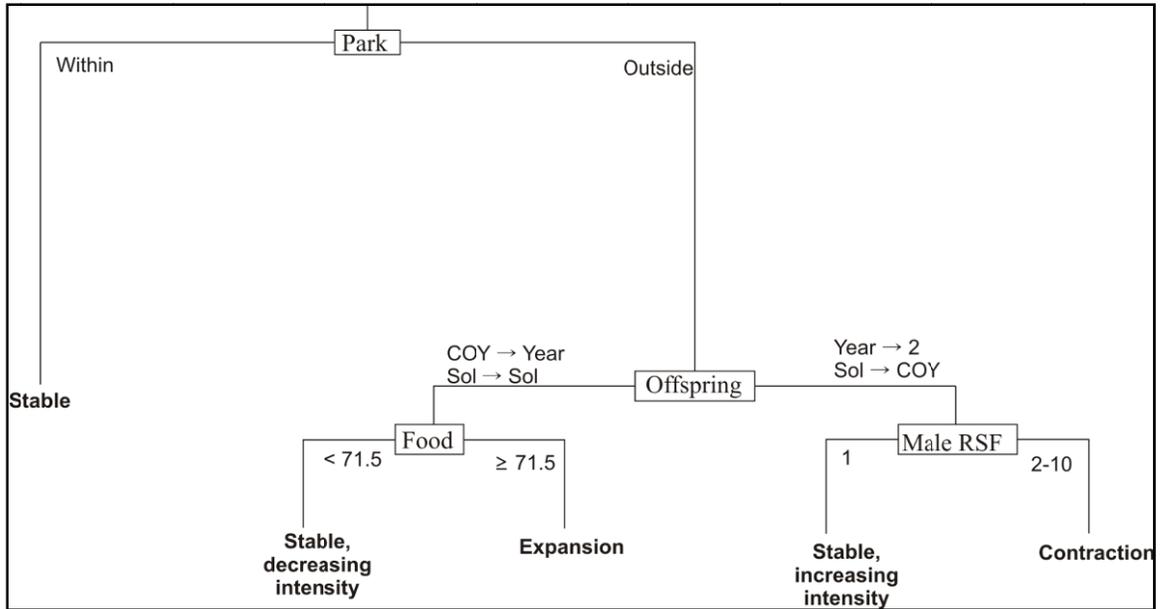
habitat occurs most frequently in spring (11km) and summer (12km), which may indicate that concentration in familiar areas becomes less important as cubs age. Regardless of offspring status, summer has the greatest amount of stable habitat use, which may relate to the summer season having the most spatially extensive available resources.

The results of the regression tree analysis provided a hierarchy of the drivers of spatial-temporal habitat use by females. In spring (Figure 14), offspring age was shown to be the most important driver of habitat use, followed by the male RSF, parks, and land cover and is supported by our pattern results along with previous studies. The regression tree results indicate that mobile females, which are solitary or have cubs greater than one year, do not avoid males or people and take advantage of high quality male habitat. In contrast, females with COY avoid better quality male habitat, particularly in parks, perhaps indicating the avoidance of males. It is interesting that females with COY do not appear to be seeking refuge inside parks. Possibly, the lower quality high elevation habitat in parks is insufficient to support the nutritional demands of bears with COY or, perhaps, males tend to use parks and are displacing females with COY.



**Figure 14.** Regression tree results for the spring season.

In summer, park boundaries are the most important predictor of space-time patterns of habitat use (Figure 15). The second most important covariate is offspring status with food availability and male RSF ranked equally as the third factor. Compared to spring, the trends associated with offspring status in the summer are less clear and may be due to the increased home range that is observed for females in the summer season. Outside of parks females having COY contract out of good male habitat (high male RSF), similar to trends observed in the spring. Also outside parks, solitary females expand into the best food areas and use areas with less abundant food with declining intensity. Less use of poorer food areas suggests solitary bears benefit from experience gained in previous years. Use of food rich areas outside of park is also observed for females with yearling cubs suggesting that male bears do not pose the same risk to yearlings as cubs.



**Figure 15. Regression tree results for summer season.**

The drivers of space-time habitat use are most complex in autumn (Figure 16). Offspring status is the most important driver of space-time habitat use in autumn; however, park boundaries, male RSF values, and food availability also play a role. While bears in the yearling to 2 year old class are associated with expansion, and the COY to Yearling class are associated with stable decreasing intensity, solitary to solitary and solitary to COY bears appear to have more complex drivers. For solitary to solitary bears, park boundaries are important with contraction occurring outside parks and increasing intensity occurring within. For solitary to COY bears, we see some expansion to locations with higher male RSFs. We speculate that the mobility of cubs has increased sufficiently to lessen the threat of male infanticide. Bears in the solitary to COY category also contract or decrease intensity of use in areas with high food availability in both high and low quality male habitat. In locations with low quality this same group expands outside the park and decreases intensity of use within the park.

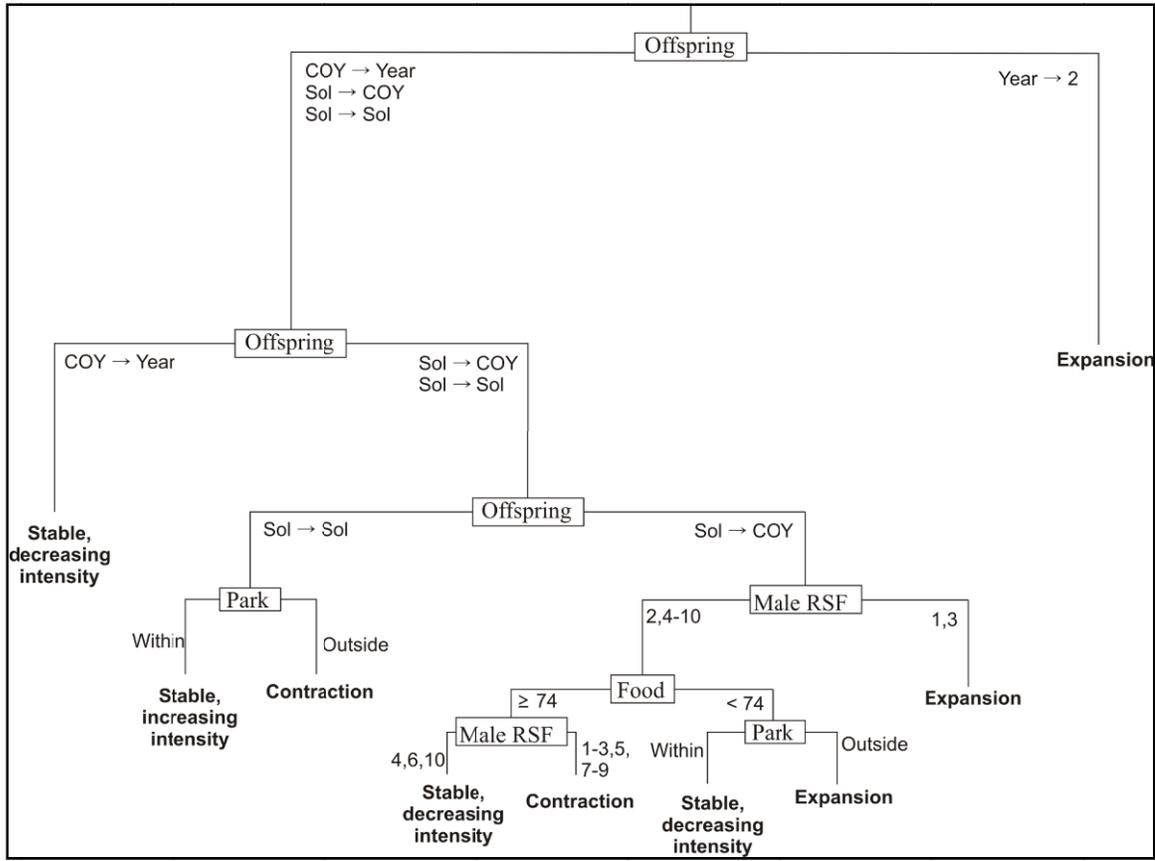


Figure 16. Regression tree results for autumn season.

**Outcome:**

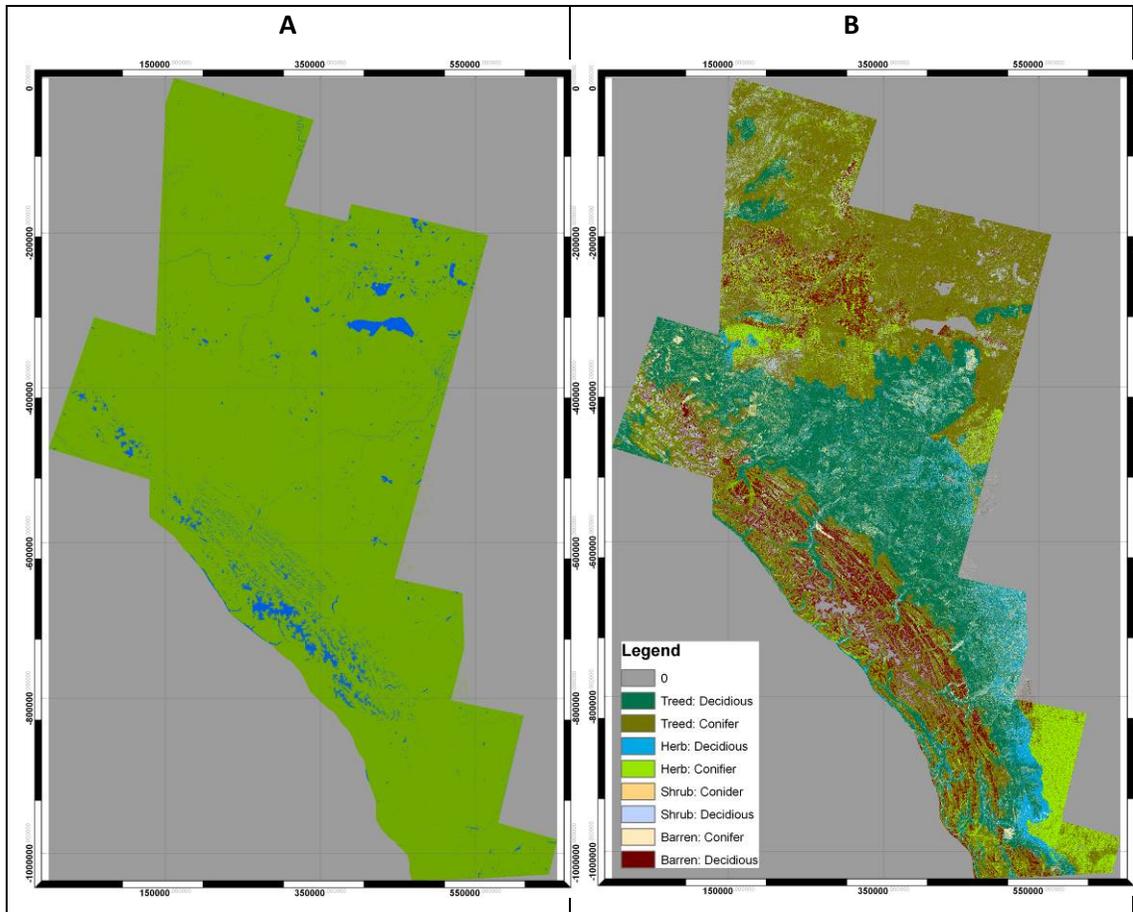
Nelson, T.N., Nielsen, S.E., Smulders, M., Laberee, K., Gralewicz, N., Wulder, M.A., and Stenhouse, G. (In prep). Drivers of grizzly bear space-time habitat use.

## TOPIC 5 - PROJECTING LANDSCAPE RECOVERY AND CHANGE

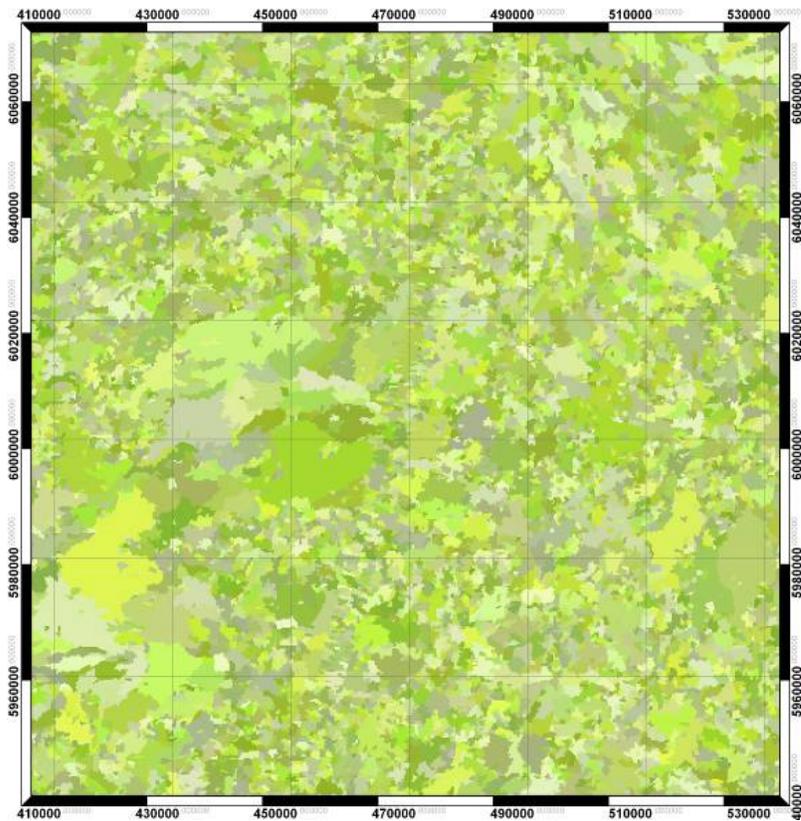
### **5.1.Scenario-based modelling approach which combines information on land cover change with forest growth and forest recovery growth rates. (2011/12 – overall) and Review of options for combining remotely sensed data and spatial data layers to project landscape recovery and change (2010/11).**

In order to develop the scenario-based modelling approaches which combine information on land cover change with forest growth, recovery and disturbance a scientifically informed platform for modelling is needed. This modelling framework / platform will allow grizzly bear energetics, occupancy, and survival to be visualised and modeled and requires base maps of landscape conditions, landscape change, and projections for future conditions. Capturing disturbance for ongoing characterization of the landscape is necessary as disturbances impact habitat quality in both positive and negative manners. By mapping landscape disturbance we will gain insights on what changes, by type and location, are occurring over the study area and how habitat quality and energy availability is impacted by change. Characterization of vegetation recovery post-disturbance is also important for this long-term monitoring and modelling program. We will capture in a spatially explicit manner detailed annual depictions of phenology. The development of phenological layers is aided by deployment and analysis of a network of cameras. The camera network captures vegetation type and change within and between years enabling modelling of phenological conditions.

Through 2010/11 we have continued to develop base layers to support this scenario-based modelling approach. A spatial database of land cover, canopy closure and disturbances by type are being integrated from existing map products and STAARCH outputs. We have begun to parameterise the LANDIS model which is simulation models which is spatially explicit and models forest succession, disturbance (including fire, wind, harvesting, insects, global change), and seed dispersal across large (> 1 million ha) landscapes. In order to capture past and future landscape patterns due to fire and harvesting disturbance regimes we have chosen to use the LANDIS modelling framework. LANDIS is a landscape scale model which works across a range of spatial and temporal scales. Regions can be defined within the study area that have varying responses to a range of disturbances such as fire, harvesting, and wind as well as forest dynamics such as succession. LANDIS can be parameterised for a range of both overstory and understory species, and has a capacity to incorporate future climate with respect to fire fuel development and changes in future forest growth patterns. LANDIS is a spatially explicit, stochastic, raster-based model which each spatial cell is tracked with respect to presence / absence of species cohorts as well as fire and fuel characteristics. The model has been applied to a large number of ecosystems around the world, and has active team of developers who are adding and refining modules based on individual model applications. We are using LANDIS-II which is a completely re-engineered version developed at University of Wisconsin-Madison. LANDIS-II has variable time steps for each extension allowing landscape prediction at a variety of time steps from a single year to decades. Some of the initial map products which have been produced to work within LANDIS-II are shown on the next two pages (Figure 17), and initial segmentation findings (Figure 18).



**Figure 17.** (A) LANDIS Ecoregion map which provides a mask of the key processing areas within the study area. Currently areas outside the grizzly bear study area and water / snow are excluded. In ongoing modelling we will divide the remaining area into a number of smaller ecoregions to represent different climatic zones. (B) A map of initial communities was developed from land cover, age and pine occurrence maps developed by UC and UBC. Used in combination we developed a initial map which indicates the current range of the two major deciduous and coniferous species in the area and their age class which is shown as either tree, shrub herb or barren (regeneration).



**Figure 18.** Using STAARCH output, and the raw Landsat imagery, we have undertaken an initial image segmentation to create management units which LANDIS-II then uses as a map base upon which to undertake harvesting. This initial segmentation process results in an over partitioning of the land base. We envision a hierarchical approach to refine and/or utilize the level of detail generated with more generalized landscape level information needs.

## APPENDIX 1: LIST OF PROGRAM PARTNERS (1999 – Present)

Ainsworth Lumber Co. Ltd.  
 Alberta Advanced Education and Technology  
 (formerly Innovation and Science)  
 Alberta Conservation Association  
 Alberta Environment  
 Alberta Fish & Game Association  
 AB Innovates (ARC)  
 Alberta Newsprint Company  
 Alberta Sustainable Resource Development  
 Alberta Tourism, Parks and Recreation  
 Anadarko Canada Corporation  
 Anderson Exploration Ltd.  
 AVID Canada  
 B P Canada Energy Company  
 BC Oil and Gas Commission  
 Buchanan Lumber – Tolko OSB  
 Canada Centre for Remote Sensing  
 Canadian Association of Petroleum Producers  
 (CAPP)  
     Petroleum Technology Alliance Canada  
     (PTAC)  
     Environmental Research Advisory  
     Council (ERAC) Fund  
     Alberta Upstream Petroleum Research Fund  
 Canadian Natural Resources Ltd.  
 Canfor Corporation  
 Center for Wildlife Conservation  
 ConocoPhillips Canada  
     (formerly Burlington Resources Canada Ltd.)  
     (formerly Canadian Hunter Exploration Ltd.)  
 Conservation Biology Institute  
 Daishowa Marubeni International Ltd.  
 Devon Canada Corp  
 Enbridge Inc.  
 Encana Corporation

ENFORM  
 Foothills Research Institute  
     (formerly Foothills Model Forest)  
 Forest Resources Improvement Association of  
     Alberta (FRIAA)  
 G&A Petroleum Services  
 GeoAnalytic Inc.  
 Government of Canada  
     Canadian Forest Service, Natural  
     Resources Canada  
     Canadian Wildlife Service  
     Environment Canada – HSP  
     Human Resources and Skills  
     Development Canada  
     Natural Sciences and Engineering  
     Research Council of Canada  
     (NSERC)  
     Parks Canada  
         Banff National Park  
         Jasper National Park  
 Grande Cache Coal Corporation  
 Hinton Fish and Game Association  
 Hinton Training Centre  
 Husky Energy Inc.  
 Komex International Ltd.  
 Lehigh Inland Cement Limited  
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 Manning Diversified Forest Products Ltd.  
 Manning Forestry Research Fund  
 Millar Western Forest Products Ltd.  
 Mountain Equipment Co-op  
 Nature Conservancy  
 NatureServe Canada  
 Nexen Inc.

Northrock Resources Ltd.  
 Peregrine Helicopters  
 Persta  
 Petro Canada Ltd.  
 Peyto Energy Trust  
 Precision Drilling Corporation  
 Rocky Mountain Elk Foundation - Canada  
 Shell Canada Limited  
 Sherritt – Coal Valley Resources  
 Slave Lake Division – Alberta Plywood  
 Spray Lake Sawmills Ltd.  
 Suncor Energy Inc.  
 Sundance Forest Industries Ltd.  
 Talisman Energy Inc.  
 TECH – Cardinal River Operations  
     (formerly Elk Valley Coal)  
 Telemetry Solutions  
 TransCanada Pipelines Ltd.  
 University of Alberta  
 University of Calgary  
 University of Lethbridge  
 University of Saskatchewan  
     Western College of Veterinary Medicine  
 University of Washington  
 University of Waterloo  
 Veritas DGC Inc.  
 West Fraser Mills Ltd.  
     Alberta Plywood  
     Blue Ridge Lumber Inc.  
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     Slave Lake Pulp  
     Sundre Forest Products  
 Weyerhaeuser Company Limited  
 Wilfred Laurier University  
 World Wildlife Fund Canada

## **APPENDIX 2: LIST OF PROGRAM PARTNERS (2010)**

CAPP - Alberta Upstream Petroleum Research Fund  
ConocoPhillips Canada  
Devon Canada Corp  
Encana  
Environment Canada  
Foothills Research Institute (Core)  
    Mountain Pine Beetle Program  
Grande Cache Coal Corporation  
Government of Alberta  
    Alberta Tourism, Parks and Recreation  
    Alberta Sustainable Resource Development  
    Alberta Employment and Immigration (STEP)  
    AB Innovates (ARC)  
Government of Canada  
    Natural Resources Canada  
    Human Resources and Skills Development Canada (CSJ)  
    Parks Canada  
    Natural Sciences and Engineering Research Council of Canada (NSERC)  
Husky Energy Inc.  
Nature Conservancy  
Nexon  
Petro Canada Ltd. (now part of Shell Canada Limited)  
Shell Canada Limited  
Sherritt – Coal Valley Resources  
Suncor Energy Inc.  
Sundance Forest Industries Ltd.  
Talisman Energy Inc.  
TransCanada Pipelines Ltd.  
Weyerhaeuser Company Ltd  
Yellowstone to Yukon

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