FOOTHILLS RESEARCH INSTITUTE
GRIZZLY BEAR PROGRAM
2012 ANNUAL REPORT

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DISCLAIMER

This report presents preliminary findings from the 2011 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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CHAPTER 1: SUMMARY OF 2012 CAPTURE PROGRAM

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Introduction

The 2012 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 of all grizzly bears handled during our operations.

In 2012 we also provided capture and handling assistance to a study being conducted by the University of Alberta in association with Alberta Tourism, Parks and Recreation looking at human interactions and grizzly bears.

Study Areas

We captured and sampled grizzly bears in two distinct study areas in 2012 (Figure 1). Twelve bears were captured in a northern area between Grande Prairie and Grande Cache, known as the Kakwa study area. Seven grizzly bears were captured south of Hinton and east of Jasper National Park, known as the Human Interaction study area (U of A study area).

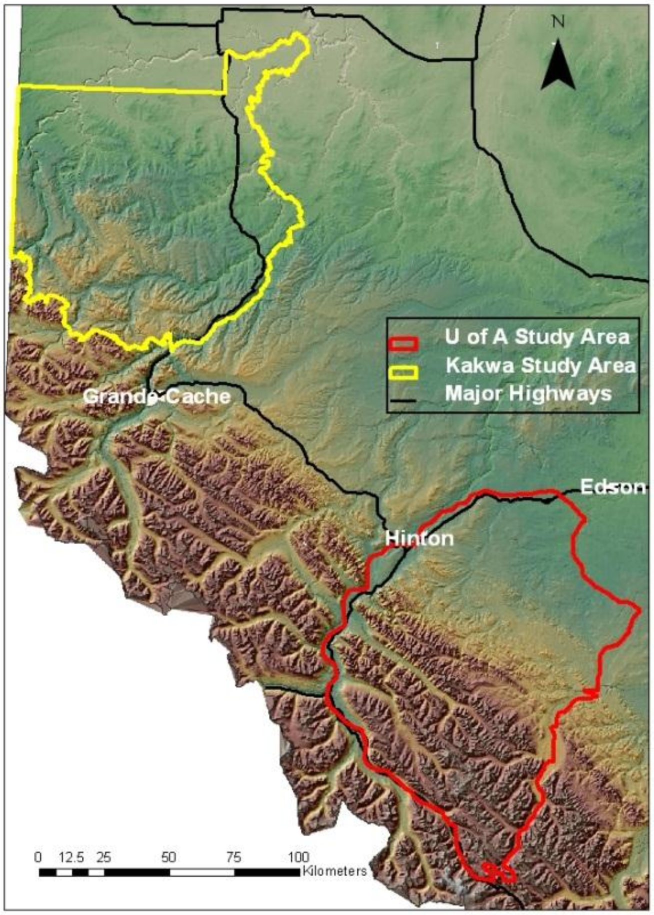


Figure 1: Study area boundaries for the 2012 capture season

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.

Field capture efforts began in early May in the Kakwa study area. The crew was based out of the Kakwa Tower camp. Capture efforts for the Human Interaction study area began in mid May. Helicopter darting was targeted at specific bears for recapture and collar replacement. New bears were captured in a culvert trap. The spring capture season ended by mid June. The fall capture season began in mid September and ended by mid October.

Table 1. Grizzly bear captures

Name	Date	Recapture	Sex	Age Class	Population Unit	Capture Method
G004	22-May-12	yes	F	adult	Yellowhead	heli dart
G016	08-Jun-12	yes	F	adult	Yellowhead	heli dart
G053	17-May-12	yes	M	adult	Yellowhead	heli dart
G111	14-May-12	yes	F	adult	Yellowhead	heli dart
G119	10-Oct-12	yes	F	adult	Yellowhead	culvert trap
G120	29-Sep-12	no	M	subadult	Yellowhead	culvert trap
G120	01-Oct-12	yes	M	subadult	Yellowhead	culvert trap
G126	04-Oct-12	no	F	subadult	Yellowhead	ground dart
G257	24-Sep-12	yes	M	adult	Grande Cache	culvert trap
G260	18-May-12	yes	F	adult	Grande Cache	culvert trap
G275	04-May-12	no	F	subadult	Grande Cache	culvert trap
G275	13-May-12	yes	F	subadult	Grande Cache	culvert trap
G277	22-May-12	no	M	adult	Grande Cache	culvert trap
G278	24-May-12	no	M	adult	Grande Cache	culvert trap
G279	28-May-12	no	M	adult	Grande Cache	culvert trap
G280	05-Jun-12	no	F	subadult	Grande Cache	culvert trap
G281	13-Jun-12	no	M	adult	Grande Cache	culvert trap
G282	15-Sep-12	no	F	subadult	Grande Cache	culvert trap
G283	16-Sep-12	no	M	adult	Grande Cache	culvert trap
G284	19-Sep-12	no	M	adult	Grande Cache	culvert trap
G285	23-Sep-12	no	M	subadult	Grande Cache	culvert trap
G285	25-Sep-12	yes	M	subadult	Grande Cache	culvert trap

We anaesthetized 7 grizzly bears using a combination of xylazine and Telazol and 12 bears using a combination of Medetomidine-hydromorphine-telazol; both 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 on the capture and handling of ursids as well as provincial standards.

In total, we captured 19 grizzly bears in our 2012 field season (Table 1) from 22 capture events (3 bears were captured twice). Twelve bears were caught in the Kakwa area, and 7 were captured in the Human Interaction study area south of Hinton, Alberta. No black bears were handled this field season and no other non-target species were captured. No capture related mortalites occurred during the 2012 field season.

Sex and Age Characteristics

Of the 19 grizzly bears captured 13 (68%) were adults, 6 (32%) were sub-adults, 10 (53%) were males, 9 (47%) were females (Table 1). Adult males were captured most often (42%), followed by adult females (26%), subadult females (21%) and subadult males (11%). 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 18 captured bears. One bear was deemed to large to collar (G053). All radio-collars have an integrated remote release mechanism in addition to a rot-off system as a backup in case of electronic failure. Radio-collars deployed consisted of Follow-it Tellus Iridium collars and Telemetry Solutions Iridium collars. Data from these collars can be acquired from a website so data upload flights were not necessary. Collars collect locations on the following schedule:

- April 1 to November 31 - 1 location/ hour.
- December 1 to March 31 - 1 location/day

We conducted data upload flights for 2 Tellus-collared bears in the Kakwa study area that were collared last year and were not Iridium collars. We collected over 40,000 GPS location points from the Tellus and Satellite collars combined.

Grizzly Bear Health Evaluation

We gathered health information from all 19 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 2012 will be entered into our project health database.

Modification of Anesthetic Protocol for Foothills Research Institute Grizzly Bear Project

Beginning in spring 2013, we will be modifying our anesthetic protocol to incrementally replace the immobilizing drug combination of xylazine-zolazepam-tiletamine (XZT), which has been our mainstay combination for the past 12 years, with the combination of medetomidine-zolazepam-tiletamine (MZT). The use of MZT will enable administration of smaller drug volumes, due to the greater potency of medetomidine, which will facilitate improved accuracy and reduced injury by remote drug delivery. Further, the anesthetic effects of MZT are more readily reversed with the antagonist drug atipamezole than are the effects of XZT. Thus, increased reliability with the reversal procedure will allow us to better ensure that captured bears are on their feet and mobile as soon as possible following handling and sampling.

We will be using the following dosages: medetomidine at 60-75 ug/kg IM, Telazol (zolazepam-tiletamine) at 2.1-2.6 mg/kg IM, and atipamezole at 240-300 ug/kg half-IM and half-IV. This protocol has been adapted for use with Alberta grizzly bears from a similar protocol used by the Scandinavian Brown Bear Project (SBBP) over the past 15 years(1). Our approach to phasing in the MZT protocol will be incremental in the sense that we will initially restrict its use to bears captured by culvert trap only. Then, once we have developed a sense of the efficacy of our protocol (i.e., consistency and speed of induction), we will extend the use of MZT to the capture of free-ranging bears by remote drug delivery from helicopter. Our project veterinarian (Marc Cattet) has extensive experience with the preparation and use of MZT in polar bears(2). In addition, Marc Cattet and Gordon Stenhouse assisted SBBP field personnel with the capture of brown bears in Sweden in 2010, and through this experience gained insight into the behavioral response of brown (grizzly) bears to anesthesia and reversal with MZT and atipamezole. In spring 2012, we tested MZT and atipamezole at the dosages listed above to anesthetize and reverse four grizzly bears captured by culvert trap. Albeit a small number of animals, induction was smooth and relatively quick (≤5 min), anesthesia was stable over a 45-60 min handling/sampling period, and reversal was also smooth and relatively quick (10-20 min). Given our experience-to-date with MZT and its similar anesthetic behavioral and physiological effects to XZT, we do not anticipate any difficulties, such as increased health risks for bears or safety risks for field personnel, in adapting to this new anesthetic protocol. Further, we will continue to look toward improving our anesthetic protocol in future, e.g., dexmedetomidine and Telazol® to eventually replace MZT.

Relevant Literature

(1) Painer J, Zedrosser A, Arnemo JM, Fahlman Å, Brunberg S, Segerstrøm P, and Swenson JE. (2012). Effects of different doses of medetomidine and tiletamine-zolazepam on the duration of induction and immobilization in free-ranging yearling brown bears (*Ursus arctos*). Canadian Journal of Zoology 90(6):753–757.

(2) Cattet MR, Caulkett NA, Polischuk SC, Ramsay MA. (1997). Reversible immobilization of free-ranging polar bears with medetomidine-zolazepam-tiletamine and atipamezole. Journal of Wildlife Diseases 33(3):611–617.

CHAPTER 2: GRIZZLY BEARS AND PIPELINES: RESPONSE TO UNIQUE LINEAR FEATURES

Year 1 Report For:

Alberta Upstream Petroleum Research Fund

Prepared by Tracy McKay, Karen Graham and Gordon Stenhouse

Foothills Research Institute Grizzly Bear Program, Hinton, Alberta

Executive Summary

Oil and gas transmission pipelines are prevalent features on the Alberta landscape. While some wildlife species avoid linear features, others may use linear features as movement corridors. Limited research has been completed regarding grizzly bear response to pipelines in Alberta. In the first year of this research project, we set out to address the current knowledge gap regarding grizzly bear habitat use, foraging patterns, and movement patterns on pipelines.

We completed an analysis of selection ratios to describe habitat use of pipelines and other linear features in our study area, including roads and seismic lines. Our results indicate that grizzly bears used roads, road-pipeline combined right-of-ways, and pipelines significantly more than expected based on habitat availability. Seismic lines were used no differently than expected. Selection patterns for pipelines, road-pipelines and roads varied by linear feature, age-sex class, and season.

To investigate what grizzly bears may be doing on pipeline RoWs, we visited 211 grizzly bear collar locations on pipelines in 2012. Analysis of field data indicates that bears are using pipeline RoWs for a range of foraging opportunities, with anting as the most common activity.

We analyzed hourly movement rates (step lengths) to investigate grizzly bear movement on pipelines and other linear features. Movement rates of grizzly bears were significantly faster on road RoWs, road-pipeline RoWs, pipeline RoWs, and seismic RoWs as compared to non-linear habitat. Fast rates of movement suggest that linear feature RoWs may serve as movement corridors for grizzly bears in our study area. Age-sex class and period of the day were also significant predictors of movement rates.

The use of pipeline right-of-ways for foraging and movement has potential consequences for grizzly bears and other species. Bears using linear features are at a higher risk of human-caused mortality. Grizzly bear use of RoWs for movement could also result in avoidance of linear features by ungulates such as caribou, and has the potential to increase grizzly bear predation rates on caribou.

As oil and gas development continues to expand in grizzly bear habitat, it is important to gain an understanding of the potential impacts of pipelines on grizzly bears. Results from this research will

help resource managers to understand and predict grizzly bear response to pipelines, assisting with resource management and recovery efforts in grizzly bear habitat in Alberta.

Background, Study Area, and Research Objectives

Background

Approximately 350,000km of oil and gas transmission pipelines have been constructed on the Alberta landscape (Alberta Environment and Sustainable Resource Development 2013). When pipeline construction takes place, a right-of-way (RoW) is cleared through the forested habitat. Following the construction phase, vegetation returns along the RoW, but it remains as a cleared linear corridor within the forest. Wildlife species such as woodland caribou (*Rangifer tarandus*) are reported to avoid linear features (James and Stuart-Smith 2000, Dyer et al. 2001). Previous research has also shown that wolves may use linear corridors (roads, seismic lines, trails, railway lines) as travel routes (Thurber et al. 1994, Musiani et al. 1998, James and Stuart-Smith 2000, Whittington et al. 2005). However, limited research on the effects of linear features has been completed for grizzly bears. A study completed in the Kakwa region (Figure 1) during 2005-2010 indicated that the majority of grizzly bears were closer than expected to pipeline features in the spring, and movement rates of these bears within 500m of pipelines were faster than when pipelines were not present (Labaree et al. 2012). In addition, females in this area have been shown to use pipeline edges more than expected, and males also used pipeline edges more than expected in the spring (Stewart 2012). Additional anecdotal evidence includes sightings of grizzly bears foraging on pipeline right-of-ways (RoWs) and traveling along pipelines. However, to our knowledge, there are currently no published data regarding the effects of pipelines on finer scale grizzly bear habitat use, foraging patterns, and movement patterns in Alberta.

Linear corridors also may provide human access into remote grizzly bear habitat. Pipeline right-of-ways differ from resource access roads in that they generally are not designed for vehicle traffic. However, pipeline RoWs may be used for a variety of human activities, including ATV travel, hunting, and general recreation. In addition, pipelines are often constructed next to roads, in order to decrease the overall disturbance footprint in the area. Human-caused mortality is considered to be the primary limiting factor for grizzly bears in Alberta (Alberta Grizzly Bear Recovery Team 2008), and areas with a higher level of human access are associated with an increased risk of human-caused grizzly bear mortalities (Jalkotzy et al. 1997, Benn 1998, Nielsen et al. 2004a, Roever et al. 2008a). Therefore, linear corridors such as pipelines could have implications for grizzly bear mortality risk.

The Foothills Research Institute Grizzly Bear Program (FRIGBP) has been working in the Kakwa region of west central Alberta since 2005. Grizzly bear GPS location data from this area along with the presence of extensive linear features in this region provide an opportunity to investigate where, when, how, and to what extent grizzly bears respond to pipeline right of ways. Research objectives in 2012 were addressed by utilizing and expanding upon our existing grizzly bear GPS location dataset in the Kakwa study area (Figure 1). GIS analysis of existing data was supplemented by detailed and directed fieldwork in 2012 at selected pipeline sites within the region.

Study Area

The 2012 study area included 8,300 square kilometres in west-central Alberta, Canada (**Error! eference source not found.**). The area includes high elevation snow, rock, and ice in the west and low elevation foothills to the east. Elevation ranges from 549m to 2446m, annual precipitation varies from 550mm to 1050 mm, and mean daily temperatures range from 4.7 to 11.3°C (Natural Regions Committee 2006). Over half of the area is conifer or conifer-dominated mixed forest. Oil and gas development and forest harvesting activities have been ongoing in this region since the 1950s (Andison 1998, White et al. 2011). As of 2011, the Kakwa study area contained approximately 4200km of pipelines, equivalent to a pipeline density of ~0.5km/km^2.

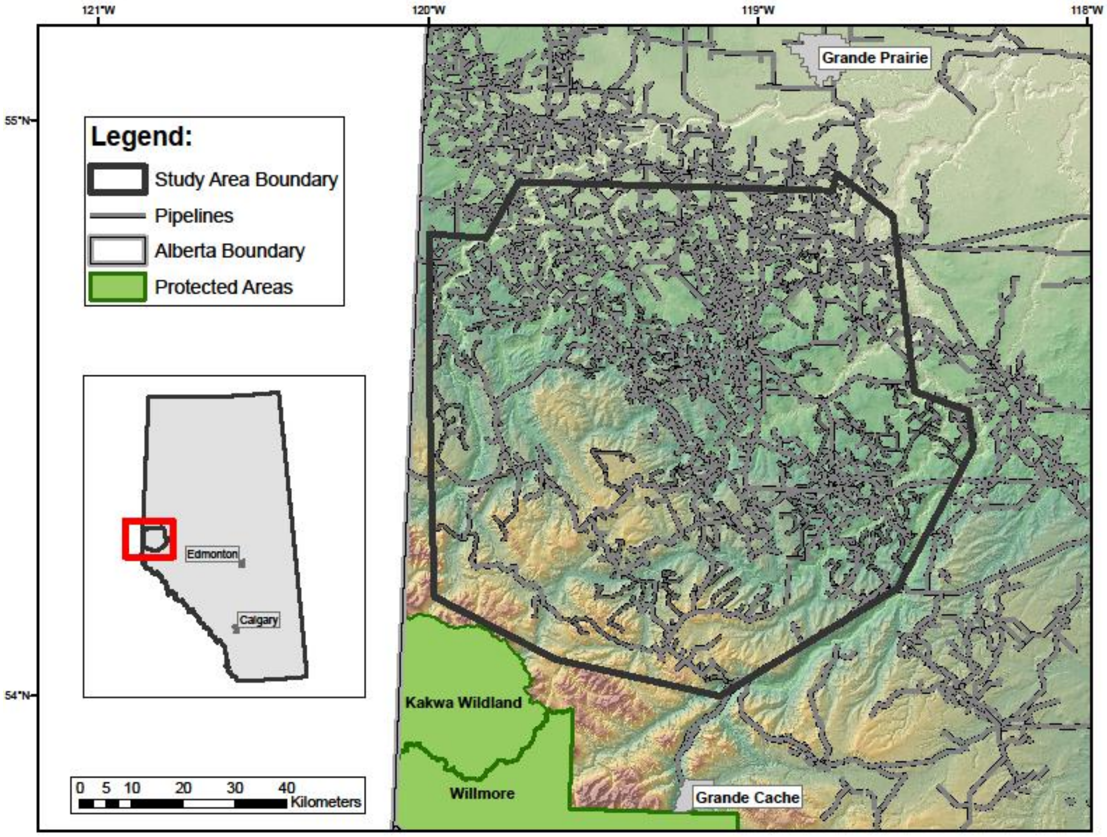


Figure 1: Kakwa study area.

Research objectives

The purpose of the first year of this project was to address the primary knowledge gaps, including:

I. Investigation of grizzly bear habitat selection patterns on pipeline RoWs:
    a. Do grizzly bears select for pipeline RoWs, avoid pipelines, or use them no differently than expected?
    b. How does use of pipelines differ from grizzly bear selection patterns of other linear features such as roads and seismic lines?
    c. Does age-sex class, season and time of day influence grizzly bear use of these linear features?

Based on preliminary data suggesting that grizzly bears do spend time on pipeline RoWs, additional objectives included:

II. Determination of grizzly bear activities on pipeline RoWs:
    a. What foraging activities are observed on RoWs (herbivory, anting, digging, berry feeding)?
    b. Are bears using RoWs or edges for bedding?
    c. What parameters predict the probability of each activity class at use sites on pipelines (e.g. season, time of day, age-sex class)?

III. Assessment of grizzly bears movement rates on pipeline RoWs:
    a. Are grizzly bears using pipeline RoWs for travel (fast movement)?
    b. How do movement rates on pipeline RoWs compare to movement rates along other linear features and in non-linear habitat?

With continued development and expansion of oil and gas pipeline operations in grizzly bear habitat, it is important to gain an understanding of the potential impacts of pipeline development on grizzly bears. Results from this research will help resource managers understand and predict grizzly bear response to pipeline right of ways (RoWs). This information can be applied to resource management and recovery efforts in grizzly bear habitat in Alberta.

2.1: Grizzly bear habitat selection patterns on pipeline right-of-ways

Prepared by Karen Graham

Foothills Research Institute

Introduction

Oil and gas pipelines have created linear features throughout forested grizzly bear habitat in Alberta. Understanding grizzly bear habitat use and response to linear features such as pipelines is essential for effective conservation, management, and recovery of this Threatened species in Alberta (Alberta Sustainable Resource Development [ASRD] 2008). Despite the fact that pipelines have been a part of the Alberta landscape for several decades, there has been limited research examining the response of grizzly bears to pipelines in North America.

Within west-central Alberta, researchers have reported that grizzly bears select for cutblocks (Nielsen et al. 2004b, Stewart et al. 2012, Stewart et al. 2013), wellsites (Sahlen 2010, McKay et al. 2012) and roads (Graham et al. 2010, Roever et al. 2010). The use of anthropogenic openings by grizzly bears has been attributed to the presence of bear foods growing along edges and within young or deforested habitats (Munro et al. 2006, Nielson et al. 2004a, Nielson et al. 2004b, Roever et al. 2008b, Larsen 2012, Stewart et al. 2013). Similar to other anthropogenic disturbances, pipelines provide edges and openings that could also support the growth of bear foods.

The main objective of our analysis was to determine whether grizzly bears select for pipelines, avoid pipelines, or use them no differently than expected. However, in investigating grizzly bear use of pipeline RoWs, it is also important to acknowledge the presence of many other linear features on the landscape. Therefore, we also investigated how use of pipelines differs from grizzly bear selection patterns of other linear features such as roads and seismic lines. Habitat selection can vary with age-sex class, season and time of day (Nielsen 2005, Berland et al. 2008, Graham et al. 2010, Roever et al. 2010). Therefore, we also investigated whether age-sex class, season and time of day influence grizzly bear use of these linear features.

Methods

Grizzly bear location data:

Location data were obtained from collared grizzly bears within the Kakwa study area during 2006-2012. Collars were programed to obtain hourly GPS locations, to a maximum of 24 locations per day. All trapping and collaring efforts met or exceeded the standards of the Canadian Council of Animal Welfare; capture procedures are described within Cattet et al. (2003a, 2003b).

For each year and bear, locations were divided into Season 1 (May 1st to July 31st) and Season 2 (August 1st to October 31st). These seasons roughly correspond to the breeding and nonbreeding seasons (Stenhouse et al. 2005); hypophagia/early hyperphagia, and late hyperphagia foraging seasons (Nielson 2005), and pre and post berry seasons (Munro et al. 2006) respectively. Because grizzly bear habitat use varies across seasons and is related to plant phenology (Nielsen et al.

2004b, Nielsen et al. 2004c, Munro et al. 2006), bears with location data consisting of <44 days for a given season were removed, in order to ensure that at least 50% of a season was represented.

We used Televilt (Followit) GPS collars for collection of grizzly bear location data. Televilt collars average 18m and 265m error distances for 3D and 2D locations respectively (Sager-Fradkin et al. 2007). We removed 2D locations from our dataset due to the potential for large location errors.

To quantify the area available to an animal, we determined annual home ranges as Minimum Convex Polygons (MCPs). MCPs were generated in a Geographic Information System (ArcInfo) using ACCRU tools (Management Unit Delineation, Home Ranges, Minimum Convex Polygon) developed for batch processing of data. The ACCRU tool runs a python script in ArcInfo, and draws a line around the outermost points in the dataset (personal communication, Charlene Nielsen, University of Alberta). To ensure that available habitat was accurately represented for each bear, bears with <90% of their annual MCP area within the study area boundary were removed from the dataset.

Grizzly bears ≥ 5years old were considered as adults. Bears were classified as subadults if they were <5 years old, >2 years old, and independent from their mother. Age determination was completed using cementum analysis of a pre-molar tooth extracted at capture. Age-sex classes used in the analysis included adult females, adult males, and subadults (male and female).

<u>Linear feature datasets:</u>
We used linear pipeline data obtained from Alberta Energy; these data were originally provided to Alberta Energy by pipeline operators in the Kakwa area. A minimum construction date was provided for the majority of the pipeline segments. For those pipelines without a construction date, an approximate construction year was determined using satellite imagery. Original line data were spatially inaccurate, and many pipelines were manually digitized to the correct locations based on satellite imagery. Pipelines with a minimum construction date prior to August 1st for a given year were considered to be present on the landscape during both Season 1 and 2 for that year, and for subsequent years. Pipelines with a minimum construction date on or after August 1st were considered present on the landscape during Season 2 of that year, and during subsequent years.

Road data were provided by Alberta Environment and Sustainable Resource Development (AESRD), and manually updated on an annual basis by FRIGBP staff. Data included the year the road was built and the road class (paved, one or two-lane gravel, or unimproved roads/trails). Power transmission lines (powerlines) and seismic line data were also provided by AESRD. Seismic line data were last updated in 2008, and the dataset did not provide a construction year. However, the vast majority of seismic lines built after 2008 were low-impact seismic; these lines are meandering and narrow in width (usually less than 3 m), and were not considered to be significant features on the landscape for the purposes of our analysis. After visual inspection using satellite imagery, we determined that the conventional (>5 m wide) seismic lines constructed prior to 2008 would be used for the seismic line dataset in our analysis.

All linear feature data were initially represented as line segments; therefore, we needed to generate a dataset that represented the actual areas of the features on the ground. We calculated the median RoW width for pipelines as measured at over 300 RoWs in the field (Chapter 3, Field methods). To determine median RoW widths for the various road classes, powerlines, and seismic lines, random locations were generated along the linear features and overlaid on LiDAR imagery in a GIS. LiDAR imagery was generated by subtracting 0.5 m heights from bare earth, making road and vegetated right-of-ways discernible. The width of the linear feature was measured at each random point using the GIS measuring tool. Median widths for all linear features were divided by half for use as a buffer along each side of the linear feature line segment. The relatively narrow footprint of linear features also makes them sensitive to collar location errors. To account for collar error, we added 18m (3D collar error distance, see above) on each side of a linear feature polygon. The final median widths and buffers applied to each linear feature class are summarized in Table 1. In the case of overlapping adjacent buffers (e.g. a pipeline next to a road), pipeline or powerline buffers that overlapped with road buffers were identified as a unique linear feature, and were subsequently classified as road-pipeline or road-powerline combined RoWs. In areas where linear features intersected, priority was given to the feature with the largest RoW width, followed by the feature with the highest level of human disturbance (e.g. roads versus pipelines). Powerlines took priority over pipelines (individually and in combined RoWs). For roads, paved roads took priority over gravel, which took priority over unimproved roads. As the smallest features, seismic lines took the lowest priority, and were overridden by any other linear feature. The end result was a polygon dataset representing the approximate areas of each class of linear feature on the ground.

Table 1: Buffers applied to linear features in the Kakwa study area, based on widths measured in the field or using a GIS.

Linear Feature Class	**Sample Size**	**Median/2 (m)**	**Collar Error (m)**	**Final buffer width (m) (applied to both sides of line segment)**
Pipeline	322	10	18	28
Roads: unimproved	27	8	18	26
Roads: one and two lane gravel	29	18	18	36
Roads: paved	5	38	18	56
Power transmission lines	5	35	18	53
Seismic lines	20	3	18	21

Analysis:

Within each annual MCP, we determined the total area of pipelines, powerlines, seismic lines, roads, and remaining nonlinear habitat for each bear, year and season, using the linear feature polygons as described above in Linear Feature Datasets. GPS grizzly bear location points were intersected with the linear feature polygons and nonlinear habitat, and the total number of bear locations by bear, year and season within each linear feature polygon and non-linear habitat was determined. Following Manly et al. (2002), we completed Chi-square analyses and the determination of selection ratios. For bears with greater than one year of data, annual data were pooled if the bear was in the same age-sex class across years. The assumptions of the Chi-square test are not met if expected values are less than five, and standard errors and confidence limits are not reliable if observed values are less than five (Manly et al. 2002). Since there were many instances of observed or expected values <5 for the different road classes, we pooled all three road types (unimproved roads, one or two lane gravel, and paved roads) into one class, and pooled all three road-pipeline combined classes into one road-pipeline combined class. There is a single powerline in our study area, with a total length of 162km; based on extremely small sample sizes for powerlines, they were pooled with pipeline RoWs. The final dataset of expected and used values by bear and season included four linear features (roads, road-pipelines, pipelines, and seismic lines) along with the remaining nonlinear habitat. We excluded 2 male bears (one adult and one subadult) from the spring analysis, and 6 bears from the fall analysis (3 adult females, 1 subadult female and 2 subadult males) because observed or expected values remained less than five after pooling the habitats.

Habitat selection patterns

The Pearson Chi-square test was used to determine if the observed number of locations were significantly different from expected for each age-sex class and season, as follows:

$$X^2 = \sum\sum (O_{ijk} - E_{ijk})^2 / E_{ijk},$$

where O_{ijk} is the observed number of locations in habitat i for bear j in season k, and E_{ijk} is the expected number of locations in habitat i for bear j for season k. E_{ijk} was determined by multiplying the proportion of habitat i in bear j's annual home range for season k by the total number of locations for bear j in season k. These values were summed by age-sex class, and if this statistic was larger than expected based on the Chi-square distribution for n(I – 1) df (where I = the number of habitat classes), overall habitat use was interpreted as different from expected for that age-sex class.

If the Chi-square test was significant, we further investigated selection using selection ratios and confidence intervals. We followed the methods outlined for a Design III analysis with sampling Protocol A, as proposed by Manly et al. (2002), where use was measured for each animal, and the proportion of available habitat was accurately determined and unique for each animal. This analysis considers selection of individual bears as the sampling unit (i.e. independent events), provided that collared animals represent a random sample from the population. As a result, the analysis removes potential biases associated with the temporal correlation typical of GPS collar data.

Selection ratios for each habitat by age-sex class were determined using equation 4.42 from Manly et al. (2002). The variance and standard error estimates of the selection ratios for each habitat class were determine using equation 4.3, and simultaneous Bonferroni 95% confidence intervals adjusted for multiple comparisons across habitat classes were determined. The adjusted confidence interval ensures that the probability will approximate the true value for the population at 1-α % across all 5 habitat classes simultaneously. We used an α level of 0.05, which resulted in confidence intervals for each habitat to be 0.995%, providing an overall 95% confidence level that the 5 habitat class results contained the true population values. If a resulting confidence interval did not enclose the value of 1.00, non-random use (i.e. selection or avoidance) of that habitat class was occurring.

Habitat selection across habitats, age-sex classes and seasons

We wanted to determine if significant differences occurred in selection ratios between different habitats, age-sex classes, and seasons. Following Manly et al. (2002), differences in selection ratios between two groups were determined by subtracting the mean selection ratio of one group from the other group. For example, the differences between selection ratios for each age-sex class for the various combinations of habitat classes were determined: between roads and pipelines, roads and road-pipelines, roads and seismic, etc., for a total of 10 different combinations. To test for significance, we used equation 4.34 to determine standard errors and applied the Bonferroni adjustment to the confidence intervals for the 10 different comparisons. If the standard error bars did not encompass zero, a significant difference existed. We repeated this for differences between age-sex classes (adult females, adult males and subadults), and seasons.

Habitat selection patterns by time of day

We further divided the final location dataset into day and night time classes. We compared location times with sunrise and sunset tables (http://www.nrc-cnrc.gc.ca/eng/services/hia/sunrise-sunset/angle-calculator.html), and a day, night or crepuscular class was assigned to all the GPS collar locations. Previous work has shown that grizzly bears in our study area are most active during the day and crepuscular periods, with little or no movement at night (Graham and Stenhouse 2013, submitted). Sample sizes for crepuscular locations were low relative to day and night locations; therefore we pooled crepuscular with day locations. We initiated the methods outlined above to calculate day and night selection ratios to determine whether bears used habitats differently than expected during the day and night.

Seasons were pooled to increase sample sizes; however, resulting datasets were not adequate for Chi-square and selection ratio analysis. Night locations were particularly low, due to the fact that there are relatively few hours of darkness in our study area during May, June and July. Fifteen out of 25 bears had observed and/or expected values less than five, and could not be included in the selection ratio analysis. Datasets with observed values less than five for the linear feature classes may represent bears that do not show selection for these habitat classes during that time period. The majority (15 out of 25) of the bears in this analysis followed this pattern; therefore, exclusion of these bears from the analysis could result in a sample that is biased. Alternate analysis techniques were investigated (compositional analysis, as in Aebischer and Robertson [1993]); however, low sample sizes also resulted in violations of assumptions for alternate techiques. Therefore, we calculated mean selection ratios and 95% standard errors by day and night by habitat class to show possible trends, but no statistical analysis was completed for time of day differences.

Results

Habitat selection patterns

There were 20 and 15 unique grizzly bears in the final analysis, with 46,159 and 39,699 locations in season 1 and Season 2 respectively. Data for Season 1 included 9 adult females, 4 adult males, and 3 subadults. For Season 2, the dataset included 8 adult females, 3 adult males, and 4 subadults.

The Chi-square results were significant for each age-sex class and season ($p< 0.05$) indicating that nonrandom use of the 5 habitat classes was occurring. Figure 2 shows selection ratios and Bonferroni adjusted confidence intervals by age-sex class and season for each habitat type.

Adult females selected road-pipelines and pipelines in both seasons, but only selected for roads in Season 2. Adult males selected roads in Season 1, pipelines in both seasons, and did not use road-pipelines differently from expected. However, there were only data for 4 and 3 adult males in Season 1 and Season 2 respectively; therefore, extrapolation of these results to adult males across the population should be interpreted with caution. Subadults selected road-pipelines combined and pipelines in Season 2 and roads in Season 1. However, as with adult males, there were only data from 3 and 4 subadults in Season 1 and Season 2, respectively; therefore, extrapolation of these results across the population should also be interpreted with caution. No age-sex class used seismic lines differently from expected, and the remaining nonlinear habitat was typically used less than expected.

In general, the vast majority (>89%) of a bear's home range is made up of nonlinear habitat. It is important to note that although the selection ratio analysis indicates grizzly bears were using linear features more than expected based on habitat availability; linear features constitute a relatively small part of overall habitat use by grizzly bears.

Habitat selection across habitats, age-sex classes and seasons

Results from the comparisons between habitats, age-sex classes and seasons are presented in Table 2. The selection ratio for adult females in the spring for nonlinear habitat was significantly smaller than road-pipelines combined. In the fall, selection ratios for seismic and nonlinear habitat were significantly smaller than roads, road-pipelines, and pipelines.

Selection ratios in the spring for adult males for nonlinear habitat were significantly smaller compared with roads and pipelines, and in the fall, the only significant difference was between pipelines and nonlinear habitat.

In the spring, subadult bears had significantly smaller selection ratios for nonlinear habitat compared with road-pipelines and pipelines, but there were no significant differences in selection ratios between habitats in the fall.

No significant differences were detected between age-sex classes across habitats or seasons (Table 2) nor was there any significant differences between seasons for any age-sex class. However, small sample sizes (especially for adult males and subadults) resulted in large confidence intervals, potentially masking real differences at the population level.

Table 2. Mean selection ratios (SR) by age-sex class and season showing significant differences in selection ratios between pairs of habitats. Superscripts indicate significant differences between two groups. No significant differences were detected between age-sex classes or season.

	AdF		AdM		Subadults	
Habitat	Season 1 SR	Season 2 SR	Season 1 SR	Season 2 SR	Season 1 SR	Season 2 SR
Roads	1.42	1.56^{bc}	1.40^{h}	1.37	1.78	1.45
Road-pipelines	2.22^{a}	1.69^{de}	1.17	1.36	1.62^{k}	1.76
Pipelines	1.94	1.54^{fg}	1.85^{i}	2.55^{j}	1.69^{l}	2.55
Seismic lines	1.03	0.80^{bdf}	1.21	1.74	1.28	0.96
Non-linear	0.95^{a}	0.97^{ceg}	0.97^{hi}	0.94^{j}	0.95^{kl}	0.95

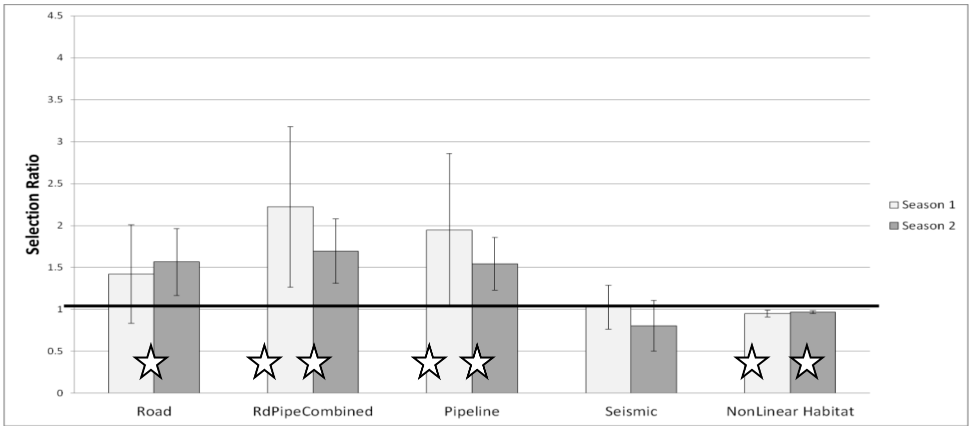
Habitat selection patterns by time of day

Mean selection ratios and 95% standard errors by day/night and habitat class are displayed in Figure 3. In general, adult females and subadults appeared to use all linear features more during the day than at night while adult males appeared to use pipelines more at night than during the day and other linear features similarly regardless of time of day.

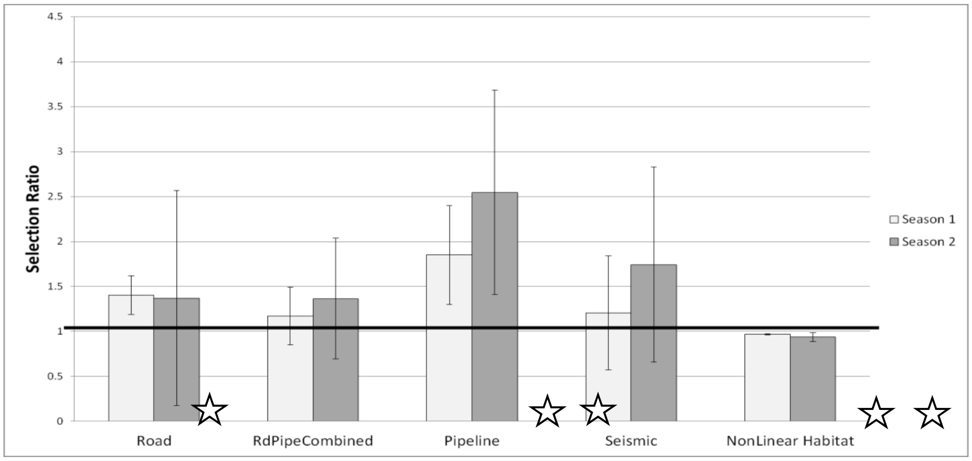
Discussion

Determining grizzly bear habitat response to pipeline RoWs is the first important step in investigating how pipelines may affect bears in Alberta. Our results indicate that grizzly bears used roads, road-pipelines, and pipelines more than expected, and selection patterns varied by linear feature type, age-sex class of bear, and season. It is important to note that although grizzly bears used these linear features more than expected based on availability, these results do not necessarily mean that these linear features constitute essential habitat because grizzly bears still spend the majority of their time within nonlinear habitat. Regardless, these results indicate that grizzly bears in our study area select linear features because use of these features is more than expected based on availability.

a) Adult Females



b) Adult Males



c) Subadults (males and females)

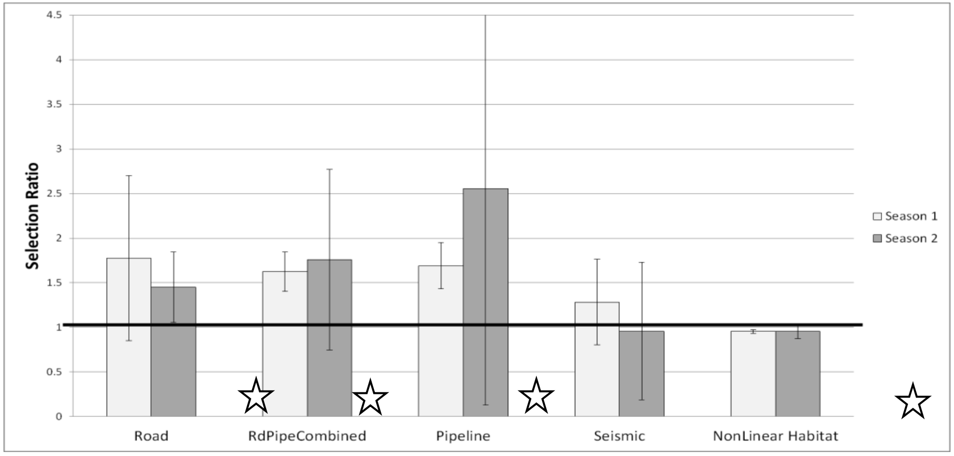
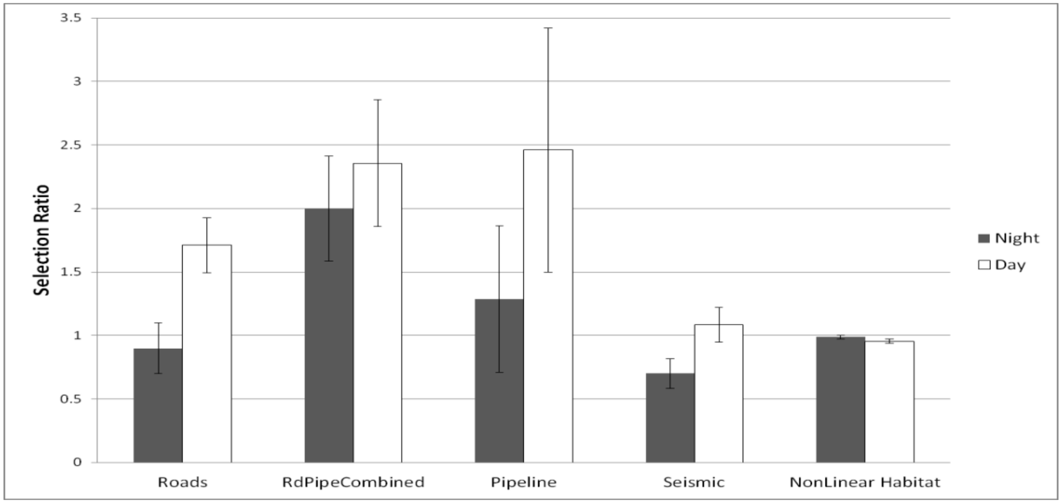
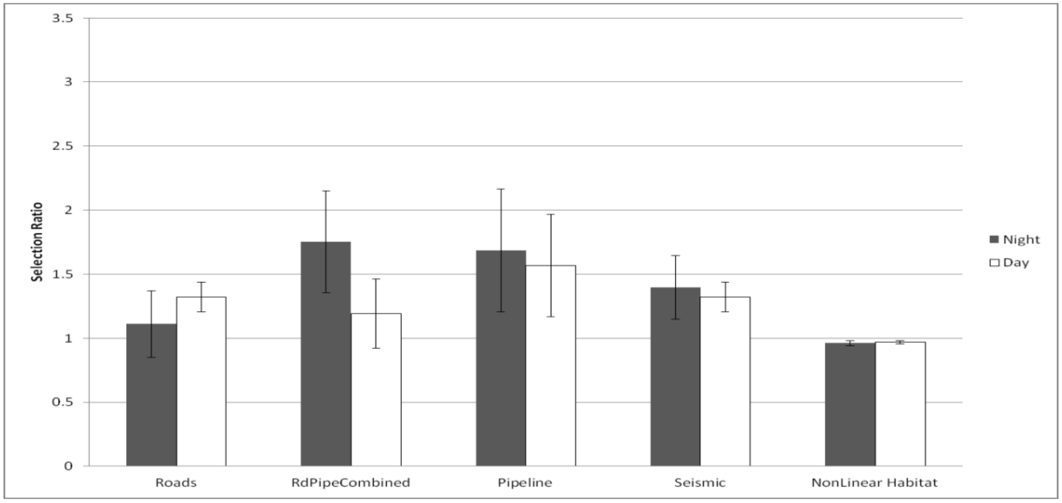


Figure 2. Selection ratios and Bonferroni corrected 95% confidence intervals by sex, season and habitat for grizzly bears in the Kakwa study area from 2006-2012. Season 1=May 1st to July 31st; Season 2=August 1st to October 31st). Stars indicate significant habitat selection for that habitat and season.

a) Adult Females



b) Adult Males



c) Subadults (males and females)

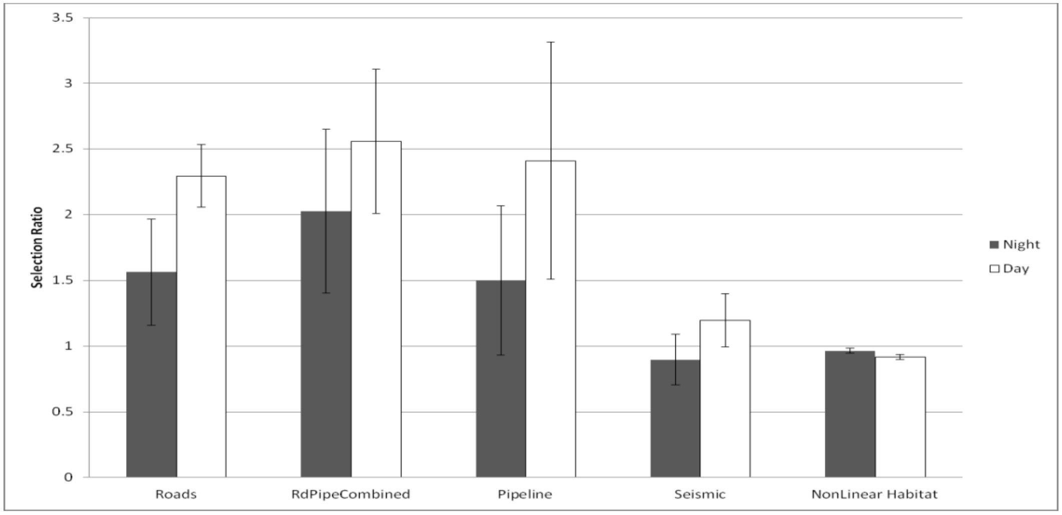


Figure 3. Selection ratios with 95% confidence intervals by age-sex, time of day and habitat for grizzly bears in the Kakwa study area from 2006-2012, Seasons 1 and 2 combined.

We used Bonferroni adjusted confidence intervals to test for significance. This adjustment results in conservative (i.e. large) confidence intervals. Small sample sizes for adult males and subadults could also have resulted in wide confidence intervals. Therefore, if a significant result was detected, we are confident that the result has true meaning for the population at the stated alpha level (p = 0.05). However, there is a chance that significant results may not have been detected (Type II error). Therefore, non-significant results suggested by the data should not be completely disregarded until further data is available.

Both adult males and adult females selected pipelines in both seasons, and subadults selected pipelines in season 1. Selection patterns for roads displayed more variation by age-sex class and season, with less selection observed overall. This suggests that pipelines and roaded habitats may be used differently by bears. Pipelines do not have an area covered with gravel, and therefore more area is available for plant growth. In addition, pipelines do not have vehicular traffic and likely less human activity compared to roads, providing more security for grizzly bears.

Adult females selected roaded habitat types (roads and road-pipelines) more than adult males and subadults. Previous work in Alberta found that females used areas near roads more than males (Graham et al. 2010), similar to findings for other population in North America (McLellan and Shackleton 1988, Chruszcz et al. 2003). This behaviour could result in a higher probability of females encountering humans, and therefore a higher risk of human-caused grizzly bear mortality.

Seismic lines were used as expected based on availability by all age-sex classes across both seasons and suggests that grizzly bears may prefer roads and pipelines relative to seismic lines. Pipelines and roads are generally maintained and cleared of trees and shrubs, while seismic lines are usually left to regenerate which could impair movement for wildlife. Pipelines and roads are also wider than seismic lines and likely allow more light into the RoWs, enhancing the growth of bear foods along these features. In addition, the RoWs of roads and pipelines may provide more forage for ungulates which are important food items for grizzly bears.

Although no statistical tests were conducted on the time of day data, some trends were observed. Adult males appeared to use linear features either the same amount or more at night than during the day, while adult females and subadults used linear features less during the night than during the day. Our pipeline site visits (Chapter 3) detected only 1 bear bed out of 211 sites and suggests that bears were not using pipelines as resting or bedding areas very often. The relatively high selection ratios for adult males at night suggest that males may have been foraging or moving along linear features at night. It is unknown whether males chose pipelines at night to travel between preferred habitats, or whether males in this area are intrinsically more active at night than females.

Our results indicate that grizzly bears select for pipelines within the Kakwa study area. Based on the knowledge that bears are spending time on pipelines, the following chapters examine grizzly bear activities and movement along pipeline right-of-ways.

2.2: Grizzly Bear Activities on Pipeline Right-of-Ways

Prepared by Tracy McKay

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Introduction

Our selection analysis in Chapter 2 indicates that grizzly bears are using pipeline right-of-ways (RoWs). Based on these selection patterns, we wanted to gain a more detailed understanding of what behaviors or activities grizzly bears were engaged in along RoWs.

Our research objectives included an investigation of grizzly bear activities on pipeline RoWs, to determine what foraging activities (activity classes) are observed (herbivory, anting, digging, berry feeding) and at what relative frequencies. In addition, we assessed whether bears were using RoWs or edges for bedding, and we investigated parameters that could predict the probability of each activity class at use sites on pipelines (month, period of day, age/sex class)?

Methods:

Site selection:
The pipeline dataset available at the start of the 2012 field season consisted of an anthropogenic feature layer created by Foothills Research Institute Grizzly Bear Program (FRIGBP) through digitized remote sensing imagery (SPOT satellite). This line dataset was buffered by 20m on each side to create a dataset approximately representing pipeline RoWs on the ground[1].

In 2012, project field crews visited grizzly bear use sites, as determined from GPS location data. Followit and Telemetry Solutions collars were used in 2012, including GPS (uploadable) and satellite collars. Collar location data were downloaded from the Followit and Telemetry Solutions websites every two weeks for satellite collars, and once per month during telemetry flights for regular GPS collars. Bear location points from 2012 were intersected with the pipeline dataset. The number of bear points on pipelines varied among the different 2-week sampling periods. Depending on the number of pipeline RoW use sites during in each sampling period, two different sampling strategies were used.

1. If there was enough time to visit all RoW use points from the two week sampling period, all were included as sampling sites.
2. If it was not feasible to complete all RoW use sites from a two week sampling period, the points were randomly subsampled (prior to the fieldwork shift) to select a set of sampling sites.

Whenever possible, bear use sites were visited within two weeks of the location date, to improve the likelihood and accuracy of detecting bear activities.

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[1] Refer to Chapter 2, Linear feature datasets, for a description of the improved pipeline dataset used for the 2012/2013 analysis.

Field methods:

Field crews visited grizzly bear GPS collar locations within pipeline RoWs. Personnel navigated to within 2 metres of the coordinates of the bear location using a hand-held GPS unit, and study plots were centered on the pipeline RoW. Each study plot was 30m long, and included the width of the RoW plus 5 metres into the forest edge on each side. Crews systematically searched the study plots for evidence of bear sign. Eight activity classes were investigated: anting, bedding, berry feeding (frugivory), herbaceous feeding (herbivory), predation (kill sites), root digging (*Hedysarum alpinum* roots), rub trees, and yellow jacket or wasp use. See Table 3 for description of evidence for each activity class. Due to the potential for subjectivity and uncertainty in observing evidence of bear activities, field crews also recorded a level of confidence for each observation, and took photos of bear activity evidence. For additional information and confirmation of bear activities, we also recorded contents (vegetation, berries, bones, hair, or ants) of any bear scat observed at the site, as estimated in the field.

Table 3: Description of field evidence for bear activity classes.

Bear activity	Evidence/sign
Anting	Disturbed ant mounts (tops missing or dug up); and/or ant logs that have been turned over and/or recently ripped apart.
Bedding	Depression in vegetation and/or soil, presence of bear scat in or near bed, consideration of appropriate location, size, appearance, and number of beds to indicate bears (versus other species).
Berry feeding (frugivory)	During berry season: shrub damage, berries missing and/or on the ground, berry shrubs disturbed.
Herbaceous feeding (herbivory)	For plant species known as bear foods: plants clipped and/or torn, ripped out of ground, presence of plants in or near beds. Can be more difficult to rule out foraging by other species, often classified as low confidence level.
Predation	Presence of bones, hair, or other animal remains. Signs of burial and digging.
Root digging	Presence of *Hedysarum alpinum* at site: disturbed soil, displaced mounds or clumps of soil, dug-up plants with roots missing.
Rub trees	Bear hair on trees or power poles.
Yellow jacket use	Dug up or disturbed yellow jacket or wasp nests.

Analysis:

Photos and descriptions of observation with medium or low confidence were reviewed by the project biologist to confirm or exclude bear activity data. The relative occurrence of each activity class was determined. Due to the fact that not all locations were potential sites for all activities, activity classes were analyzed separately. Results for anting, root (*Hedysarum*) digging, and herbaceous feeding were further investigated to determine whether period of day, age-sex class, and month could influence the probability of these activities. Observed occurrences were insufficient to further investigate factors affecting the remaining activities.

Study sites were considered as potential anting sites if the presence of ant mounts and/or ant logs was observed in the field. Each potential anting site was classified as either “anting observed” or “no anting observed”, based on the criteria described in Table 3. Data were analyzed using mixed-effects logistic regression in Stata 12.1^{TM} (StataCorp, Texas, U.S.A), with individual bears included as a random effect. Month, age-sex class, and period of day were included as categorical predictor variables. April and September data were excluded due to a low number of study sites from these months. The month of May had the lowest frequency of anting, and was used as the reference group in the regression. Differences between all other months were investigated using post-estimation pairwise comparisons. Age-sex classes included adult females (N=1), adult males (N=4), and subadult females (N=2). No data were available for subadult males in the study area in 2012. Period of the day was initially defined as diurnal, crepuscular (twilight morning and twilight evening), and nocturnal, based on timing of local sunrise and sunset. Crepuscular and nocturnal points were subsequently pooled in the analysis due to a low number of points from the twilight periods.

Sites were considered as potential root digging sites if *Hedysarum alpinum* was present at the site, and if the use date was either during April to June or August to September (based on seasonal availability of *Hedysarum* root, Munro et al. 2006). Sites were classified as “digging observed” or “no digging”. After preliminary analysis, it was apparent that regression analysis of root digging by time of day was not possible, as all potential root digging sites were from the diurnal period. In addition, analysis by age-sex class was not possible, due to a low sample size. Therefore, data were analyzed by month using a mixed-effects logistic regression in Stata, with individual bears included as a random effect.

All bear locations between the months of May through early September were considered as potential herbaceous feeding (herbivory) sites. April data were excluded, as herbaceous plants are not available in the Kakwa during early spring. Sites were classified as “herbaceous feeding observed” or “no herbaceous feeding”. As for anting, herbivory data were analyzed using mixed-effects logistic regression in Stata, with individual bears included as a random effect. Month, age-sex class, and period of day were included as categorical predictor variables. The month of May was used as the reference group in the regression. Age-sex classes included adult females (N=2), adult males (N=4), and subadult females (N=2). Period of the day was defined as diurnal, crepuscular, and nocturnal. The sample size for potential herbivory sites was larger than for anting and digging sites; therefore, crepuscular and nocturnal points were not pooled in this analysis.

Results

Field crews visited 211 grizzly bear GPS collar points on pipeline RoWs in 2012. Bear sign was observed at 75 of the 211 study sites, including: 42 sites with anting, 11 herbaceous foraging (herbivory) sites, 8 root digging sites, 2 berry feeding sites, 1 site with digging for yellow jackets, 1 kill site (moose), and 1 bedding site. Anting was observed at 47% of sites with available anthills or mounds, and included 24 sites with use of anthills, 11 sites with anted logs, and 7 sites with both. Herbivory included foraging of clover (*Trifolium sp.)*, dandelion (*Taraxacum sp.)*, alfalfa (*Medicago)*, and cow parsnip (*Heracleum lanatum*). All root digging sites involved sweet vetch (*Hedysarum alpinum*). Berries foraged included *Lonicera* and *Vaccinium sp*. Bear sign was not observed at 138 sampling sites.

Out of the 211 sites visited, 90 study sites were classified as potential anting sites. In the mixed-effects logistic regression analysis, month had a significant effect on the probability of anting. Pairwise comparison indicated that the probability of anting in July was significantly greater than in May (p=0.017) and June (p=0.047), but not different from August. There were no other statistically significant differences in the probability of anting between months. Age-sex class and period of day were not significant predictors of anting.

Hedysarum alpinum was available at 12 study sites, with recent root digging observed at eight of these sites. There were no significant differences in the probability of digging between the months of May, June and July. No data were available for the fall period.

There were a total of 204 bear locations considered as potential herbivory sites. Herbaceous foraging was observed at 11 of these sites. In the logistic regression analysis, month, age-sex class, and period of day were not significant predictors of herbivory.

Discussion

Our results indicate that anting was a relatively common foraging activity on pipelines, with more anting occurring during the summer months (i.e. July and August) than in the spring. Based on scat analysis, Munro et al. (2006) also reported a peak in anting during these months for grizzly bears in the foothills and mountains of west-central Alberta. Additional activity classes observed at study sites included all potential foraging activities (root digging, herbivory, berry feeding, predation, yellow jacket use), indicating that grizzly bears are using pipelines for a range of foraging opportunities.

Neither time of day nor age-sex class were predictors of anting, digging, or herbivory in our analysis. These results suggest that grizzly bears in our study area were not more likely to forage on pipelines during particular times of the day, and that there are not significant differences between age-sex classes with regards to foraging activities on pipelines. However, sample sizes were small following the first year of data collection. Time of day differences could have implications for grizzly bear mortality risk on pipelines, however, no insight is provided by current results. Following data collection in Year 2 of this project, samples sizes may be adequate to detect differences in use by time of day or age-sex class.

Results from Chapter 2 indicate that grizzly bears are using pipelines, suggesting that they are attracted to pipeline RoWs at some level. Results from this analysis of bear activities on pipelines indicate that bears are not primarily using these sites for bedding or resting, and that bears are not killing large numbers of ungulates directly on pipeline RoWs. These results suggest that grizzly bears are primarily using pipelines for foraging. However, it is also important to consider that out of 211 study sites, bear activities were not observed at 138 sites. It is possible that bear sign was missed at these sites, or that these locations were adjacent to foraging sites. Alternatively, some of these locations could represent travel paths, or periods of fast movement. Based on the potential for use of pipeline RoWs as movement corridors, the next chapter is focused on movement rates along pipelines.

2.3: Grizzly Bear Movement Rates On Pipeline Right-Of-Ways And Other Linear Features

Prepared by Tracy McKay

Foothills Research Institute

Introduction

Our analyses in Chapters 2 and 3 have shown that grizzly bears use pipeline right of ways, and that anting, herbaceous foraging, and digging may be the main activities that bears engage in along pipeline RoWs. However, a significant number of grizzly bear GPS locations on pipelines had no evidence of foraging activities. To further understand the characteristics of grizzly bear use of pipelines, we also wanted to investigate movement rates of bears along RoWs.

Previous research has shown that wolves use linear corridors as travel routes (Thurber et al. 1994; Musiani et al. 1998; James and Stuart-Smith 2000; Whittington et al. 2005; Latham et al. 2011; McKenzie et al. 2012). In the foothills of Alberta, research suggests that grizzly bears use roads and roaded habitats for travel (Roever et al. 2010). Studies in the Kakwa region from 2005-2010 indicated that movement rates of bears within 500m of pipelines were faster than movement rates when pipelines were not present within the surrounding 500m (Labaree et al. 2012); however, the scale of their analysis did not investigate grizzly bear movement patterns directly on linear feature RoWs. To our knowledge, there are currently no published data describing whether or not grizzly bears use pipeline RoWs and other linear features for travel.

Therefore, the objective of our research was to investigate grizzly bear movement on pipeline right of ways in the Kakwa study area, including investigating whether grizzly bears were using pipeline RoWs for travel (i.e. fast movement), and how movement rates on pipeline RoWs compare to movement rates along other linear features (roads, seismic lines) and in non-linear habitat.

Methods

Grizzly bear location data:

Location data were obtained from collared grizzly bears within the Kakwa study area from 2006-2012. Due to the relatively narrow areas of linear features, only 3D fixes were included in the analysis, to increase the spatial accuracy of the location dataset. To ensure that results analyzed within the Kakwa study area best reflected overall movement patterns for individual bears, bears were included in the analysis only if ≥90% of their home range fell within the study area. Previous research has shown that grizzly bear movements are reduced prior to den entry (Nelson et al. 1983, Friebe et al. 2001, Manchi and Swenson 2005) and immediately after den exit (Craighead and Craighead 1972, Nelson et al. 1983, Schwartz et al. 2010). Therefore, we removed locations within 500 m of known den sites within one week of a bear's den entry and exit dates. Bears may also have reduced movements for an average of four weeks after a capture event (Cattet et al. 2008); therefore, locations within 28 days of a capture were not used for analysis.

Bears were considered to be adults if they were ≥5 years old, and subadults if 3 or 4 years of age and independent from their mother during the location year. Females were classified as "with young" (cubs of the year, yearlings, or older) or as "single females" depending on whether they were accompanied by cubs or not (as confirmed by sightings). Reproductive status was classified by season, due to the possibility that females with cubs of the year in spring may lose their young over the course of the summer.

Datasets:

Pipelines, roads, powerlines, and seismic line datasets were buffered and converted to polygons based on average RoW widths, level of disturbance, and collar error, as described in Chapter 2, Linear feature datasets. Linear feature classes were initially defined as road RoWs, pipeline-road combined RoWs, pipeline RoWs, powerline RoWs, seismic line RoWs, powerline-road combined RoWs, and remaining non-linear habitat. Powerline right of ways were minimal in our study area. Therefore, to maintain adequate sample sizes, powerline RoWs were pooled with pipeline RoWs, and road-powerline combined RoWs were pooled with road-pipeline combined RoWs.

Age-sex class is known to influence movement rates in grizzly bears (McKay 2011, Graham and Stenhouse 2013, in review). Initial age-sex classes included solitary adult females, adult males, females with young ≥1 year of age, subadult females, subadult males, females with cubs of the year, and females with unknown reproductive status. Previous research (Graham and Stenhouse 2013, in review) and exploratory analysis of step length data in our study indicated no significant differences in movement distances between subadult males and females, or between females with young ≥ one year of age and adult females. After examination of home range sizes for two adult females with unconfirmed reproductive status, these females were assumed to be without young of the year, and were also pooled with adult females.

Previous data from the Kakwa study area indicate that bears move very little during the night (22:00h to 05:00h). Therefore, our analysis of movement investigated step lengths during the daytime "active" periods only. Bears in our study area show a distinct diurnal movement pattern, with periods of high activity in the morning (06:00h to 11:00h) and evening (17:00h to 21:00h), and a period of moderate activity in the afternoon (12:00h to 16:00h) (Graham and Stenhouse 2013, in review). For our analysis, we pooled data for the high activity periods, and included two activity periods (moderate and high) as variables in the analysis. These activity periods were included as a parameter rather than modeling the activity periods separately, in order to investigate potential interactions between linear features and activity periods.

Seasonality can affect habitat selection and movement patterns, due to long distances traveled by males during mating season and the seasonal availability of bear foods. Nielsen (2005) defined foraging seasons for grizzly bears in west-central Alberta that included hypophagia (den emergence to June 15th), early hyperphagia (June 16th to July 31st), and late hyperphagia (August 1st to den entry) as. Hypophagia (spring) also corresponds with mating season and the ungulate calving season. These three seasons were included as parameters in our analysis.

The final categories for explanatory variables associated with each grizzly bear location point included in the analysis are as follows:

Linear feature type

1. Non-linear habitat
2. Road RoWs
3. Pipeline-road combined RoWs and powerline-road combined RoWs
4. Pipeline RoWs and powerline RoWs
5. Seismic line RoWs

Age-sex class

1. Adult females (solitary and with young ≥ 1 year old)
2. Adult males
3. Subadults (females and males)
4. Females with cubs of the year

Activity period

1. Moderate activity (afternoon)
2. High activity (morning and evening)

Season

1. Hypophagia
2. Early hyperphagia
3. Late hyperphagia

Analysis:

Step lengths were generated for each grizzly bear location using the movement path metrics tool in Geospatial Modeling Environment (Hawthorne L. Beyer, 2012, Version: 0.7.2 RC2, www.spatialecology.com/gme). A movement step consists of the distance (in metres) between two consecutive GPS collar locations; we limited our dataset to those locations that were one hour apart, to allow for direct comparison of movement metrics across the dataset. Using hourly data also allows for direct interpretation of all step lengths as hourly movement velocities. Steps were intersected with the linear feature polygon datasets, and each step was assigned a linear feature class associated with the start of the step. Step length datasets were grouped by individual bear, and were used only if they included ≥100 steps.

Step length data were highly skewed and could not be directly analyzed by linear regression. Log transformed (natural logarithm) data approximated a normal distribution. To determine the best analysis technique for this dataset, three methods were compared using Stata 12.1™ (StataCorp, Texas, U.S.A): 1) a mixed model using log transformed data, with bear as a random effect, and all other variables as fixed effects; 2) linear regression using transformed data, clustered by bear; and 3) a general linearized model (glm) with untransformed data, using a log link, clustered by bear. Based on tests of model specification, the glm best fit the dataset and allowed for analysis without data transformation. Data were clustered by individual bear to account for variation resulting from behavioural differences between individuals. Variables were checked for collinearity based on variance inflation factors and eigenvalues.

A suite of models were analyzed with the generalized linear model in Stata 12.1, including all possible combinations of the independent variables. Interaction terms were limited to those including linear feature class, as this was the main variable of interest. To maintain the total number of parameters (k) in the models below the total sample size (n), a maximum of one interaction term was included each model. Model selection was based on comparing differences in Akaike's Information Criterion for small sample sizes (ΔAICc), and candidate models were ranked using model weights (AICcW). We completed model averaging of our top candidate models to estimate coefficients. Significance of pairwise comparisons was determined using $p<0.05$.

Results

Step lengths were analyzed for 23 individual bears, including 7 adult females, 5 adult males, 8 subadults, and 3 females with cubs of the year.

Two of the candidate models had ΔAICc values less than 10; all remaining models had extremely low AiC weights (Table 4). A complete list of all candidate models and AiC scores is included in Appendix 1. The top two models both retained the variables of age-sex class (AS), linear feature type (LF), and activity period (AP). The top model also retained an interaction term including linear feature type and activity period (LF*AP). Season was not retained in the top models. The coefficient estimates obtained from averaging the two top models are displayed in Table 5.

Table 4: Top two models with parameters, AiCc scores and AiCc weights.

Model	Parameters	Log likelihood	df	AiCc	Δ AiCc	AiCc Weight
5	AS, LF, AP	178475.7	9	356983.2	2.00	0.2677
20	AS, LF, AP, LF*AP	178457.4	13	356981.2	0.00	0.7282

Pairwise comparisons of parameters indicated that step lengths were significantly greater for roads, road-pipeline combinations, pipelines, and seismic lines as compared to non-linear habitat ($p<0.001$). However, there were no significant differences among step lengths on pipeline RoWs, road RoWs, or road-pipeline combinations. Step lengths on seismic lines were significantly smaller than those on pipelines and roads, but not significantly different from pipeline-road combinations ($p=0.078$).

Females with cubs of the year had significantly shorter step lengths than all other age-sex classes ($p<0.001$). Step lengths for adult males were significantly longer than those for adult females, but shorter than those for subadults. Mean step lengths and confidence intervals by linear feature type and age-sex class are displayed in Figure 4. Step lengths during the high activity periods (morning and evening) were significantly larger ($p<0.001$) than those during the moderate activity period (afternoon).

Table 5: Average coefficient estimates and robust standard errors for parameters from the top two candidate models. In the case of different p values between the two models, higher values are displayed. Reference categories in the analysis were LF: non-linear habitat, AS: adult females, and AP: moderate activity period.

	β	SE	p value
Linear feature type			
Road	0.703	0.105	<0.001
Road-pipeline	0.774	0.168	<0.001
Pipeline	0.698	0.090	<0.001
Seismic	0.398	0.087	<0.001
Age-sex class			
Adult male	0.249	0.088	0.06
Subadults	0.366	0.078	<0.001
Females with cubs	-0.541	0.084	<0.001
Activity period			
high	0.516	0.117	<0.001
Linear feature* activity period			
Road*high	-0.189	0.092	0.040
Road-pipeline*high	-0.432	0.146	0.003
Pipeline*high	-0.267	0.116	0.021
Seismic*high	-0.152	0.110	0.164

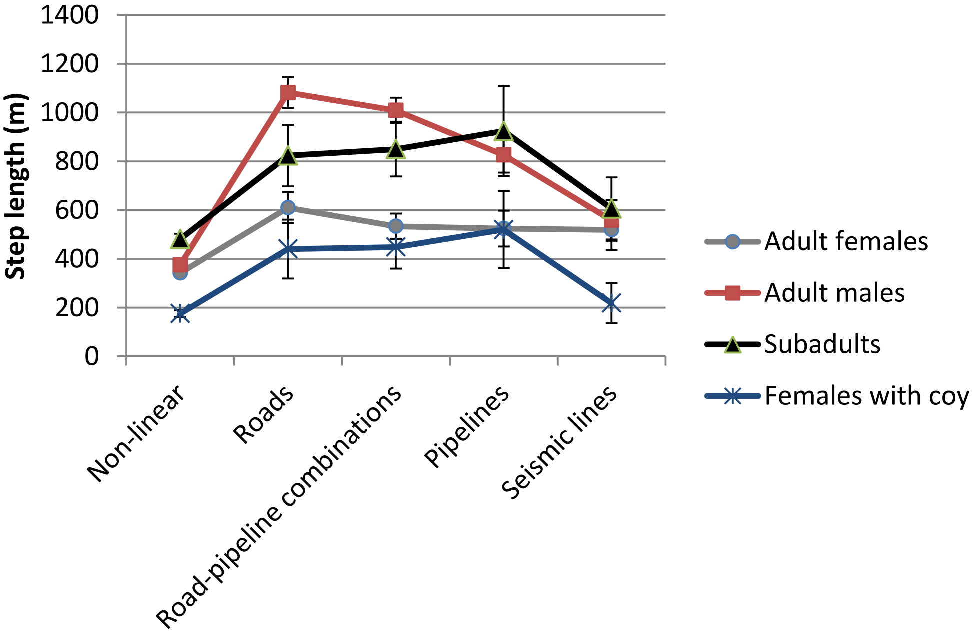

Figure 4: Mean step lengths with 95% confidence intervals for linear feature classes, by age-sex class.

Comparison of interactions between linear features and activity class included 10 interaction terms; results are described here only if they provide more insight than the above overall comparison of linear features. Step lengths from the high activity period in non-linear habitat were lower than those in moderate activity for some linear features (road-pipeline combinations and pipelines), although not significantly different for others (roads, seismic). In contrast to results for the overall comparison of pipelines and roads (no significant differences), pipeline step lengths during the moderate activity period were lower than for roads during the active period, indicating some potential time-related differences between these two groups. Similarly, while overall results did not indicate a significant difference between seismic lines and road-pipeline combinations, step lengths on seismic lines during periods of moderate activity were significantly lower than those on road-pipeline combination RoWs during periods of higher activity. Step lengths on roads, pipelines, and seismic were significantly greater during the high activity period than the moderate activity period, but differences were not significant for road-pipeline combinations.

Discussion

Step lengths were significantly longer on road RoWs, road-pipeline RoWs, pipeline RoWs, and seismic RoWs as compared to non-linear habitat. Higher movement rates can be interpreted as avoidance of a feature, non-use of a habitat, or an indication of a flight response away from a disturbance. However, results from Chapter 2 of this study indicate that grizzly bears are not avoiding pipelines and other linear features in our study area; in contrast, bears appear to be selecting for these features. Therefore, the fast rates of travel observed in this analysis suggest that linear feature RoWs may serve as movement corridors for grizzly bears in our study area.

Studies of movement patterns of other predators have similarly concluded that linear features can serve as movement corridors. James and Stuart-Smith (2000) reported that wolves were closer than expected to linear corridors in northeastern Alberta, and wolves in Jasper National Park strongly selected for low-use trails (Whittington 2002). Using step selection functions, Latham et al. (2011) reported that wolf movement paths in northeastern Alberta followed conventional seismic lines more closely than simulated paths, and wolves selected for steps closer to seismic lines during the snow-free season. In studies of step lengths and movement rates, McKenzie et al. (2012) reported that wolves had longer step lengths on seismic lines versus off seismic in the central east slopes of the Rocky Mountains, and Musiani et al. (1998) reported that wolves in Poland traveled significantly faster on trails and roads than in the forest.

Research investigating the movements of bears in relation to linear features is more limited. Roever et al. (2010) found that grizzly bears in the foothills of west-central Alberta were more likely to select steps closer to roads. Step lengths were also longest near roads, suggesting overall faster movement along roads (Roever et al. 2010).

Research in our study area from 2005-2010 indicated that movement rates of grizzly bears within 500m of pipelines were faster than movement rates when pipelines were not present (Labaree et al. 2012). However, at the larger scale of the analysis, it was not possible to investigate grizzly bear movement patterns directly on linear feature RoWs. Similar to our current analysis, McKenzie et al. (2012) used a small spatial scale in their investigation of wolf step lengths of wolves on seismic lines, buffering their line data by the average seismic RoW width plus estimated collar error. It can be difficult to detect effects at such a small spatial scale, particularly with hourly GPS data; the timing of a GPS collar location may not exactly coincide with a bear location in a narrow right-of-way. However, analyses of this type provide direct information regarding grizzly bear use of these features, building on information obtained from larger landscape scale analyses. In spite of the relatively narrow areas of linear features, we detected highly significant differences in step lengths between linear features and non-linear habitat in our analysis.

Step lengths were not significantly different among roads, road-pipeline combinations, and pipelines, suggesting that these three linear features are used similarly for fast movement. However, steps on seismic lines were significantly shorter than on roads and pipelines. Pipeline and road right-of-ways are generally maintained for use and inspections and are cleared of trees and shrubs, while seismic lines are usually left to regenerate. As a result, seismic lines are more overgrown, possibly providing more of a barrier to travel than the wider, more open road and pipeline RoWs. Alternately, the narrower seismic lines may provide more security for grizzly bears; with less exposure, bears may be less inclined to move quickly. Regardless, step lengths on seismic were larger than those in non-linear habitat, suggesting that seismic lines were used for travel to some extent, although potentially less than other linear features.

As previously reported for our study area, step lengths were significantly different among age-sex classes in our analysis. However, similar patterns for step lengths were observed across age-sex classes in our study, with significantly longer steps on linear features than in non-linear habitat (Figure 4). The interaction term including linear feature and age-sex class was not retained in the top models. These results suggest that all age-sex classes in our study moved faster on linear features than in non-linear habitat.

As expected, step lengths were significantly longer during the periods of high activity (morning and evening) as compared to the moderate activity period (afternoon). Results of interactions between linear features and activity periods suggest there may be some effects of activity period on use of linear features for movement. Step lengths on roads, pipelines, and seismic lines were significantly greater during the high activity period than the moderate activity period, suggesting that bears are generally using these features more for travel during mornings and evenings than in the afternoon. In contrast, Roever et al. (2010) reported that use of roads was consistent throughout the day; however, time periods were not directly compared in their study, as each period was modeled separately. Bears in our study may also be moving quickly along linear features during their active foraging periods in order to access areas of high quality habitat. Previous research on black bears reported fast rates of movement between high quality habitat patches (Bastille-Rousseau et al. 2011). Research to be completed in the second year of this study will investigate how adjacent habitat may influence movement patterns on pipelines; these results may provide further insight into potential interactions between linear features and activity periods.

Grizzly bear use of linear features could have impacts for ungulate prey species, including caribou populations. James and Stuart-Smith (2000) reported that caribou were further than expected from seismic lines, roads, and pipelines, and Dyer et al. (2001) reported that caribou avoid roads and seismic lines. Caribou have also been shown to move away from areas associated with high predation risk from wolves (Johnson et al. 2002). Use of linear features by grizzly bears could increase avoidance of these features by ungulates, resulting in habitat displacement. Currently, it is unknown whether grizzly bears are a significant cause of mortality for caribou adults or calves in the Kakwa region. A master's thesis project at the University of Calgary is currently underway to investigate predation by grizzly bears on ungulates in the Kakwa area. This study will provide important information regarding baseline levels of predation by grizzly bears in our study area. Fast movement rates along linear features have the potential to increase encounter rates between predators and prey species (McKenzie et al. 2012), potentially increasing kill rates of large ungulates (Webb et al. 2008, McKenzie et al. 2009). Based on our current data we have no evidence to suggest that this pattern occurs with grizzly bears, ungulate prey species, and pipeline RoWs in our study area. Season was not retained in our top models, suggesting that the spring ungulate calving season did not have an influence on step lengths; spring is a time when caribou and other ungulates are most vulnerable to predation. However, preliminary analyses did indicate that step lengths for some bears were longer during June than during May or July. One of the research objectives for the second year of this study is to specifically examine whether or not grizzly bears may be using pipeline RoWs for access to prey. More detailed analysis of step lengths to investigate predation will include analysis of movement patterns of individual bears, a more specific focus on the ungulate calving season, potential interactions between location months and linear features, possible overlap with caribou locations in the Kakwa region, and investigation of bear activities at location clusters.

Roads are known to increase human-caused mortality risk for grizzly bears. If bears are using pipeline RoWs as movement corridors, the time spent on these features could increase their exposure to humans, particularly when pipelines are adjacent to roads. However, human-caused mortalities associated with linear features also depend upon actual encounter rates with humans. Research to be completed in Year 2 of this study will investigate levels of human use on pipeline right-of-ways in order to better estimate potential human-caused mortality risk near linear features in the Kakwa region.

Results from this analysis show that grizzly bears move faster on road RoWs, road-pipeline RoWs, pipeline RoWs, and seismic lines than through surrounding non-linear habitat. In turn, faster movement rates suggest that linear feature RoWs in the Kakwa area serve as movement corridors for grizzly bears. Research to be completed in the second year of this study will investigate how adjacent habitat and other pipeline parameters (pipeline age, distance to road, linear feature density) may influence movement patterns on pipelines, providing insight into the reasons behind these movement patterns, their potential consequences, and the characteristics of pipelines that may be used more often as movement corridors. This information may assist in focusing mitigation efforts on sections of pipeline that are more likely to be used for travel.

Year 1 Conclusions

The main objective for the first year of this project was to address the current knowledge gap regarding grizzly bear habitat use, foraging patterns, and movement patterns on pipelines. Investigation of grizzly bear use of pipeline RoWs in our study area also requires consideration of other linear features present on the landscape, including roads and seismic lines.

Our results indicate that grizzly bears used roads, road-pipeline combined right-of-ways, and pipelines significantly more than expected. Selection patterns for pipelines, road-pipelines and roads varied by linear feature, age-sex class, and season. Bears did not appear to use seismic lines more or less than expected based on availability. It appears that grizzly bears in the Kakwa study area are not avoiding linear features. However, it is important to distinguish that these results do not necessarily mean that these linear features constitute critical habitat for grizzly bears; grizzly bears continue to spend the majority of their time within nonlinear habitat.

Our results suggest that bears may be attracted to pipeline and road right-of-ways. Analysis of 2012 field data from GPS collar locations indicates that bears are using pipeline RoWs for a range of foraging opportunities, with anting as the most common activity.

Our results suggest that bears in the Kakwa region may also use pipelines and other linear corridors for travel. Movement rates of grizzly bears were significantly faster on road RoWs, road-pipeline RoWs, pipeline RoWs, and seismic RoWs as compared to non-linear habitat. Fast rates of movement suggest that linear feature RoWs may serve as movement corridors for grizzly bears in our study area.

Based on the combined results from the selection analysis, bear activity data, movement data, and preliminary analysis of 2012 bear food availability on pipelines, it is likely that grizzly bears in our study area use pipeline RoWs for a combination of foraging and travel. The use of pipeline right-of-ways for foraging and movement has potential consequences for grizzly bears and for other species. The presence of linear features on the landscape results in an increase in human-caused mortality risk for grizzly bears. Grizzly bear use of RoWs for movement could result in further avoidance of linear features by ungulates such as caribou, and also has the potential to increase grizzly bear predation rates on caribou at certain critical periods, such as the calving season.

Research objectives currently proposed for the second year of this project include:

- Investigation of how pipeline parameters (adjacent habitat, linear feature density, bear food availability, distance to road) influence bear use and activity on pipeline RoWs.
- Investigation of whether grizzly bears may use pipeline RoWs for access to ungulate prey.
- Estimation of levels of human use along pipelines and probabilities of bear-human interactions.

Research investigating the characteristics of pipelines and adjacent habitat may assist in describing pipelines that are used more often by grizzly bears for either foraging or movement. Estimation of the levels of human use on pipeline right-of-ways will help to assess human-caused mortality risk near linear features in the Kakwa region. Investigation of grizzly bear predation rates on caribou and other ungulates in the Kakwa region and how this may be related to linear features, will provide information regarding potential effects on ungulates such as woodland caribou, a threatened species in the Kakwa region.

Results from the first year of this research project begin to address the knowledge gap regarding grizzly bear response to oil and gas pipelines in Alberta. We believe this new knowledge will play an important role in grizzly bear recovery efforts and resource management in Alberta.

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Appendix A

Candidate models for step length (movement) analysis, including AiCc scores and weights.

Model	Parameters	Log likelihood	df	AiCc	Δ AiCc	AiCc Weight
null	constant	-179349.3	1	358700.8	1719.55	0.0000
1	AS	-179048.3	4	358106.8	1125.58	0.0000
2	AS, LF	-178717.2	8	357460.7	479.44	0.0000
3	AS, AP	-178759.6	5	357532.7	551.48	0.0000
4	AS, S	-179041.2	6	358099.7	1118.41	0.0000
5	AS, LF, AP	178475.7	9	356983.2	2.00	0.2677
6	AS, LF, S	-178716.3	10	357470.9	489.69	0.0000
7	AS, AP, S	-178747.7	7	357516.9	535.62	0.0000
8	AS, LF, AP, S	-178472.8	11	356991.6	10.36	0.0041
9	LF	-179049.6	5	358112.7	1131.48	0.0000
10	LF, AP	-178845.8	6	357708.9	727.61	0.0000
11	LF, S	-179024.2	7	358069.9	1088.62	0.0000
12	LF, AP, S	-178810.3	8	357646.9	665.64	0.0000
13	AP	-179106.3	2	358217.2	1235.96	0.0000
14	AP, S	-179050.1	4	358110.4	1129.18	0.0000
15	S	-179309	3	358625.3	1644.02	0.0000
16	AS, LFn, AS*LF	-178667.9	17	357795.8	814.56	0.0000
17	AS, LF, AP, AS*LF	-178433.2	18	357832.4	851.16	0.0000
18	AS, LF, S, AS*LF	-178667.2	19	358377.4	1396.16	0.0000
19	AS, LF, AP, S, AS*LF	-178430.6	20	357906.2	924.96	0.0000
20	AS, LF, AP, LF*AP	178457.4	13	356981.2	0.00	0.7282
21	AS, LF, S, LF*S	-178696	18	357599	617.76	0.0000
22	AS, LF, AP, S, LF*AP	-178454.2	15	357007	25.73	0.0000
23	AS, LF, AP, S, LF*S	-178448	19	357187.3	206.09	0.0000
24	AS, LF, S, S*LF	-178696	18	357599	617.76	0.0000
25	LF, S, LF*S	-179005.1	15	358108.8	1127.53	0.0000
26	LF, AP, S, LF*S	-178786.9	16	357696.5	715.22	0.0000
27	LF, AP, S, LF*AP	-178797.5	12	357650.2	668.96	0.0000
28	LF, AP, LF*AP	-178834.4	10	357707.1	725.89	0.0000
29	LF, S, LF*S	-179005.1	15	358108.8	1127.53	0.0000

CHAPTER 3: RESEARCH AND APPLIED TOOLS TO ENHANCE FOREST MANAGEMENT LINKAGES TO GRIZZLY BEAR CONSERVATION AND RECOVERY IN ALBERTA

Year One Progress Report for
Forest Resource Improvement Association of Alberta (FRIAA) –

Prepared by Terry Larsen[1], Jerome Cranston[2], Gordon Stenhouse[1],

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Project Background and Objectives

Grizzly bears are a threatened species that has a high value among the public of Alberta both from a recreational perspective and as an indicator of forest ecosystem health. Maintaining this important wildlife species, in conjunction with the wise and sustained use of other forest resources such as pulp, lumber, oil and gas, will demonstrate to Albertans, and all user and stakeholder groups that the use of forest resources is indeed possible and being actively pursued. There is clear evidence within the forest product marketplace that consumers are concerned about sustainable forestry practices when making purchasing decisions. Our research program supported by FRIAA and member companies have invested in new knowledge and planning tools that will support grizzly bear conservation and recovery in Alberta, while showing leadership and commitment to sustainable forest management and non-timber values in this province.

This FRIAA project was undertaken in order to build upon existing data sets, knowledge, and investment that have been gathered over the past 12 years within the Foothills Research Institute grizzly bear program. This accumulated knowledge and data has been assembled with the ongoing support from over 60 program partners including significant support from FRIAA funding during this time period. Over the past 12 years approximately $14 million has been invested by the program partnership which has resulted in what can be considered the most extensive and up to date data set for grizzly bears in North America. The research findings presented in this report have been supported by seven (7) FRIAA member companies.

In the first year of this two year FRIAA project we have focused on two species at risk in Alberta; grizzly bears and woodland caribou. This research report focuses on new and important knowledge related to grizzly bear habitat use in relation to forest cutblocks and presents new GIS based applications to understand impacts of forest harvesting on grizzly bear and caribou habitat use. The second year of this project will continue gathering data to aid in our understanding of forest structure and cutblock retention in relation to grizzly bear habitat selection. In addition we will continue our work to further integrate knowledge and planning tool applications for grizzly bears and caribou in west central Alberta.

Our project goal is that our research results and the new tools that we have prepared from these findings will play a major role in ongoing integrated land use and forest management planning and operations in the boreal forests of Alberta where these species occur. Our research team has continued to communicate our research findings with our FRIAA partners throughout the year with discussions and email updates. We are now planning a half day workshop, sponsored by ESRD, to formally present and demonstrate our new GIS applications to our program partners in the summer of 2012.

3.1. Grizzly Bear Habitat Use and Activity Associated With Edge and Interior Forested Habitat

Prepared by Terry Larsen[1], Jerome Cranston[2], and Scott Nielsen[3]

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Introduction

Grizzly bears (*Ursus arctos*) are threatened in the province of Alberta and a recovery plan is in place to address concerns regarding population viability. Efforts to recover grizzly bear populations have been directed towards issues of survival (mortality risk) associated with roads and access (Nielsen *et al*., 2010) with no emphasis to date placed on habitat conservation or enhancement. Recovery at the provincial level remains a formidable management challenge given that industrial development and human activity on public land continues to increase within grizzly bear range. While high survival is fundamental to recovery, there is also a need to maintain or enhance essential resources for grizzly bears such as food and cover. Because forest harvesting accounts for the majority of the anthropogenic footprint within provincial grizzly bear habitat, there has been a concerted effort to better understand how forestry practices and the cumulative impacts of resource extraction industries influence grizzly bear habitat supply. Today, this is particularly important given changes in harvest regime associated with mountain pine beetle (*Dendroctonus ponderosae*) mitigation (Stewart *et al*., 2012).

Because grizzly bears show a strong affinity for the cutblock edge interface (Nielsen *et al*., 2004a, Stewart *et al*., 2013), there is concern that larger harvest openings may create more cutblock interior and less habitat edge, which could lead to less favorable conditions for grizzly bears. However, as part of natural disturbance based forestry, residual stand structure is left behind as variable green tree retention to emulate fire (Rosenvald and Lohmus, 2008). In Alberta, forest companies have set a range of retention targets, anywhere from .5% - 10% target of retaining 5% of the merchantable timber on the land base. The calculation of these percentages can be either area or volume based .Whether or not retention at this level and the spatial context of retention within cutblocks creates the desired effective edge (food, cover) for grizzly bears has not been tested. In addition, the specific factors influencing the proximity, habitat use and movement of grizzly bear along the edge relative to the interior of cut and uncut forest (see Figure 1) is not well understood. Forest structure (Mascarúa López *et al*., 2006) and succession (Harper and Macdonald, 2002), local and landscape level environmental gradients (moisture, climate) (Redding *et al*., 2003; Nielsen *et al*., 2004b), and the juxtaposition (Boutin and Hebert, 2002) between edge types (age, tree composition) may create unique conditions within a specific distance from the edge of cut and uncut forest (Harper and Macdonald, 2001; Harper and Macdonald, 2002), which could enhance or reduce available resources (food, cover) for grizzly bears.

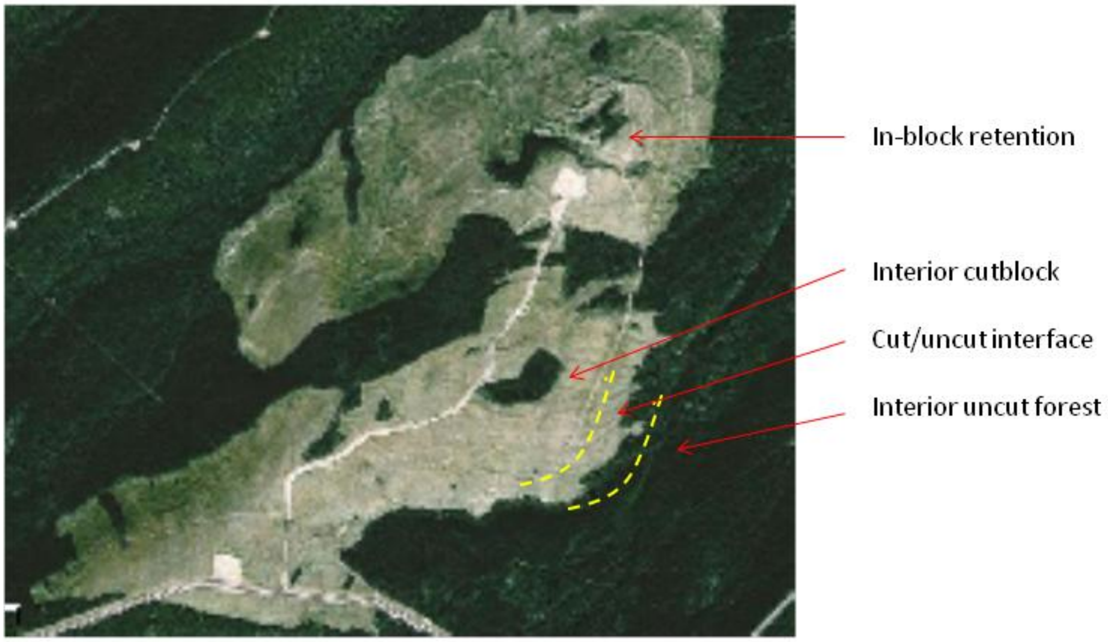

Figure 1. Forest structure attributes described in this research report.

Timber harvest that supports diverse and abundant food resources could benefit grizzly bears, particularly if the amount of edge habitat is reduced with larger in block retention patches. Following harvest and depending on the eco-site, drag scarification or mounding may be used to promote conifer regeneration by exposing mineral soil. However, research suggests that soil disturbance with mechanical disturbance can have both negative and positive effects on grizzly bear foods (Nielsen *et al*., 2004b; Zager *et al*., 1983). One of the main concerns in Alberta is the potential effect that soil disturbance might have on important fruit production shrubs, particularly those that reproduce from vegetative rhizomes (*Vaccinium* spp.) (Larsen 2012; Nielsen *et al*., *in prep*). Silvicultural techniques that reduce soil disturbance such as harvesting in different seasons (summer vs. winter) may reduce the negative effects of mechanical equipment on sensitive shrub species (Coxson and Marsh, 2001). However, there is limited information on which to base management decisions regarding changes in grizzly bear food abundance associated with silvicultural prescriptions in Alberta (Nielsen *et al*., 2004b). Determining whether or not site preparation might be having a negative effect on fruit production in cutblocks is not known and is an important component of enhancing habitat for grizzly bears. In addition, determining what effect herbicide and planting (species, date) regimes might have on bear foods is additional information that can be used for management purposes. Collectively, identifying the specific mechanisms (food vs. cover) influencing grizzly bear habitat use, activity (foraging, resting), and movement relative to edge and interior habitat, retention patches, and silviculture treatment is fundamental to addressing issues surrounding grizzly bear habitat supply and future forest harvesting regimes. At the same time, this additional knowledge may also identify new opportunities to enhance habitat where appropriate to support provincial grizzly bear recovery efforts.

Our research project objective (Activity 1) was to identify factors affecting the use of forest cutblock edges and in-block retention patches by grizzly bears. To meet our objective, we combined multiple datasets for inference including Global Positioning System (GPS) locations from collared grizzly bears (Telemetry), investigations of grizzly bear use-site locations, and vegetation plots. More specifically, we assess variation in grizzly bear response (habitat use, movement) and activity (foraging, resting) to edge and interior habitat, silviculture treatments, and in-block retention. And, we test whether food resource availability and/or security cover explains patterns of habitat use and activity. The information, along with the maps and models generated from this research will assist with forest management planning in provincial grizzly bear habitat.

Here we present detailed methodology on progress to date and results from a preliminary analysis using Telemetry data to answer the following questions:

1. How far are grizzly bears away from the edge when using cutblocks versus uncut forest, and does edge proximity differ from random?

2. Do grizzly bears avoid the interior of cutblocks compared to the edge and the interior of uncut forest?

3. Does 1 and 2 vary by season, sex and offspring dependence, or forest age?

In addition, we assess grizzly bear activity in relation to edge proximity based on the results of the Telemetry analysis to aid in our interpretation.

Methods

Study Area

The study area encompasses the southern portion of the Weyerhaeuser (Grande Prairie) Forest Management Agreement (FMA) area (9192 km^2) excluding the Saddle Hills (Figure 2). It is bound on the east and south-east by the Smoky River, on the west by the British Columbia border, and by private agricultural land in the north. There is a prominent elevation gradient from the south-west to the north-east. The higher elevations in the south-west are rugged and dominated by coniferous tree species characteristic of the Sub-alpine and Upper Foothills Natural Subregion (NSR) (Natural Regions Committee 2006). The transition to lower elevations and the Lower Foothills NSR consists of gently rolling terrain with forests dominated by mixed coniferous and deciduous species (Natural Regions Committee 2006). Although forest harvesting since the early 1970’s has created a mosaic of regenerating cutblocks, the land base is dominated by mature fire origin stands, many of which are lodgepole pine (*Pinus contorta*).

Typically, timber harvest follows a two-pass system whereby a cutblock must regenerate to a height of 2m for conifer dominated stands and 3m for deciduous, or 15 years, before the adjacent stand can be harvested. However, this 'green-up' rule does not apply during the mountain pine beetle surge cut that is scheduled to occur until 2019 (Weyerhaeuser, 2011). Harvesting intensity, represented by the annual allowable cut, is spatially dependent and decreases at higher elevations (Subalpine NSR) where beetle infestation risk is lower and where much of the high value caribou habitat occurs (Weyerhaeuser, 2011). Where harvesting does occur, there is an In-Block Retention Strategy that aims to leave 2.5% conifer and 3% deciduous merchantable volume on the land base as a means to maintain ecological and biodiversity values following timber harvest (Weyerhaeuser, 2011). Cutblock regeneration strategies are dependent on broad differences in climate associated with NSR as well as local factors associated with eco-site (Weyerhaeuser, 2011). This approach allows for silvicultural treatments to be site specific and improve conditions for tree growth (Weyerhaeuser, 2011). Pine and white spruce (*Picea engelmanni*) are planted post harvest, but natural regeneration techniques are also utilized (Weyerhaeuser, 2011).

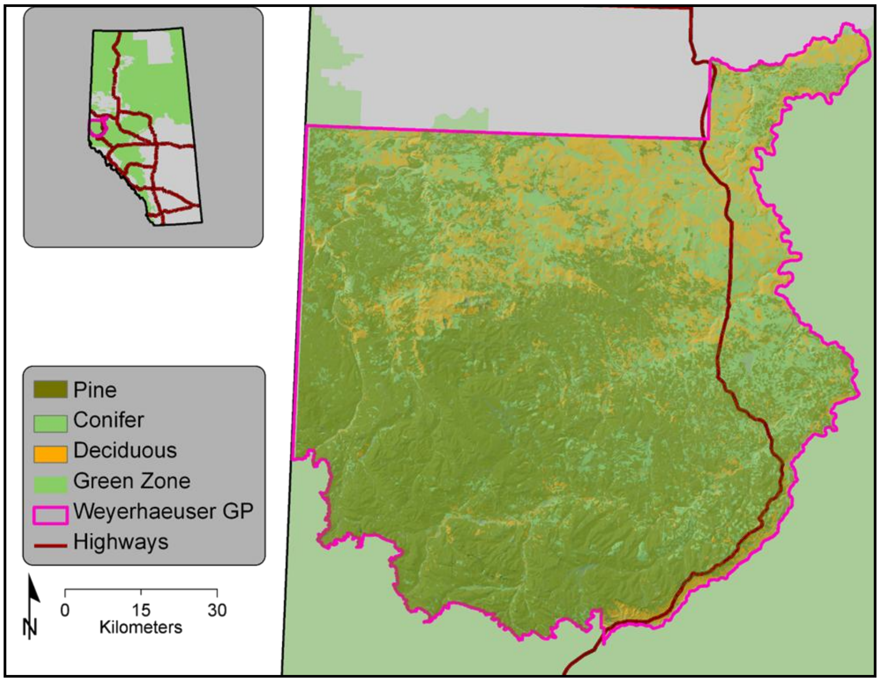

Figure 2. Dominant forest types within Weyerhaeuser Grande Prairie Forest Management Agreement area, Alberta, Canada.

Capture and Monitoring

Grizzly bears (n=29) were captured (2005-2012) by the Foothills Research Institute's Grizzly Bear Program via helicopter, leg hold snare, or culvert trap. After 2009, leg hold snares were phased out since capture by this method was more likely to cause significant muscle injury compared to the other techniques (Cattet *et al*., 2008). Animals were fit with an ATS G2000 (ATS; Isanti, Minnesota, USA), Televilt Tellus (1 or 2) 2D, or Followit brand GPS radio-collars (Followit®, formerly Televilt® TVP Positioning AB, Lindesberg, Sweden) programmed to collect locations at a 20 minute or hourly interval during the non-denning period. Each collar was equipped with a standard VHF radio beacon and a mechanical drop-off system. However, bears were also fit with an ATS VHF ear tag transmitter as a backup in the event that the collar failed and capture was required. A premolar tooth was extracted to determine age and a hair sample was taken for identification (DNA; 20 loci) purposes. Individuals were considered to be an adult when older than or equal to 5 years of age, otherwise, they were classified as a sub-adult. Visual observations, primarily from monthly data acquisition flights using fixed-wing or helicopter (Skymaster 337, Bell 206 Jet Ranger) but supplemented with ground observations, were used to determine if adult females were accompanied by newborn cubs, yearlings, or cubs ≥2 years of age.

Habitat Mapping

Stratification and Edge Classification

We used Alberta Vegetation Inventory (AVI) to define grizzly bear habitat for each year of GPS data. As this was a composite of many spatial layers that split polygons, internal borders were eliminated by dissolving on the following fields: strata, leading tree species by cover (≥60% in 10% increments), year of stand origin, and riparian buffer zone (lake, river, or flooded). We also eliminated islands of in-block retention patches from the cutblock layer. Leading tree species and percent cover were derived from AVI for uncut forest and from silviculture records (planted species) for cutblocks. Where no planting record existed for a harvested block, leading species was taken from AVI. The assumption was that a cutblock would be planted with the same species that was cut. Polygons were stratified as cutblock, uncut forest, natural opening, or non-habitat (anthropogenic features, water bodies, other). Forested (cut and uncut), polygons were identified as distinct patches according to age of origin (cutblocks were 1970 to 2012); adjacent patches differed by at least 1 year of age. Natural openings were identified as non-forested vegetated (herb, shrub) land, however, many were actually cutblocks according to a master cutblock layer and subsequently updated. From AVI, non-habitat was defined as anthropogenic features (4% excluding seismic lines) and non-vegetated land including oil and gas well sites (60m buffer), power lines (60m buffer), roads and pipelines (20m buffer) as well as water bodies. Because anthropogenic features were generally older (built prior to 2005), a base stand polygon layer was successively updated with new disturbances (roads, well sites, and harvest blocks) for each of the 8 years of Telemetry data. Annual layers were referenced to a Landsat image (path 46 row 22) for that year, although cloud or scan line errors reduced the effectiveness in 4 of the 8 images. Wherever possible, features were classified by year to match the Landsat image, creating a synoptic representation of a continuously changing landscape. Boundaries (edges) between habitats were represented by polylines defined by the habitat strata. For each polyline, the attributes (strata) of adjacent polygons were assigned. For our purposes we erased all polygons and polylines where a habitat stratum was not a cutblock or uncut forest and if the difference in age between patches was zero. Originally, we were going to assess grizzly bear use of edges associated with natural openings versus those of cutblocks. Because our preliminary evaluation suggested that natural openings were relatively rare (2%) and on averaged used minimally (3%) by grizzly bears, we focus exclusively on forestry cutblock edges in subsequent analyses. However, Stewart et al., 2013 showed using a landcover map that natural edges between forest types were more abundant and that grizzly bears showed a response to their availability.

In-block Retention Patches

We defined in-block retention as single trees (dispersed) or clusters of trees (patch) that were excluded from harvesting and completely surrounded by the cutblock edge. Patches touching the edge were assumed to be functionally connected to the uncut forest. We used one of three data sources to represent in-block retention for each cutblock based on what we viewed to be the most accurate dataset from visual examinations with high resolution orthophotos. In order of accuracy, these included: 1) digitized single tree and patches for cutblocks with an origin year between 2006 and 2010; 2) digitized patches for cutblocks prior to 2006; and 3) Light Detection and Ranging (Lidar) for all other cutblocks where Lidar was available. Lidar data for cutblocks more recent than 2010 was not available and for blocks older than 1990, it was difficult to differentiate retention from post-harvest regeneration. The difference between 1) and 2) reflects a greater effort to precisely identify single trees and outline patches in 1). The steps to blend these layers together into a single dataset are as follows. First, point features (single trees) from 1) were buffered by 3m to approximate 6m wide crowns and then merged with patches where they overlapped. Second, cutblock inner features from 3), buffered by 20m to eliminate pixels next to the tree line, were converted to raster (4m pixel) and used to clip the Lidar canopy height model (Full feature surface minus Bare Earth surface). Pixel values greater than 10m (vegetation height) were converted to point features, buffered by 6m to approximate tree crowns, and merged with overlapping patches. The 10m cutoff was used to distinguish regenerating trees from residual uncut mature timber. A buffer distance of 6m, rather than 3m, was used to eliminate gaps between clusters of single trees that in 1) were digitized as patches. Finally, layers 1) – 3) were merged into a single dataset, and the area of individual non-overlapping patches was calculated. We summarized the following attributes for each cutblock; the number (patch counts), total amount (ha), average size (ha) and standard deviations in the size of retention patches. Finally, retention patch area was then divided by cutblock area to determine the amount of retention as a proportion.

Silviculture Treatment

For cutblocks up to 2010, we appended attributes identifying specific silvicultural prescriptions undertaken such as what scarification and chemical treatments were performed and when as well as what species of trees were planted and when. We are currently in the process of updating 2011 and 2012 cutblocks from recently acquired datasets that will be completed during the second year of this project and will be included in our final report for this project.

Forest Cover

The Lidar technique to map vegetation structure has been refined following the retention patch work. We will use Lidar imagery to map forest height classes and percent cover across within edge and interior forested areas to portray security cover. This work is in progress and will be completed during the second year of this project and will be included in our final report for this project.

Grizzly Bear Activity

Grizzly bear locations (use-sites) were investigated (n=270) between June and September, 2006 and 2007, to obtain activity (foraging, bedding) information. One GPS location for each bear day was randomly selected from a sample of collared grizzly bears (5 females and 1 male) and visited on average 22 days (SD=8, Min=1, Max=47) after the bear left the area. At each location (±10m GPS error) we meander searched for sign (activity) within the plot area. Sign was assumed to be from the study animal if the following was observed. Torn open or rolled coarse woody debris (ants) such as logs and stumps; ant mounds or sweet-vetch roots dug; animal remains usually with excavated ground vegetation; clipped forbs; fruiting shrubs with broken branches and missing leaves; or bed sites as shallow depressions usually dug out and that usually contained grizzly bear hair (Munro *et al.*, 2006). Foraging on certain forbs (e.g. horsetail) is most likely difficult to detect with any certainty, therefore, observer's judgment regarding grazing was not as stringent as it was with other activities (Mattson, 1997).

Food Quantification

Datasets from two previous studies that quantified grizzly bear foods, competing vegetation, and forest structure and composition are available as well as data collected from the 2012 field season specific to this project. Bear foods included shrubs, fruits, forbs, coarse woody debris (CWD) (ants), anthills, and ungulate pellets. Although not direct measures, CWD, anthills, and ungulate pellets represent surrogates of abundance for ants and ungulates.

At each grizzly bear activity location (section 2.4) and 1 random (2006) location 300m away on 1 of 4 random bearings (cardinal direction), a 30m transect was established south to north. Plot center was positioned either at the nearest bear sign within the 30x30m sample area, or centered nearest the actual GPS coordinate when no sign was observed or at random locations (n=197). Along transects, five sub-plots (1x1m) were established in 2006 at every six meters starting in the south. Similarly, in 2007, 3 sub-plots (1x1m) were staggered by 15m, again beginning in the south. Percent cover of bear foods, other vegetation, and coarse woody debris were estimated within each subplot, while tall shrubs (e.g. buffaloberry) were counted within a 1m wide belt along each transect. The presence of foods including counts of ungulate pellets and anthills was determined at the plot level from meander searches. The dominant two tree species was determined by ocular estimation and a prism sweep was performed at plot center.

Using a stratified random design, 30x30m plots (n=249) were established from June to October over 2 years (2008, 2009) within the Upper Foothills NSR where lodgepole pine occurred. Stratification was by forest age with a 5yr interval in cutblocks and 30yr interval in uncut forest. To avoid possible edge effects (Harper and Macdonald, 2002; Redding *et al.*, 2003; Mascarúa Lopez *et al.*, 2006), plots (30x30m) were moved up to 30m perpendicular from anthropogenic habitat boundaries. Plots were also moved up to 30m if greater than ten percent green tree retention (single trees, patches) occurred. Twenty-five subplots (1x1m) and five transects (1x30m) were aligned south to north and equally spaced within the plot. For each sub-plot, percent cover was estimated for dwarf shrubs and stems of smaller more clumped forbs (e.g. horsetail) were counted, whereas the stems of taller and more dispersed shrubs (e.g. buffaloberry) and forbs (e.g. cow parsnip) were counted along transects. In addition, ungulate pellets and anthills were counted and the percent cover of all bear foods, dominant shrubs, and trees by height class were estimated at the plot level. A prism sweep was taken at plot center.

From June to August 2012, sites (n=8) consisting of three parallel 50m transects spaced at 1, 10, and 30m from the cut/uncut edge and on each side of the edge were intensively sampled. Edges were located randomly within the Upper Foothills NSR following a pre-stratification by forest age (0-9, 10-19…29-39), site preparation technique based on depth of soil disturbance (deep vs. light), and a gradient (low vs. high) of in-block retention derived from Lidar. The intent of the design was to capture the abrupt change in food abundance associated with relatively small changes in edge distance while controlling for factors associated with cutblock age and site preparation type. It was hypothesized that at 10m there would be a marked decline in the effect of edge with 30m representing interior forest conditions. Retention sampling followed that single trees would be captured within plots whereas if patches were encountered, transects (n=3) would be sampled, but their length was dependent on the width of the patch (<50m). Bear foods and other competing vegetation including trees were quantified (counts, percent cover, biomass, and/or DBH) simultaneously along the transect using three different methods: 1) belt (2m width); 2) line intercept; and 3) circular quadrats (1m^2).

Year 1 Analysis

Telemetry and Activity Location Datasets

To answer the questions identified within this research project we created separate datasets from GPS and grizzly bear activity locations.

Grizzly bear GPS locations that fell within summer (June 16 to 31 July) and fall (August 1 to October 15) were retained in our analysis. We chose these timeframes because they represent the hyperphagic period when bears capitalize on available resources for growth and reproduction (McLellan *et al*., 2011; Robbins *et al.*, 2007) and signifies a major dietary shift from protein to carbohydrate (fruit) rich foods during the growing season (Munro *et al.*, 2006). Food availability during the growing season likely has a profound effect on the health of individuals and the reproductive potential of females, particularly lactating females with newborn cubs that have high energy demands (Farley and Robbins, 1995; Robbins *et al.*, 2012). Home ranges (multi-season and year) were delineated for each grizzly bear using minimum convex polygons (MCP). MCP's were clipped to the FMA boundary and then Geospatial Modeling Environment (2012) was used to generate 1 random location for every 10ha of an individual grizzly bears home range.

GPS and activity locations were intersected with habitat (section 2.3.1) that corresponded to the appropriate bear year, and for home ranges and random locations the most recent bear year. This process removed areas of home ranges and locations that overlapped with or occurred in non-forested habitat. The distance of the nearest cutblock edge and associated attributes were appended to remaining locations. All GIS based processing and analysis was performed in ArcGIS 10.1 (ESRI® Redlands, CA)

Telemetry and Activity Locations - Because our intent was to compare edge proximity, habitat selection, and grizzly bear activity within cutblocks to adjacent uncut forest, we used Telemetry (n=68,345) and grizzly bear activity locations (n=252) in uncut forest that were less than 1025m from a cutblock edge. 1025m was the maximum distance to edge of a random location within a cutblock. In addition, we only considered grizzly bears that had more than 50 GPS locations per season. Within the Telemetry dataset, we considered three sex and offspring dependent classes including males (adult and sub-adult), females (adult and sub-adult), and females with cubs of the year (COY). Females with COY were distinguished from females with or without cubs older than a year because of apparent differences in home range size, movement, and habitat selection (Larsen, unpublished data; Nielsen *et al., in prep*). Class assignment was changed in any given season for those females with COY that lost their entire litter. We did not consider this classification for the activity dataset because the majority were adult females (n=5) none of which had COY.

Forest Age Class – Because we were interested in variation in edge proximity and habitat selection relative to forest age, we created a four class categorical variable to represent age in cutblocks as three successional stages of tree regeneration and a single class for uncut forest. The 1-10 yr age class in cutblocks represents tree establishment and growth typically up to 3m in height while the 11-20 yr age class represents further canopy development. The 11-20 yr age class generally corresponds to the 'free to grow' period where a stand reaches minimum height requirements before the adjacent stand can be harvested. In this system, fruit production declines precipitously in cutblocks after about 20 years because of canopy closure, while forbs remain abundant (Larsen, 2012). The amount of forbs and fruit in the 1-10 and 11-20 age classes tends to be similar (Larsen, 2012).

Statistical Analysis

Telemetry and Edge Proximity – First, we collapsed the Telemetry dataset into individual observations by averaging edge distance (integer) values by season, sex and offspring dependent classes, and forest age. We used a generalized linear model with a log link to predict mean edge distance as a function of model covariates. Standard errors were adjusted for sample size (n=30) using a sandwich variance estimator and then calculated by the delta method. We tested whether or not a particular *a priori* model that consisted of effects related to season, sex, forest age, or interaction amongst these variables fit better than an intercept only (null) model. Support for the best fit model was determined using Akaikie weights (Burnham and Anderson, 2002). We then compared the mean and variance of edge distance predictions from the best fit model obtained through Telemetry locations to estimates of edge distance derived from random locations that were modeled separately. Differences were considered to be statistically significant when the confidence intervals (95%) of the mean effects were non-overlapping.

Activity and Edge Proximity – Activity data was analyzed by creating binary variables to identify locations that were classed as no activity, bed site, carcass site, herbaceous or berry feeding, and digging for roots and ants (coarse woody debris and anthills). Because of the number of individual grizzly bears sampled was limited (n=6) and observations of certain activities (i.e. berry feeding) were small, we were unable to model the potential effects of edge proximity and forest age class using a generalized linear model. Instead, we report summary statistics describing grizzly bear activity in relation to edge proximity and forest age.

Edge vs. Interior Selection –To represent the edge and interior of habitat, we created a binary variable based on the average distance (90m) grizzly bears were from the edge of cutblocks. By season and sex and offspring dependent classes, we estimated habitat selection ratios (w_i, Manly *et al*., 2002) for the edge and interior of forested habitat. To reduce the potential effect that rare habitats might have on selection ratios, we limited observations where habitat availability exceeded 5%. For each combination of season, sex and offspring dependent classes, selection or avoidance of edge and interior habitat was determined from a one-sample *t*-test against a hypothesized mean of 1.0 (% use = % availability). All statistical analyses were performed in Stata 12.1.

Results

Edge Proximity

The top model explaining grizzly bear edge proximity included the additive effects of sex and forest age (Akaikie weight=0.6). On average, males were further from the edge than females irrespective of forest age; however, there was some support (Akaikie weight=0.3) for a model with an interaction effect. Males tended to be further from the edge in 11-20 year old cutblocks than females, but the absolute distance (11m) was minimal and the significance of the effect was marginal (Coef=0.18, SE=0.12, Z=1.57, p=0.12). Edge distance of grizzly bears generally increased as cutblocks aged, yet edge proximity was similar amongst the younger (≤20 years) cutblock age classes. This pattern was also evident with random locations. Grizzly bear edge distance did not differ from random in cutblocks with the exception that females were significantly closer to the edge when using cutblocks older than 20 years (Figure 3). Random locations showed that edge distance in younger (84m) cutblocks was about 40% higher than in cutblocks older (117m) than 20 years (Figure 3). Overall, when grizzly bears used cutblocks, they were about 84m from the edge compared to 272m in uncut forest. In uncut forest, females were significantly closer to the edge compared to males and at random (Figure 3).

Table 1. Summary statistics of grizzly bear (n=6) activities by forest age class.

Activity Type	Age	n	Mean	Min	Max	SD	Median
No Sign	**1-10**	17	84.4	12.6	196.2	59.7	71.7
Bed		13	76.8	1.3	224.0	72.7	57.0
Carcass		0					
Herb		4	44.2	3.6	77.9	35.2	47.7
Berry		7	83.1	7.1	186.6	63.0	66.1
Root		3	125.6	104.1	142.3	19.5	130.5
Ant		10	107.6	3.3	197.3	69.9	116.2
No Sign	**11-20**	4	46.5	7.9	66.5	27.6	55.7
Bed		5	83.7	24.1	200.7	71.2	66.9
Carcass		1	24.1	24.1	24.1	.	24.1
Herb		2	80.7	66.9	94.6	19.6	80.7
Berry		3	158.5	88.1	195.9	61.1	191.6
Root		0					
Ant		13	117.8	24.1	231.4	73.1	94.6
No Sign	**>20**	12	97.2	26.5	237.4	71.5	74.7
Bed		39	126.1	5.5	574.0	108.0	93.6
Carcass		5	68.1	18.1	111.4	44.0	73.2
Herb		12	73.8	18.2	195.5	45.5	66.0
Berry		4	59.9	32.2	120.2	41.3	43.6
Root		0					
Ant		23	106.1	8.7	574.0	116.6	78.5
No Sign	**Uncut**	35	268.3	5.2	1018.9	263.6	218.2
Bed		61	243.9	5.9	855.3	229.8	184.7
Carcass		10	308.2	2.2	813.2	311.8	152.8
Herb		8	138.9	28.7	435.1	141.2	95.1
Berry		6	337.1	81.2	911.7	302.1	280.2
Root		11	196.5	10.1	435.1	139.8	235.7
Ant		6	307.8	13.9	516.2	193.1	316.1

Edge distance by grizzly bear activity appears to be influenced to some extent by forest age. Resting (bed) activity occurred more frequently and was further from the edge of cutblocks as age increased (Table 1); 80m in younger cutblocks versus 120m in those older than 20 years. Distance of foraging activities also appeared to increase with cutblock age based on the average maximum distance, yet no clear patterns could be elucidated for each specific activity type (Table 1). In cutblocks, carcass sites and herbaceous feeding were closer (Mean=47, Max=99) to the edge whereas foraging for berries and ants tended to be further away (Mean=106, Max=262). In uncut forest, edge distance for all activities ranged from relatively close to far with the exception being that herbaceous feeding was substantially closer on average (Table 1). Overall, foraging activities were about 88m from the edge in cutblocks and 258m in the uncut forest.

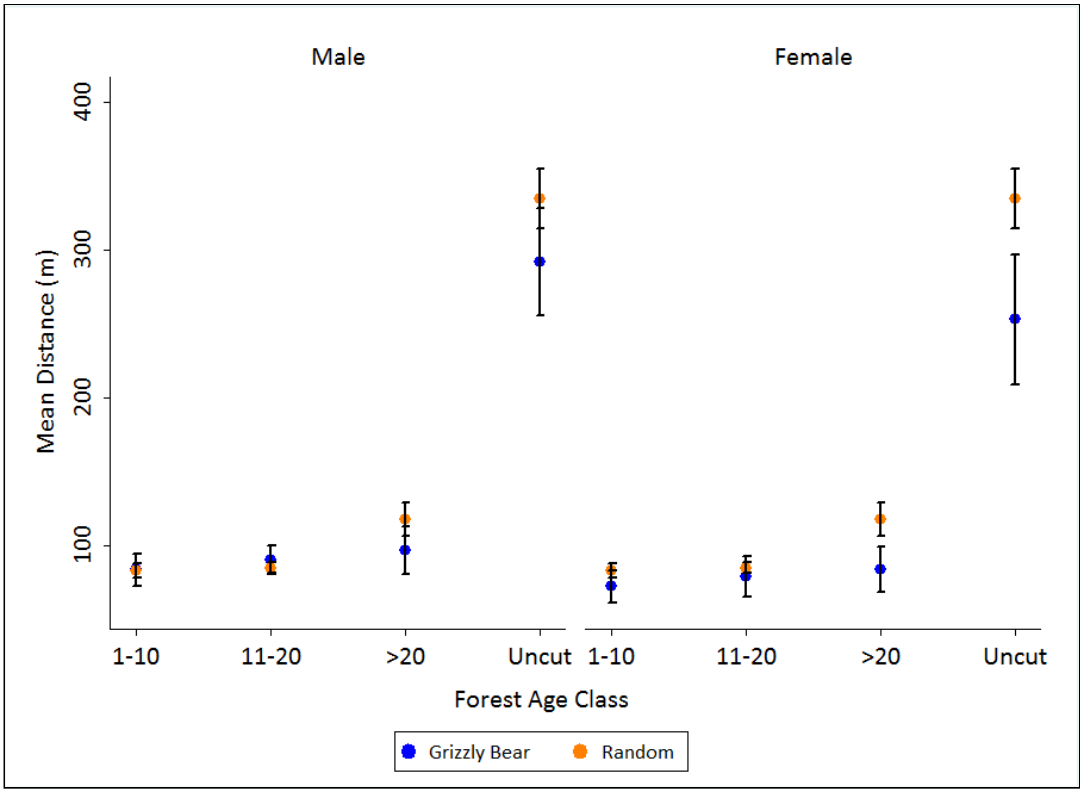

Figure 3. Predicted mean distance to edge and 95% confidence intervals of male and female grizzly bear and random locations among four forest age classes.

Edge vs. Interior Selection

Selection of interior and edge habitats varied according to season, sex, and forest age (Figure 4). In summer, the strength of selection for cutblock edge and interior habitats was similar among male and female grizzly bears. Cutblocks older than 10 years were either selected or used at availability. Both male and female bears avoided the interior of uncut forest, but unlike males that used uncut edge at availability, females showed strong selection. Selection for the uncut edge was even more apparent in females with COY (n=4). During the fall season, males showed strong selection for 1-10 year old cutblocks with the effect being stronger on the edge compared to the interior. Otherwise, edge and interior habitats were avoided or used at availability. Conversely, female grizzly bears selected for the edge of cutblocks younger than 20 years of age, while the interior of this age class was used at availability. Like males, older cutblocks and particularly the interior was avoided by females. Again, females avoided the interior of uncut forest and showed strong selection for the edge, while those with COY selected the edge and used the interior at availability. Finally, it should be mentioned that sample size differed between edge and interior habitat treatments associated with forest age. About 55% of the observations not included in the analysis were individuals having less than 5% of their home range consisting of young (<20 years) cutblock interior.

Resting and foraging activities by grizzly bears occurred more frequently within the edge of cutblocks and interior of uncut forest (Table 2). Of the specific types of foraging activities, there were proportionately more instances of berry and herbaceous feeding 90m from the edge in cutblocks. Ant activity occurred with equal frequency within the cutblock interior and edge, while carcass sites were associated with the uncut forest interior.

Table 2. Proportion of grizzly bear (n=6) activities among the edge and interior of cutblock and uncut forest.

		Interior		Edge	
Activity	n	Cut	Uncut	Cut	Uncut
None	68	0.21	0.38	0.28	0.13
Bed	118	0.23	0.34	0.25	0.18
Ant	52	0.44	0.10	0.44	0.02
Berry	20	0.30	0.25	0.40	0.05
Carcass	16	0.13	0.38	0.25	0.25
Dig	14	0.21	0.50	0.00	0.29
Herb	26	0.12	0.15	0.58	0.15
Average		0.19	0.32	0.31	0.18

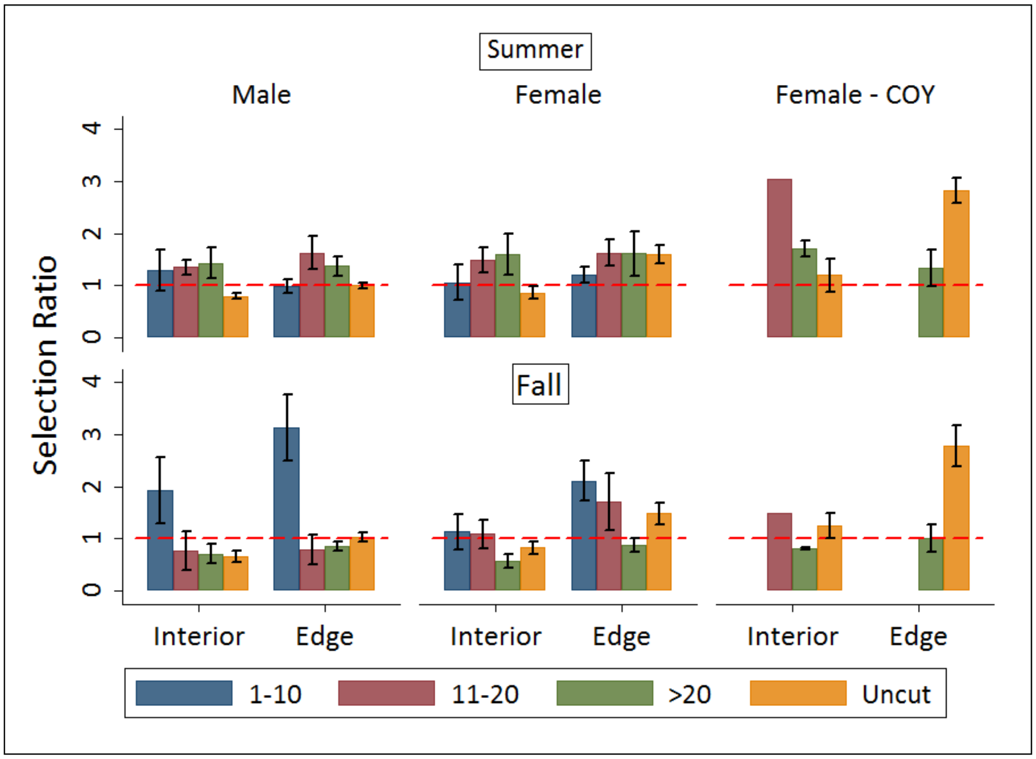

Figure 4. Grizzly bear selection of interior and edge habitat by season, sex and offspring dependence and forest age.

Discussion

Our findings suggest that biological factors (sex) and forest age influences the distance grizzly bears are from a forestry cut block edge. In our study, females tended to be closer to the edge than males. This is consistent with other research that suggests females are attracted to anthropogenic edges more than males (Stewart *et al*., 2013). In cutblocks, foraging activity tends to occur within close (~90m) proximity to forested edges, presumably because food and cover are readily available (Blanchard 1983; Mattson 1997; Mattson *et al*., 2002; Mertzanis *et al*., 2008). We suspect the increase, albeit small, in edge distance as function of forest age is more related to food resource availability than to security cover. We believe this is due to greater canopy development in older cutblocks, and this results in certain foods (forbs and ants) being more abundant than in uncut forest (Nielsen *et al*., 2004b; Larsen, 2012). We suspect that because females were closer to the edge in older cutblocks compared to a random distribution of locations, there may be a lasting ecotone effect (Mattson *et al*., 2004). Although food is often associated with edge proximity, other activities unrelated to foraging such as tree rubbing or movement may also be occurring (Green and Mattson, 2003). Female bears tend to be in closer proximity to the edge, particularly on the uncut side perhaps to ensure there is escape cover for young when foraging (Brodeur *et al*., 2008). The implication is that bears may use edges for a variety of purposes that may be associated with specific foraging activities. For females, foraging and traveling along the forest cutblock edge interface may represent a strategy to maximize the availability of food and cover.

Our results suggest that under current landscape conditions, male and female grizzly bears at the population level do not avoid the interior of any cutblock age classes during the summer when food resources are most available. In fact, the strength of selection for the interior was similar to the edge in summer suggesting that the size of the interior had little to no influence on the use of cutblocks by grizzly bears during this time period. This changed in the fall when edge selection in male and female bears exceeded that of the interior given the respective age classes being selected. The current design (shape, size) of younger cutblocks (<20 years) in particular appears to be attractive to grizzly bears, but this could change especially for female grizzlies if edge distance increases with the size of cutblocks associated with natural disturbance based forestry (Nielsen *et al.,* 2008) or as a result of the surge cut for mountain pine beetle management (Stewart *et al*., 2012). However, over the long-term, fall habitat is not likely to improve given that a decrease in uncut forest corresponds to an increase in cutblocks older than 20 years (Larsen, 2012). Females not only showed strong selection for uncut forest edge, but both male and females avoided the edge and interior of these older cutblocks. If fruit production tends to decline in cutblocks with canopy closure (Larsen, 2012), and the fall is the critical season for bears to gain the necessary fat reserves for denning and reproduction (McLellan *et al*., 2011, Robbins *et al*., 2012), creating smaller cutblocks adjacent to uncut forest appears to be the most beneficial to grizzly bears in the short-term. Silvicultural prescriptions (e.g. thinning) are likely necessary to improve fall habitat, regardless of cutblock size.

Key Research Findings

- When using cutblocks, grizzly bears occurred within 84m of the cutblock edge interface versus 272m when bears were within the uncut forest.
- Females tended to be closer to the cutblock edge interface than males.

- Male and female grizzly bears did not avoid the interior of any cutblock age class during the summer or fall when food is most available.
- Selection of habitat edge was stronger than the interior during the fall season
- Females including those with cubs of the year showed strong selection for the edge of uncut forests during the summer and fall.

Year 2 Research Initiatives

Edge vs. Interior Habitat

There are several unknown factors regarding the use of interior and edge habitats by grizzly bears. Whether the observed relationships from this analysis are related to the availability of food and/or cover is not known, however, evidence suggests that both may be playing a role. Although we have identified that edge use differs by season and forest age class, we must also determine if edge use is influenced by the type (i.e. second-pass, tree composition, environmental conditions) of adjacent edge habitat. Many of the stands being harvested for mountain pine beetle management are associated with second pass harvesting, and in other areas 'green-up' delays may be waived during the surge cut leading to less habitat edge. We also aim to determine if there are specific stand level factors (e.g. species composition, riparian zone) and environmental conditions (moisture, solar radiation, climate) at the cutblock edge interface that influences grizzly bears use of the edge and whether or not this can be best explained by food or cover. Additional analyses will be undertaken in the second year of this project to examine variation in the use (clusters) and movement (step length, turning angles) to better understand the behavior of grizzly bears when using the edge and interior of habitats.

Silviculture Treatment and In-block retention

Year 2 work will investigate grizzly bear response and activity including food resource availability in cutblocks with natural regeneration versus where silviculture treatments such as scarification, herbicide, and tree planting occurred. We will determine whether or not food is more abundant within or near in-block retention patches, and assess if the amount, size, and configuration of retention in cutblocks relative to the forested edge influences grizzly bear behavior.

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3.2. Research and Applied Tools To Enhance Forest Management Linkages To Grizzly Bear Conservation And Recovery In Alberta

Prepared by Jerome Cranston

Canadian Cooperative Wildlife Health Centre

Summary

This document describes the GIS tools that comprise the project deliverables for Activities 3, 4, and 5 of the 2012 FRIP Fund Initiative (2011-2012), which are:

Activity 3: A GIS application that evaluates the effect of forest harvesting on caribou and grizzly bears on a shared landscape;

Activity 4: A GIS application to calculate the effect of road reclamation on grizzly bear habitat security;

Activity 5: A GIS application that calculates the proportion of planned cutblocks visible from roadsides.

These three applications will forecast the effect of forest management activities, such as timber harvest and road reclamation, on various aspects of grizzly bear and caribou habitat quality such as resource selection (Activity 3) and habitat security (Activities 4 and 5).

These applications are draft versions and will be presented to FRIAA program partners at a planned workshop in the summer of 2013 (see note on page 19) for testing and review.

Toolset Description

The three GIS tools are all accessed through an ESRI ArcGIS Desktop (v10) toolset that consists of:

- Base GIS layers representing model predictor variables;
- Geoprocessing scripts, written in Python 2.6.5;
- An ArcGIS Toolbox (*.tbx), containing the user interface to the scripts.

The toolset is contained in the folder *GBtools*. The Python scripts reference subfolders by their relative path within the *GBtools* folder, therefore subfolders must not be renamed. This folder structure is consistent with other versions of *GBtools* produced by the FRIGBP, which are distributed annually to program partners. To use the tools:

1) Copy the folder *GBtools* to a location on your PC or server.

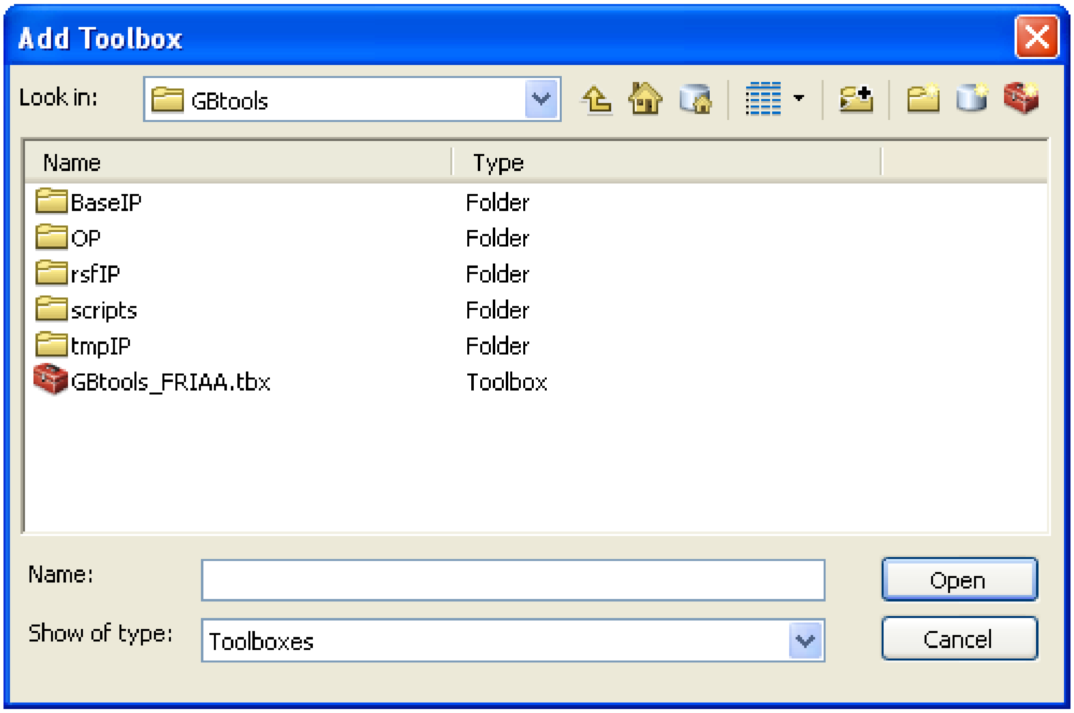
2) In an ArcMap or ArcCatalog session, add the *GBtools_FRIAA.tbx* toolbox to ArcToolbox (Figure 5).

The scripts were written for ArcGIS 9.3 but have been tested on version 10.0. *ArcInfo functionality and Spatial Analyst extension are required*.

3) Examine the layers in ArcCatalog to ensure they have copied correctly (Figure 6). The folder *GBtools* contains the following subfolders:

- */BaseIP/* This folder contains GIS base layers containing inputs to the various models.
- */OP/* This folder (initially empty) is used to store tool outputs.
- */rsfIP/* This folder (initially empty) is used to store temporary datasets created during tool processing.
- */scripts/* This folder contains the Python geoprocessing scripts.
- */tmpIP/* This folder (initially empty) is used to store temporary datasets created during tool processing. Also it contains *temp.mdb*, a personal geodatabase used to store temporary datasets.

The folder *GBtools* also contains the file *GBtools_FRIAA.tbx*, which stores the user interface to the scripts.



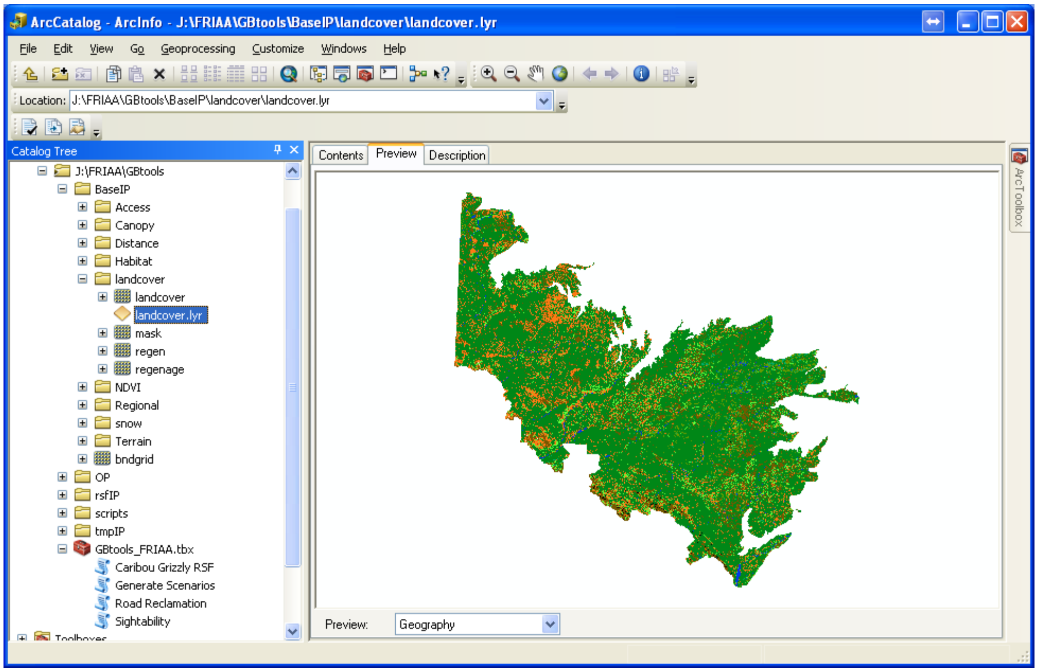
Look in: GBtools

Name	Type
BaseIP	Folder
OP	Folder
rsfIP	Folder
scripts	Folder
tmpIP	Folder
GBtools_FRIAA.tbx	Toolbox

Name:

Show of type: Toolboxes

Figure 5. GIS tools in ArcToolbox



Location: J:\FRIAA\GBtools\BaseIP\landcover\landcover.lyr

Preview: Geography

Figure 6. ArcCatalog layers

Model extents

The caribou/grizzly RSF tool and the road reclamation tool can be applied anywhere within the extent of the base layers, which is defined as: *the portion of the core and secondary grizzly bear conservation areas within the Grande Cache grizzly bear population unit that are covered by the caribou RSF models (15,585 sq km)* (Yellow, Figure. 7).

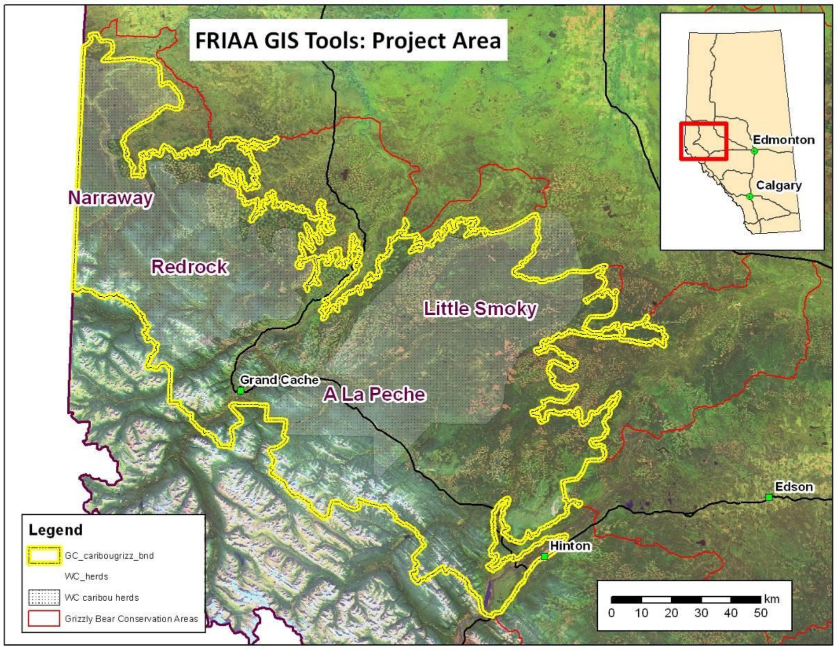


Figure 7. Model extent

Activity 3. New GIS planning tool for two species at risk in Alberta (Caribou/Grizzly Bears).

Objective

The objective of Activity 3 was to create a new planning tool to simultaneously evaluate forest harvesting effects on caribou and grizzly bears on a shared landscape.

This tool generates Resource Selection Function (RSF) models for both caribou and grizzly bears, and summarizes their interactions. Optionally, the user may input a timber harvest scenario, consisting of a block layer attributed with stand age, as is produced by timber supply models such as Patchworks or Woodstock/Stanley, and the regenerated RSF models will reflect the change in resource selection by both species under these different landscape configurations.

The grizzly bear RSF models used in this application were developed by Dr. Scott Nielsen (Nielsen, 2002) and are specific to the five Alberta population units south of the Peace River (Grande Cache, Yellowhead, Swan Hills, Clearwater, Livingstone, and Castle), and three seasons: spring (May 1 – June 15), summer (June 16 – 31 July), and fall (Aug. 1 – Oct. 15).

The caribou RSF models were developed by Nick DeCesare (DeCesare, 2011) and are specific to the nine Rocky Mountain caribou herds of Alberta (Banff, Tonquin, Maligne, Brazeau, A La Peche, Little Smoky, Redrock, Narraway, and Redwillow), and two seasons: summer (May 16 – Oct. 16) and winter (Oct. 17 – May 15).

To ensure spatial and temporal consistency between RSF models for the two species, the summer caribou RSF model was used in conjunction with a combined spring/summer/fall grizzly bear RSF, and the extent of the interaction model was limited to where caribou herds overlap with grizzly bear populations, in areas subject to forest harvest. The Banff herd was excluded from the model due to its extermination in an avalanche in 2009; the Redwillow and Narraway herds were excluded due to their summer range being located in BC; and the Tonquin, Maligne, and Brazeau herds were excluded due to being situated entirely within Jasper National Park, which is not subject to forest harvest.

The application generates the summer RSF for three west-central Alberta caribou herds (Redrock, A La Peche, and Little Smoky) as well as the seasonal composite grizzly bear RSF for the Grande Cache population unit.

To represent the interaction between grizzly bear and caribou, the RSF for each species was reclassified into high, medium, and low categories, and combined in a matrix of nine possible combinations. By comparing current RSF values with forecast values across the planning unit, forest managers can better understand the trade-offs implicit in different harvest scenarios, in terms of their impact on both of these at-risk species.

Note that this application is a draft version only and may be revised following peer review. A demonstration analysis was performed in September 2012 for Canadian Forest Products Ltd. (Canfor). The script was modified to incorporate long-term (up to 50 years) timber supply scenarios generated by Patchworks timber supply modeling software (Phase 2 of Activity 3). In this demonstration, 3rd-order summer and winter RSFs for the Little Smoky herd were regenerated for the Caribou Special Management Zone (710 sq km) in the Canfor FMA, based on 5 different timber harvest scenarios. Methodology and output for this sample analysis was distributed to 14 expert *reviewers representing federal and provincial government, universities, and forest industry partners. A number of modifications to the initial application were made in response to comments from the reviewers, including: regenerating 1st-order, 2nd-order, and scale-integrated RSFs; changing the upper age limit for cutblocks from 40 to 50 years; generating RSFs for the A La Peche and Redrock herds; and incorporating a 20-year delay in removal (ie, reforestation) of seismic lines following harvest.*

A workshop will be held in May 2013 with the program partners to review this version of the application, and to determine future development and revisions.

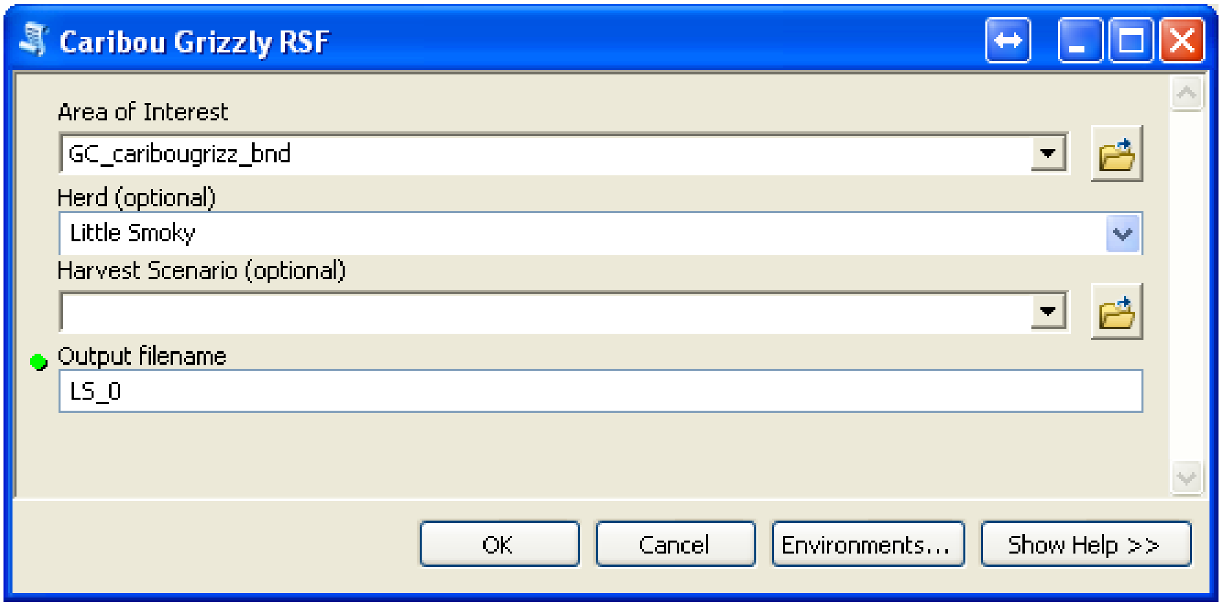
<u>User Interface</u>
The inputs (Figure 8) to the CaribouGrizzly application are:

1) **Area of interest** (Required) This is a polygon shapefile or feature class representing an analysis area, such as a watershed, operating compartment, or other planning unit (Area of Interest, or AOI).

2) **Herd** (Required) The user has a choice of regenerating RSFs for one of three herds: the Little Smoky, A La Peche, or Redrock.

3) **Timber Harvest Scenario** (Optional) This is a geodatabase polygon feature class representing harvested areas, as can be output by timber supply models such as Patchworks or Woodstock/Stanley. *The feature class must contain an integer attribute field named [STANDAGE], with values for stand age at the time of the forecast scenario*.

4) **Output scenario name** (Required) This is a string, up to 9 characters long, that names the output caribou and grizzly RSFs, and the interaction matrix.



Area of Interest
GC_caribougrizz_bnd

Herd (optional)
Little Smoky

Harvest Scenario (optional)

Output filename
LS_0

Figure. 8: Caribou Grizzly RSF tool: User interface

Process Description

The polygon feature layer entered as the first parameter is first clipped by the model boundary, and the result is converted to 30m raster. This is used to extract portions of the grizzly RSF (seasonal maximum) and caribou RSFs (1st-order, 2nd-order, and 3rd-order) for the herd chosen in the 2nd parameter.

If no timber harvest scenario is entered in parameter 3, the grizzly RSF is reclassified into high, medium, and low classes. The 3 caribou RSFs are multiplied together in a MapAlgebra expression to create the scale-integrated RSF (*srsf*). The *srsf* is also reclassified into high, medium, and low classes. The reclassified grizzly and caribou final RSFs are multiplied together to form a matrix of unique combinations:

	Grizzly: LO (5)	Grizzly: MED (6)	Grizzly: HIGH (7)
Caribou: LO (1)	5	6	7
Caribou: MED (2)	10	12	14
Caribou: HIGH (3)	15	18	21

If a timber harvest scenario is entered as a third parameter, the grizzly and caribou RSFs are regenerated from base layers for the AOI. The timber supply scenario consists of a block layer, clipped to the AOI, with a field for stand age. This layer represents all harvested areas at the time of the scenario and is used to generate 3 different block layers, depending on stand age:

- ALL blocks are blocks less than 50 years old. These are burned into the existing 11-class landcover for caribou. This layer is used to recalculate cutblock density at three different scales (12k, 5km, and 70m search radius), as a predictor for caribou RSF. Crown closure values are assigned to each block based on stand age.
- OLD blocks are blocks >50 yrs old in the scenario. These areas revert to the original landcover class (assumed to be closed conifer).
- MED blocks are blocks that existed in 2012 but are >20 yrs old in the scenario. These are used to erase seismic lines, on the assumption that seismic lines are reforested following harvest, following a 20-year regeneration delay. Seismic line density is then recalculated at three different scales (12k, 5km, and 70m search radius).

The assumption underlying this process is that all areas that are not harvested will remain unchanged. While this is not realistic in that it does not account for changes in habitat due to construction of new roads, pipelines, and other features, nor for natural changes such as wildfires or MPB kill, the purpose of this tool is to compare the effects of different harvest scenarios, and introducing other disturbances would disguise the changes attributable solely to changes in harvest planning.

The predictor variables for the caribou and grizzly RSFs consist of both static variables, such as terrain (and, for this purpose, climate-driven variables such as snow cover, as well as NDVI), and dynamic variables based on forest disturbance. Each of these variables is multiplied by its respective coefficient and added together in a Spatial Analyst MapAlgebra expression. The dynamic (updateable) variables are:

Grizzly:

- Wet tree Landcover classes
- Shrub Landcover classes
- Wet herb Landcover classes
- Upland herb Landcover classes
- Non-vegetated (barren) Landcover classes
- Regen (regenerating forest, <50 years stand age)
- Crown closure in regen areas
- Crown closure in forested areas
- Percent conifer in upland tree areas
- Distance to forest edge inside upland tree class
- Distance to forest edge inside wetland tree class
- Distance to forest edge inside upland tree class
- Distance to forest edge inside upland herb class
- Distance to forest edge inside regen
- Distance to forest edge inside non-vegetated class
- Range (occupancy) factor
- non-habitat mask

Caribou:

- Cutblock density
- Seismic line density
- Open conifer landcover class
- Mixed conifer/deciduous landcover class
- Muskeg landcover class
- Shrub landcover class
- Herbaceous landcover class
- Alpine vegetated landcover class
- Rock/ice landcover class
- Cutblock landcover class
- Burn landcover class

Predictions (Figure 9) for each of these variables are made for all areas harvested in a timber supply scenario. Regenerating forest is treated as its own landcover class in both the grizzly and caribou landcovers, and when a block is more than 50 years old, it is assumed to revert to closed conifer class in the caribou landcover, and to upland tree class in the grizzly landcover. Percent conifer and crown closure is assigned to each block as a function of stand age, based on preliminary regression analysis of the Phase 6 Remote Sensing representation of these attributes on cutblocks within the model boundary (McDermid, 2005), ranging from 0 to 55 years old.

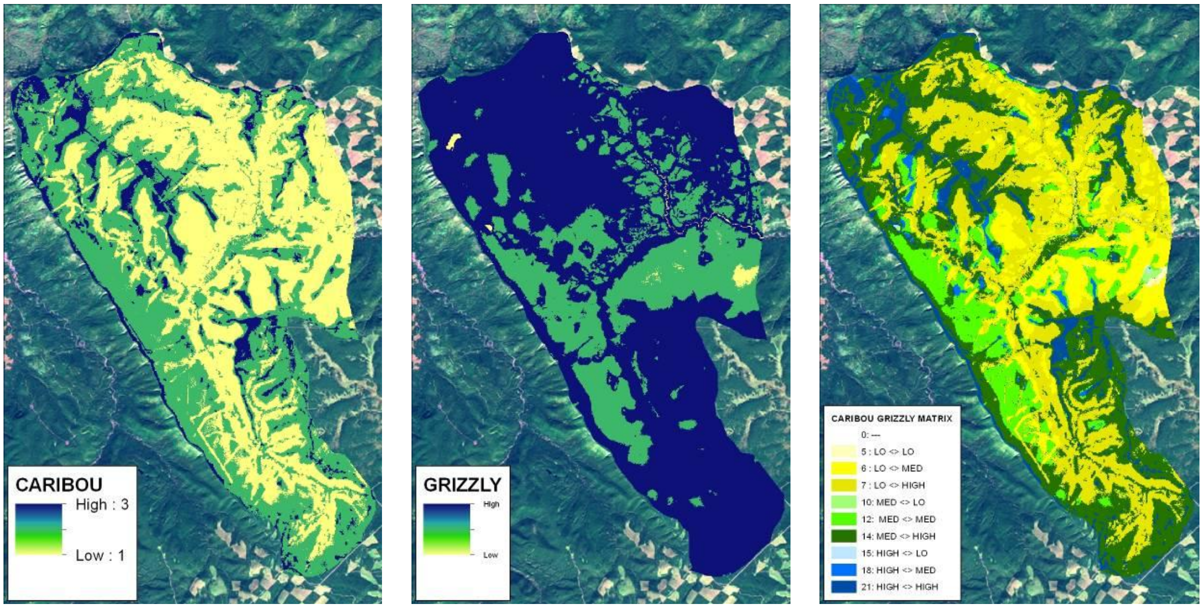


Figure 9: Caribou RSF (left) Grizzly RSF (center) and interaction matrix (right)

Activity 4. Road reclamation guidance and analysis tool for Grizzly Bear Conservation Areas.

Objective

The objective of Activity 4 was to develop a new GIS application to calculate the effect of road reclamation on grizzly bear habitat security.

A road within grizzly bear habitat can turn an area of secure, high-quality habitat into an attractive sink, where bears are attracted by habitat resources but are vulnerable to increased risk of anthropogenic mortality. The road reclamation tool defines the area of habitat associated with a given set of roads, and evaluates current and future habitat quality within the area accessed by the selected roads.

For a user-specified Area of Interest (AOI), the script will summarize the current state of grizzly bear habitat, as represented by the RSF, risk, and Habitat States models, and by other measures of habitat security such as length of road within the AOI, and mean distance to road.

Optionally, the user may also enter a set of roads selected for reclamation. The script will recalculate the mortality risk for the AOI, and combine it with the RSF to create a new Habitat State model. Other measures of habitat security summarized by the application are: current and projected road density; mean distance to road within the AOI; and area of safe harbor created.

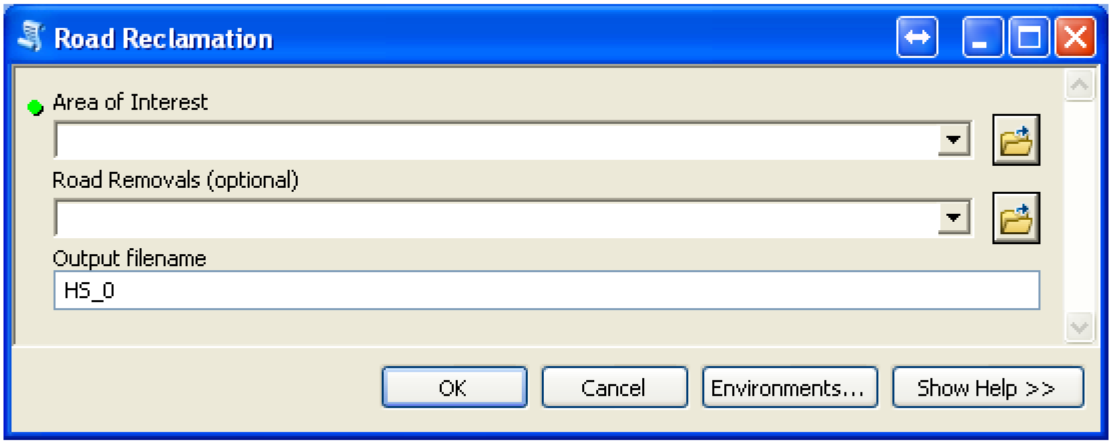
User Interface

User inputs (Figure 10) are:

1) **Area of interest** (Required) This is a polygon shapefile or feature class representing an analysis area, such as a watershed unit or operating compartment. The grizzly bear Habitat States model will be generated for this area and summary statistics generated.

2) **Road Removals** (optional) This is a line shapefile or feature class representing roads selected for reclamation.

3) **Output filename** (Required) This is a string that names the habitat state model to be generated. Raster name must not exceed 13 characters.



Output filename: HS_0

Figure 10: Road Reclamation tool: User interface

Process Description

The script accepts a polygon layer as the first parameter and converts it to a raster at 30m cell size. This is used to clip out the current grizzly bear RSF and risk models for the area and combine them into a Habitat State model (named in the third parameter), representing current habitat conditions. Mean values for these three models across the AOI are written to dbf files. A fourth habitat security metric written to an output file is the mean cost distance to roads over the AOI. This statistic is more indicative of road impact than a simple measure of length of road per unit area; since it reflects how widely dispersed roads are distributed across a landscape unit. The cost surface used is the Terrain Ruggedness Index, which is a predictor variable for risk and is more biologically meaningful than Euclidean distance.

Optionally, if a set of roads selected for reclamation is entered as the second parameter, the application will erase the selected roads from the clipped road layer, and regenerate the mortality risk model. This modified risk surface will be used in recalculating the Habitat States model for the unit. Another cost distance to road surface is generated from the modified road layer, and the mean written to a dbf file.

In the example below (Figure 11), the removal of a selected road (dashed) from this watershed (highlighted) has caused the mean Habitat State value for the watershed to increase from 0.8177 to 0.8291 (a positive outcome in terms of change in habitat security), and the mean cost distance to roads has increased from 4107m to 4344m (also a positive outcome) . Such statistics are useful when comparing the costs and benefits of various road reclamation options.

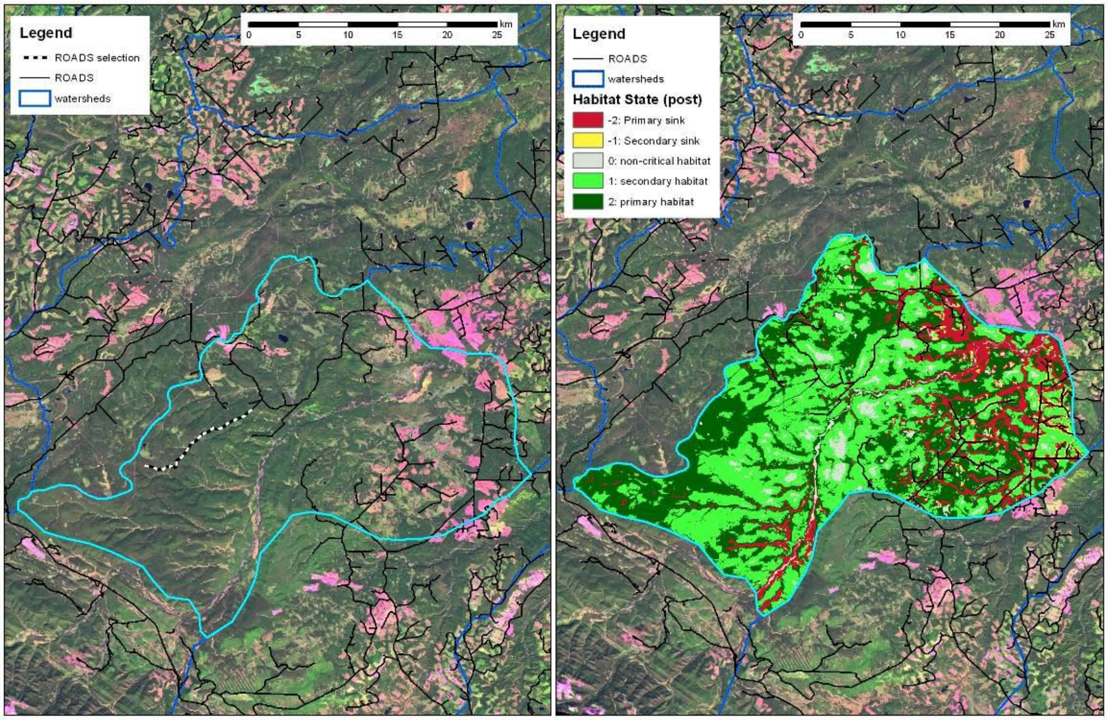


Figure 11: Watershed (highlighted) and road selected for reclamation (dashed), left; and regenerated Habitat State model with road removed, right

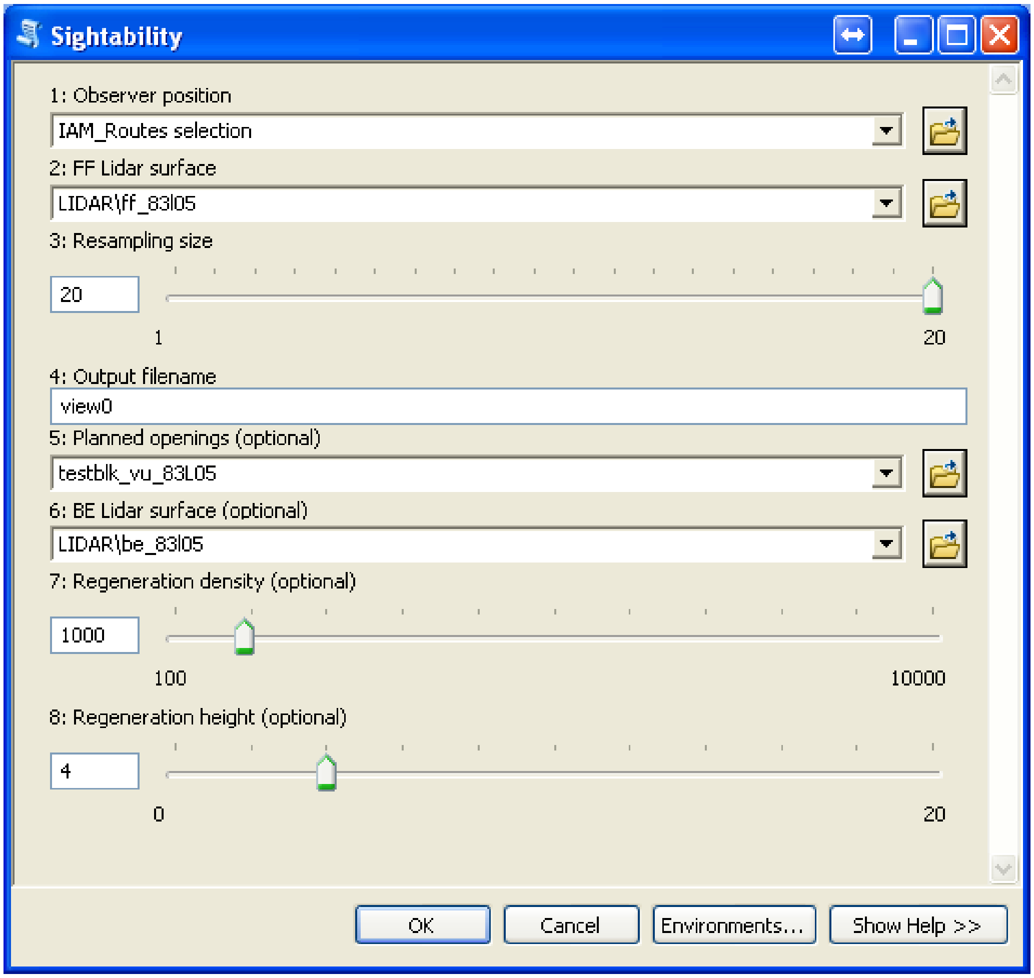
Activity 5: New planning tool to enhance grizzly bear survival in forest cutblocks.

Objective

The objective of Activity 5 was to develop a GIS application to calculate the proportion of planned cutblocks visible from roadsides.

User interface

The viewshed tool (Figure 12) uses Lidar surfaces to evaluate cutblock design by calculating the area within a block that will be visible from an observer position along the roadside. The tool will also simulate regeneration within the block according to a user-specified density and height.



Sightability

1: Observer position
IAM_Routes selection

2: FF Lidar surface
LIDAR\ff_83l05

3: Resampling size
20

4: Output filename
view0

5: Planned openings (optional)
testblk_vu_83L05

6: BE Lidar surface (optional)
LIDAR\be_83l05

7: Regeneration density (optional)
1000

8: Regeneration height (optional)
4

Figure 12: Viewshed calculator: User interface

<u>Inputs:</u>
(Note that all inputs to this tool are supplied by the user, including the Lidar surfaces; therefore, it may be applied anywhere that Lidar coverage is available, and is not limited to the extent shown in Figure 7).

1) **Observer position**. (Required) This a line feature layer representing a roadside vantage point.

2) **Full Feature Lidar surface** (Required) Raster layer representing Full Feature Lidar. The surface must fully cover the analysis area (buffered road).

3) **Resampling size** (Required) This is an integer between 1 and 20 that determines the pixel size of the output. The larger the resampling size, the shorter the processing time; this may be appropriate as a basic measure of habitat security within a watershed. For detailed block design, and particularly for design scenarios incorporating regeneration, a better result is obtained using the highest-resolution surface available.

4) **Output filename** (Required). A string is entered as the name of the viewshed raster in /GBtools/OP/. Filenames must not exceed 13 characters and should not contain special characters.

5) **Planned openings** (Optional). This is a polygon feature layer representing planned harvest blocks. If a parameter is entered here, the script will update the Full feature Lidar surface with the block, by substituting Bare Earth elevation values within the block.

6) **Bare Earth Lidar surface** (Optional). A Bare Earth raster surface must be entered as a parameter if planned openings are entered. The grid must fully encompass the planned openings.

7) **Regeneration density** (optional). User may enter an integer between 100 and 10,000, which represents target regeneration density (stems per ha). This parameter may be left empty to model conditions immediately post-harvest; if a number is entered here, random points will be generated within the planned cutblock at the specified density.

8) **Regeneration height** (Optional). User may enter an integer between 0 and 20, which represents regeneration height (in m). This parameter may be left empty if regeneration density is also left empty. If a number is entered, the random points are assigned this value, and converted to grid. The pixels are added in MapAlgebra to the updated Full Feature Lidar surface.

Process Description

The road feature entered as an observer position is buffered by 1000m, based on the assumption that a bear situated > 1 km from a road side, even if visible, is not at imminent risk of poaching. This imposes a biologically meaningful limit on the line-of-sight analysis, which is very computationally time-consuming. This buffer polygon is converted to raster (using the cell size entered as the 3rd parameter) and multiplied by the Full Feature Lidar surface (entered as the second parameter) in a MapAlgebra expression. This process “clips” the Full feature surface to within 1 km of the roadside.

If no optional inputs are entered, the application will generate an integer raster (named as the fourth required parameter) representing areas visible from the roadside. Pixel values represent the number of observer points from which the pixel can be seen. This layer represents conditions current at the time the Lidar was flown. A hillshade layer of the clipped Full Feature surface is also generated for map display.

Optionally, the user may enter a polygon shapefile or feature class representing planned cutblocks to be evaluated. The planned cutblocks are first clipped by the 1-km road buffer and unioned with it. The resulting shape is converted to raster and reclassified into a position raster. This is used by Spatial Analyst Pick tool to substitute Bare Earth elevation values (using the Bare Earth Lidar surface entered as the 6th parameter) for Full Feature elevation values within the planned blocks.

If no values are entered for the 7th and 8th parameters, the script will recalculate sightlines from the road using this modified Full Feature surface. The resulting viewshed surface can be overlaid with the original surface to determine the increase in sightlines resulting from the opening.

If the user enters a value for regeneration density (stems per ha, or sph) as the 7th parameter, the script will generate random points within the cutblocks to represent regenerating trees and model their effect on sightlines. The script first dissolves the layer of planned cutblocks into a single multipart feature, and stores the feature’s area (in ha) from the Shape_Area field. The total number of trees to be regenerated is the density (sph) times the number of hectares. The Minimum Inter-Tree Distance (MITD) is calculated as the inverse of the density (1.0m for a density of 1000 sph), to ensure that random points are as evenly spaced as possible. The height of the regenerating trees is entered as the 8th and final parameter. The random points are attributed with this height and converted to raster at 1m pixel size. Null values are converted to zeros, and this raster is added to the elevation values of the clipped Full Feature raster using MapAlgebra. Sightlines are then recalculated (Figure 13).

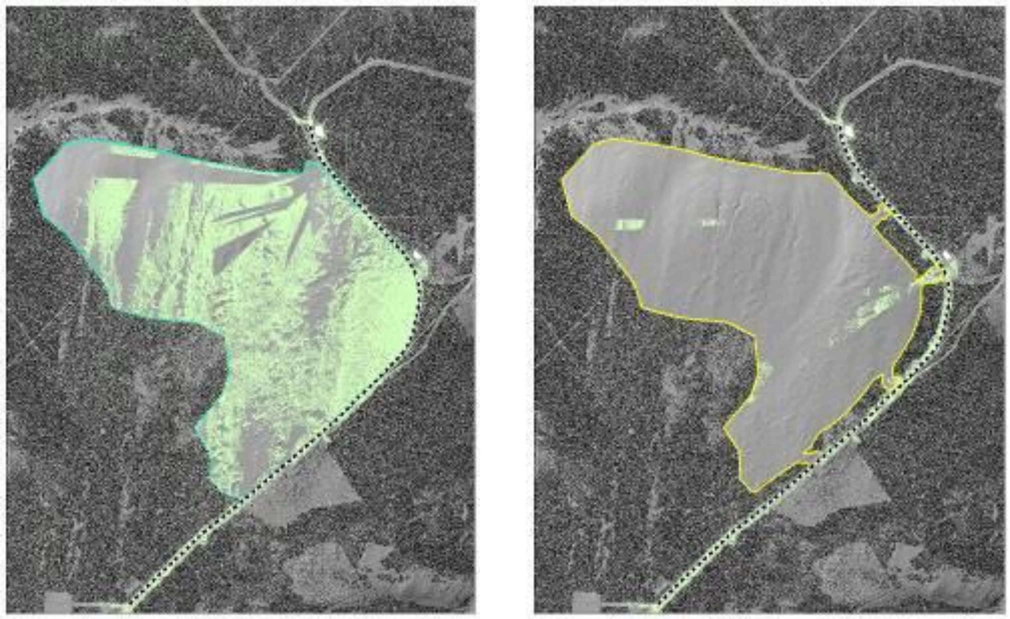


Figure 13: Sightlines (green) from roadside (dashed) with timber visual buffers (right) and without (left).

References

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

Nielsen, S.E., Herrero, S., Boyce, M.S., Mace, R.D., Benn, B.,Gibeau, M.L., Jevons, S., 2004. Modelling the spatial distribution of human-caused grizzly bear mortalities in the Central Rockies Ecosystem of Canada. Biological Conservation 120, 101–113.

Nielsen, S.E., Stenhouse, G.B., and Boyce, M.S. 2006. A habitat-based framework for grizzly bear conservation in Alberta. Biological Conservation 130: 217-229.

McDermid, G.J. 2005. Remote Sensing for Large-Area, Multi-Jurisdictional Habitat Mapping. PhD Thesis. Department of Geography, University of Waterloo, Waterloo, Ontario, Canada.

Appendix 1: Outline of the GBtools folder

	Dataset Name	Description
/GBtools/BaseIP/		
/Access/		
	access.mdb/GC_caribougrizz_bnd	boundary of habitat models
	access.mdb/ROADS	Roads (driveable by on-highway vehicles)
	access.mdb/TRAILS	Trails (potentially driveable by off-highway vehicles)
	access.mdb/watersheds	watershed units
	ned_rd	cost distance to road
	ned_tr	cost distance to trail
/Canopy/		
	cc	crown closure
	p_uptree	proportion of upland tree within 17km radius
	pctcon0	percent conifer
/Distance/		
	ddtree_01k	decay distance to treeline, 1km search radius
	ddtree_05k	decay distance to treeline, 5km search radius
	ddtree_12k	decay distance to treeline, 12km search radius
	ddwater_01k	decay distance to water, 1km search radius
	ddwater_05k	decay distance to water, 5km search radius
/Habitat/		
	risk	grizzly bear mortality risk model
	rsf_max	grizzly bear RSF model (seasonal maximum)
/Landcover/		
	landcover	landcover 10-class

	mask	Nonhabitat mask (water, snow/ice, rock)
	regen	regenerating forest
	regenage	age of regenerating forest
/NDVI/		
	ndvi	Normalized Difference Vegetation Index
/Regional/		
	femalerngpct	female range scalar (occupancy surrogate)
	protd6mi_pct	proportion of protected area within 10km radius
/snow/		
	snow_s	Proportion of days pixel is under snow (summer)
	snow_w	Proportion of days pixel is under snow (winter)
/Terrain/		
	asp_ew	East-west aspect
	asp_ns	Morth-south aspect
	cti150m	Compound Topographic Index
	d100_strm	Proximity to streams
	d500_strm	Distance to streams
	dem_km	elevation
	p6tri	Terrain Ruggedness Index
	slope	Slope
	tpi_01k	Topographic Position Index (1 km scale)
	tpi_05k	Topographic Position Index (5 km scale)
	tri_cost	reclassified TRI

CHAPTER 4: RESEARCH TO SUPPORT RECOVERY AND LONG TERM CONSERVATION OF GRIZZLY BEARS IN ALBERTA

Year One Progress Report for

Alberta Innovates Biosolutions

See specific sections for applicable Authors

Project Background and Objectives

Alberta's current and future economic prosperity is directly linked to our natural resources. One of the many challenges facing resource managers in Alberta is how to balance the economic needs of our province while at the same time ensuring sound environmental management. Grizzly bears are widely recognized as an indicator of ecosystem health and ecological function. In June 2010 Alberta changed the status of grizzly bears in Alberta to a threatened species and the provincial grizzly bear recovery plan (2008-2013) identified a series of actions needed to achieve grizzly bear recovery. This project funded by Alberta Innovates Biosolutions, with matching funds from industry partners identified two key research activities and knowledge gaps to support the recovery of provincial grizzly bear populations. We focused on provincial grizzly bear habitat which includes the establishment of current nutritional landscapes for grizzly bears, the development of carrying capacity estimates for different population units and the development of new models to link landscape resources with grizzly bear growth and reproduction. We are also developing and validating non-invasive biomarkers of reproductive status using grizzly bear hair which will allow investigators to examine the effect of long-term stress on reproduction, and identify relationships between demographic metrics, reproductive function, long-term stress, and environmental covariates. This report provides a summary of activities completed in year one of a three year project.

In addition, we continue to monitor and measure, on an annual basis, landscape condition and change within Alberta's grizzly bear range which is necessary for relating landscape condition and rates of change to changes in grizzly bear habitat and reproductive performance and for use in nutritional landscape research. We will provide new GIS tools and applications designed to aid land management decisions in provincial grizzly bear habitat. These tools will facilitate predictions of landscape conditions and a better understanding of the consequences to and management actions necessary for addressing future challenges to sustaining Alberta's flagship conservation species and the economic viability of the industries sharing those landscapes.

4.1. Understanding How Variations In Stress And Energy Influence Reproduction In Female Brown Bears With Applications For The Recovery Of Brown Bears In Alberta

Prepared by Marc Cattet and David Janz

An Overview of a New Research Collaboration between the:

- **Foothills Research Institute Grizzly Bear Program** (*Gordon Stenhouse*);
- **Scandinavian Brown Bear Research Project** (*Jon Swenson, Andreas Zedrosser, and Jonas Kindberg*);
- **Washington State University Bear Research, Education, and Conservation Program** (*Charles Robbins, Heiko Jansen, and Lynne Nelson*); **and**
- **Canadian Cooperative Wildlife Health Centre** (*David Janz and Marc Cattet*)

Background:

Brown bears (*Ursus arctos*) possess the hallmarks of a highly adaptable species. They are the most widely distributed bear species and occur throughout the Holarctic ecozone (Servheen *et al*. 1999, Swenson *et al*. 2000). They occupy a wide assortment of habitats from the Arctic islands and tundra of Canada and Alaska, to the dense forests of Sweden and eastern Russia, to the desert edges in Central and South Asia (McLellan *et al*. 2008). They appear to be indifferent to altitude and occur anywhere from sea-level to elevations approaching 5,000 m (16,000 ft) (Sathyakumar 2006). They are omnivorous and consume the greatest variety of foods of any bear species (Schaller *et al*. 1993, Krechmar 1995, Hilderbrand *et al*. 1999, Persson *et al*. 2001). Possibly as a consequence of their broad dietary habits, they also show extreme phenotypic variation, particularly in body size, and have proven complicated and contentious to classify taxonomically (Schwartz *et al*. 2003). Given these characteristics, it would not be preposterous to suggest brown bears are a highly resilient species. Yet, while this may be the case when considering the species as a whole, brown bears at the level of populations generally do not fare well in the presence of humans (McLellan *et al*. 2008). The brown (grizzly) bears of Alberta, Canada, provide a case-in-point. This provincial population, currently classified as Threatened, is believed to have decreased substantially in number from historic levels with declines likely reflecting recent increases in human access and activity from energy and forest extraction industries and local human population growth (Nielsen *et al*. 2009).

Considerable attention has been directed toward how the intentional killing of brown bears, whether through hunting, poaching, or in the defense of human life and property, affects their populations (e.g., McLellan *et al*. 1999, Bischoff *et al*. 2009). Undoubtedly, mortality is an important factor that can limit the performance of brown bear populations by lowering sex- and/or age-specific survival rates and reducing abundance. However, the number of studies to determine if human activities such as urbanization, agriculture, resource extraction, and recreation also impact brown bear populations in other ways is far fewer. For instance, do increases in human access and activity also reduce reproductive output by delaying the onset of reproductive maturity, increasing inter-birth interval, reducing litter size, decreasing cub survival, or a combination of these factors? In most cases, we simply don't know. Yet, from the perspective of developing population recovery plans, this stands as a significant knowledge gap. Actions to limit mortality (e.g., moratorium on hunting, increased enforcement and penalties to prevent poaching, minimizing human/brown bear conflicts) may not be enough without concurrent actions to also enhance reproductive output and, more generally, the health of individual brown bears.

In 2006, the Foothills Research Institute Grizzly Bear Program (FRIGBP) and Canadian Cooperative Wildlife Health Centre (CCWHC) initiated research to understand relationships between environmental composition and change (both natural and human-related) and the health of brown (grizzly) bear populations in Alberta to inform and enable effective land management and grizzly bear conservation. Our working hypothesis was that negative effects of environmental composition and change on brown bear populations can arise as a consequence of chronic physiological stress in individual bears. When faced with unpredictable or uncontrollable anthropogenic (human-caused) stressors in their environment, we postulated that bears may suppress body condition, immunity, reproduction, or a combination of these health expressions as a response to chronic stress. An outcome of this research was the development and validation of sensitive and practical techniques for detecting chronic stress in free-ranging brown bears (Chow *et al*. 2010b, Macbeth *et al*. 2010, Janz *et al*. – manuscript in preparation), as well as other species-at-risk including polar bears (Chow *et al*. 2010a, Macbeth *et al*. 2012) and caribou (Ashley *et al*. 2011). Subsequent analyses have identified associations between chronic stress and measures of growth and movement activity (Cattet *et al*. – manuscripts in preparation), and established associations between stress levels of individual bears and their environment within home ranges along a gradient of human-caused alteration (Stenhouse *et al*. – manuscript in preparation). However, our attempt to confirm linkages between chronic stress and reproduction, particularly in females, was constrained by a small sample size of family (mother and offspring) groups and uncertainty concerning the pregnancy status of solitary adult females.

Since 2008, the FRIGBP and CCWHC have formalized partnerships with two other long-term brown bear research programs with a common goal to share knowledge, expertise, and experience conserving and managing brown bears in boreal forest and mountain ecosystems. The first collaboration, with the Scandinavian Brown Bear Research Project (SBBRP), was initiated in 2008. The SBBRP has a 29-year history involving approximately 2000 captures of 700 individual brown bears in Sweden and Norway. Their database and sample archive is extensive, and includes data and samples collected from multiple lineages spanning three generations. Further, the brown bear population in Scandinavia has recovered from the brink of extirpation at roughly 130 bears in 1930 to over 3,500 bears today, and it is currently the fastest growing brown bear population in the world. Yet, on the surface, the brown bears of Scandinavia and Alberta are similar with respect to climate, diet, and exposure to human activity. Clearly, there is much to learn from the SBBRP with respect to the life history, particularly strategies influencing reproduction, conservation, and management of brown bears.

More recently, in 2012, we initiated collaborative research with the Washington State University (WSU) Bear Research, Education, and Conservation Program. This program, which was established in 1986, is engaged in a wide range of studies that utilize both captive brown bears, housed at the WSU Bear Center, and free-ranging bears to better understand bear physiology and ecology. The captive bears are viewed as an important source of information or a means to develop new techniques that can then be applied to understanding the needs of wild bears, and thus improving their conservation. Our partnership with this program developed, in part, from a shared interest in the validation and application of 'capture-free biomarkers' of health, specifically energy (i.e., body fat content) and reproduction. A biomarker is generally defined as anything that can be used as an indicator of the presence and intensity of a particular disease state or some other physiological state of an organism. Capture-free biomarkers are indicators that can be collected and measured without the need to capture and physically restrain an animal, e.g., feces, hair, photograph or video-recording.

In this 3-year study, we will use hair collected from brown bears to identify the patterns of a range of capture-free biomarkers to understand how variations in stress and energy influence reproduction in female brown bears. We predict that female brown bears exposed to chronic stress caused by human disturbance suppress reproductive output through two paths (Figure 1). The first is a direct path in which female brown bears respond to unpredictable, persistent human disturbance by long-term activation of the hypothalamic-pituitary-adrenal (HPA) axis which in turn suppresses the hormonal cycles required for normal reproduction. This can be viewed as an adaptive response when long-term stressors occur under natural conditions, e.g., forest fires, drought, high population density (Boonstra 2013). Female brown bears are long-lived carnivores with multiannual reproductive lives, so suppressing reproduction for the next year or two when faced with long-term stressors is a prudent strategy. However, when faced with long-term stressors associated with human disturbance that can last or recur over many years, suppression of reproduction for indefinite periods may reduce fitness for the individual while contributing to a decrease in the reproductive rate for the population (Wingfield 2013).

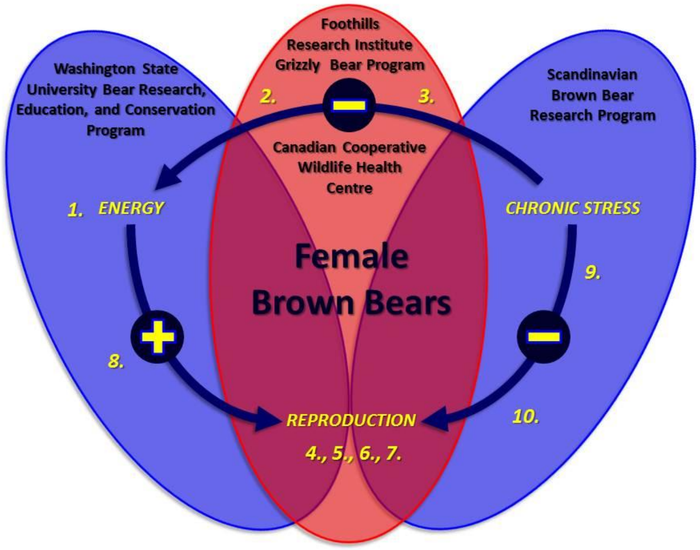


Figure 1. Female brown bears exposed to chronic stress caused by human disturbance are predicted to suppress reproductive output through two paths, a direct path in which chronic stress suppresses the hormonal cycles required for normal reproduction, and an indirect path in which chronic stress reduces the capacity to store energy (body fat) which in turn suppresses reproduction or, if reproduction occurs, causes a delay in birth and small cub size at den emergence. The numerals represent the research hypotheses described in the text, and the overlapping ellipses depict the partnership between the four research groups.

The second path is indirect and involves the potential influence of chronic stress on the tight relationship between female fat stores (energy) and reproduction (Figure 1). The occurrence, number, size, and survival of bear cubs emerging from winter dens are highly dependent on the body condition of the mother prior to entering the den (Robbins *et al*. 2012). Not only do females require a certain level of body fat (~20%) before they will produce cubs, but the fattest females also give birth earlier, which gives their cubs more time to grow before they emerge from the den. However, the chronic stress response is an energy-consuming process. Long-term activation of the HPA axis elevates the concentration of glucocorticoids (cortisol, corticosterone, etc.) in circulation, which stimulates mobilization of stored energy and inhibits further deposition of fat (Romero 2004, Schultner *et al*. 2013). Further, human disturbance can potentially affect energy gain by altering optimal foraging and resting, and also because responses to perceived threats impose energetic costs (Preisser *et al*. 2005). In this regard, Ordiz *et al*. (2013) have recently provided conclusive evidence to show that brown bears in Scandinavia increase movements at night-time and move less at day-time in response to human approach by foot, in effect altering their foraging and resting routines for at least a couple of days. We predict that female brown bears exposed to chronic anthropogenic stressors have reduced capacity to store energy as a consequence of long-term activation of the HPA axis, coupled with increased energy demands due to increased activity throughout the day, night, or during both periods. The net effect is failure to attain good body condition which, in turn, can lead to suppression of reproduction or, if reproduction occurs, a delay in birth and small cub size at den emergence.

Although we could evaluate biomarkers in a variety of biological media (blood serum/plasma, saliva, feces, etc.), we have restricted this research only to using hair for the following reasons:

1) Bear hair can be collected by large-scale, intensive sampling without capture and physical restraint (i.e., barbed wire hair snag), and the technique of 'bear hair trapping' has become established as a valid technique to monitor the demography and genetic structure of brown bear populations (Kendall *et al*. 2009, de Barba *et al*. 2010). Not only will this enable avoidance of issues associated with capture and handling (i.e., stress, injury, monetary cost), but it will significantly enhance the value of bear hair trapping by expanding the information extracted from hair samples to potentially include assessments of energy status, reproduction, and chronic stress.
2) Hormones (steroid, and possibly peptide) indicative of a range of physiological processes are assumed to be incorporated into the hair shaft as it grows, providing a long-term record of endocrine activity integrated over the period of hair growth (Koren *et al*. 2002, Meyer and Novak 2012). Point-in-time values for hormone concentrations as determined in blood, urine, or saliva samples are of limited use to assess physiological function because of normal temporal fluctuations (e.g., diurnal, seasonal) in hormone levels. However, concentrations measured in hair provide an integrated measure over a much larger window-of-time (weeks to months), thus the effect of cyclical fluctuations in hormone levels is dampened.
3) We have already developed and validated laboratory procedures to accurately measure biomarkers of stress (cortisol and corticosterone) and reproduction (estradiol, progesterone, and testosterone) in brown bear hair. Therefore, we have the knowledge, expertise, and equipment in place to develop and fully validate additional procedures for new biomarkers in hair. To this end, we are currently developing techniques to measure four peptide hormones in bear hair (leptin, adiponectin, relaxin and prolactin). In combination with the established steroid hormone analyses listed above, these data will be utilized to test the hypotheses described below.
4) The availability of archived hair samples and ancillary data (bear-specific and environmental) from Scandinavia and Alberta will make it possible for us to carry out this study without need to capture and sample additional free-ranging bears. In fact, the only bears that will need to be sampled during this study are captive brown bears at the WSU Bear Center, and the sampling schedule for these animals will coincide with that for a concurrent related study by our WSU collaborators (C. Robbins, H. Jansen, L. Nelson) to understand seasonal variation in leptin and adiponectin production, adipose function, and whether either hormone can be used to estimate body fat content in brown bears.

Hypotheses:

We will test the following ten hypotheses in brown bears, primarily females, in the areas of energy, reproduction, stress, and the linkage paths depicted in Figure 1. Without exception, these hypotheses will be tested using guard hair samples collected during spring to ensure that we are measuring hormones incorporated into hair over the longest time possible (Jones *et al*. 2006, Macbeth *et al*. 2010). The source(s) for biological samples and data are italicized in parentheses following each hypothesis, i.e., ***FRIGBP, SBBRP, WSUBC***. All hypotheses tested at the WSUBC will also involve the serial collection and analysis of hormones in blood serum to evaluate relationships with the same hormones measured in hair.

Energy

1) Adiponectin and leptin concentrations in bear hair are directly (positively) related to body fat content in the fall just prior to hibernation and, thus, can be used to predict body fat content when females enter the winter den with reasonable accuracy and precision. Previous studies have already established strong relationships between the peptide hormones, leptin and adiponectin, hair growth, and energy status (Iguchi *et al*. 2001, Poeggeler *et al*. 2010, Won *et al*. 2012). ***(WSUBC)***

Stress - Energy Path

2) The concentrations of biomarkers of energy (leptin and adiponectin) in the hair of adult females are inversely (negatively) associated with the hair cortisol concentration (stress biomarker). ***(WSUBC, SBBRP, FRIGBP)***
3) The hair cortisol concentration of adult females is inversely associated with their body condition. Although we have already tentatively confirmed this association in both Alberta (Pearson r = -0.319, p = 0.003, N = 48) and Scandinavia female brown bears (r = -0.417, p = 0.004, N = 45) (Cattet *et al*. - manuscript in preparation), we need to further evaluate these associations to ensure that they are not confounded by associations with other variables, e.g., age, presence/absence of cubs. ***(SBBRP, FRIGBP)***

Reproduction

4) The testosterone concentration in hair is markedly higher in adult male brown bears than in adult female brown bears, whereas the estradiol concentration in hair is markedly higher in adult female brown bears than in adult male bears. Both hormones, testosterone and estradiol, will be detectable only at low concentrations in the hair of juvenile (reproductively immature) male and female bears. ***(WSUBC)***
5) Progesterone and relaxin concentrations in hair are markedly lower in non-pregnant brown bears than in pregnant bears or bears undergoing false pregnancy (pseudopregnancy). The progesterone concentration in blood serum has been established as a reliable marker of true and false pregnancy in brown bears (Tsubota *et al*. 1987, Ware *et al*. 2012). To our knowledge though, relaxin has not been evaluated as a pregnancy marker in bears (ursids), but it has been evaluated in other carnivores (canids and felids) where it has been found to be elevated in blood concentration during late pregnancy (Carlson and Gese 2007, Asa 2012). ***(WSUBC, SBBRP, FRIGBP)***

6) Whereas the progesterone concentration in hair is elevated in both pregnant and pseudopregnant brown bears, the testosterone concentration in hair is elevated only in pseudopregnant bears. Thus, the combination of progesterone and testosterone concentrations can be used to differentiate true from false pregnancy (Stoops *et al*. 2012). ***(WSUBC, SBBRP, FRIGBP)***
7) The prolactin concentration in hair is elevated in lactating brown bears, and can be used to distinguish females with cub(s) in their first year from other family groupings (e.g., females with yearlings or 2-year olds) and solitary adult females. ***(WSUBC, SBBRP, FRIGBP)***

Energy - Reproduction Path

8) The concentrations of biomarkers of pregnancy (progesterone and relaxin) in the hair of adult females are directly associated with the concentrations of biomarkers of energy (leptin and adiponectin). If the concentrations of energy biomarkers are low, pregnancy will not occur or, if it does occur, will not be carried to full term. ***(SBBRP, FRIGBP)***

Stress - Reproduction Path

9) The concentrations of biomarkers of pregnancy (progesterone and relaxin) in the hair of adult females are inversely associated with the hair cortisol concentration (stress biomarker). If the hair cortisol concentration is high, pregnancy will not occur or, if it does occur, will not be carried to full term. ***(SBBRP, FRIGBP)***
10) The hair cortisol concentrations of adult females and their yearling offspring are directly associated. This hypothesis is based on a growing body of experimental work indicating that the circulating levels of stress hormones in a pregnant female serve to link ecological stressors with preparative programming of the stress axis in the offspring (Love *et al*. 2013). In this regard, we have confirmed a direct association ($r = 0.560$, $p = 0.024$, $N = 16$) between the hair cortisol concentrations of mother polar bears and their cubs-of-the-year across a small number of family groups (Macbeth *et al*. 2012). ***(SBBRP, FRIGBP)***

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4.2. Future Of Alberta's Forests For Grizzly Bears: Climate And Landscape Scenarios And Simulations

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Executive summary

The accurate and timely mapping of anthropogenic and natural disturbance patterns is critical to improve our understanding of changing habitat states and selection by grizzly bears. In addition to mapping current landscape and habitat conditions, there is a need to provide future projections of habitat development under different management, climatic, and disturbance regimes. To achieve this result, we project species distributions using bioclimatic envelope modeling and use the LANDIS-II succession and disturbancemodeling framework to evaluate the effects of historical patterns of landscape change on habitat development.

In this annual report, we continue our derivation of high-spatial (30m) and -temporal (bi-weekly) resolution geospatial predictions of disturbance generated by the Spatial Temporal Adaptive Algorithm for mapping Reflectance Change (STAARCH). The STAARCH-based changes detected for the period of 2001-2011 were consolidated and gaps in the data were filled with newly processed imagery

The Province of Alberta in cooperation with industry partners have recently compiled a large collection of Lidar data, which provide more direct measurements of forest structural characteristics than traditional optical remote sensing data. To utilize this newly available data, we processed thedata to produce gridded products of canopy and topographic metrics at resolutions relevant to habitat processes.

In order to produce tree species distributions maps for the grizzly bear study region in the foothills region, we utilized a new approach that fuses process-based modeling with bioclimatic envelope modeling. As a result of the analyses, we have produced maps of species distribution and suitability of climate conditions for common tree species in the Foothills area

To estimate the effects of changing climatic and disturbance regimes, we use the LANDIS-II model to project the future effects of the continuation of three different historical 30-year patterns in forest fire distribution and climatic change. Using LANDIS, we output five key metrics related to the landscape state: (1) Stand Age; (2) Species Change; (3) Fire Severity; (4) Species Richness; and, (5) Age Class Evenness.

Work Package 1: Disturbance Mapping, Layer Update and Data Management and Accessibility

Data Management

Bi-weekly, monthly and annual land cover and land cover products over the Grizzly Bear range in Western Alberta is essentially to their ongoing management. As a result we have an ever increasing collection of image data covering the study area. This image data has been the basis of many of the generated products as well as forms the basis for ongoing analysis and investigation. Because of the volume of this data archive, we have recognized the importance of creating a clear structure for storing all the data that allows for easy access and reanalysis. To facilitate this we have updated the STAARCH software to directly ingest the base datasets as they are in our image warehouse with minimal manual intervention in the processing workflow.

Image Geo data collection

Landsat TM-5

The collection covers 16 Landsat TM-5 Tiles, and covers the years 2001, 2004, 2008 and 2011. All scenes are fully corrected to surface reflectance and projected in their native UTM-WGS84 system.

EOSD land cover classification

The STAARCH algorithm uses these 30m gridded land cover classifications in its change detection process. The EOSD products are clipped to the each of the Landsat Tiles are projected in the same UTM-WGS84 system.

MODIS

MODIS data is archived as mosaics covering the whole Foothills area in a 250m resolution. The mosaics are in the native projections of MODIS which is a sinusoidal system. To use this data in the starch processing, it needs to be resampled and projected to the grid of the Landsat scene and. The reprojection is automated by the STAARCH wrapper tool using the MODIS reprojection software distributed by NASA.

LIDAR Data

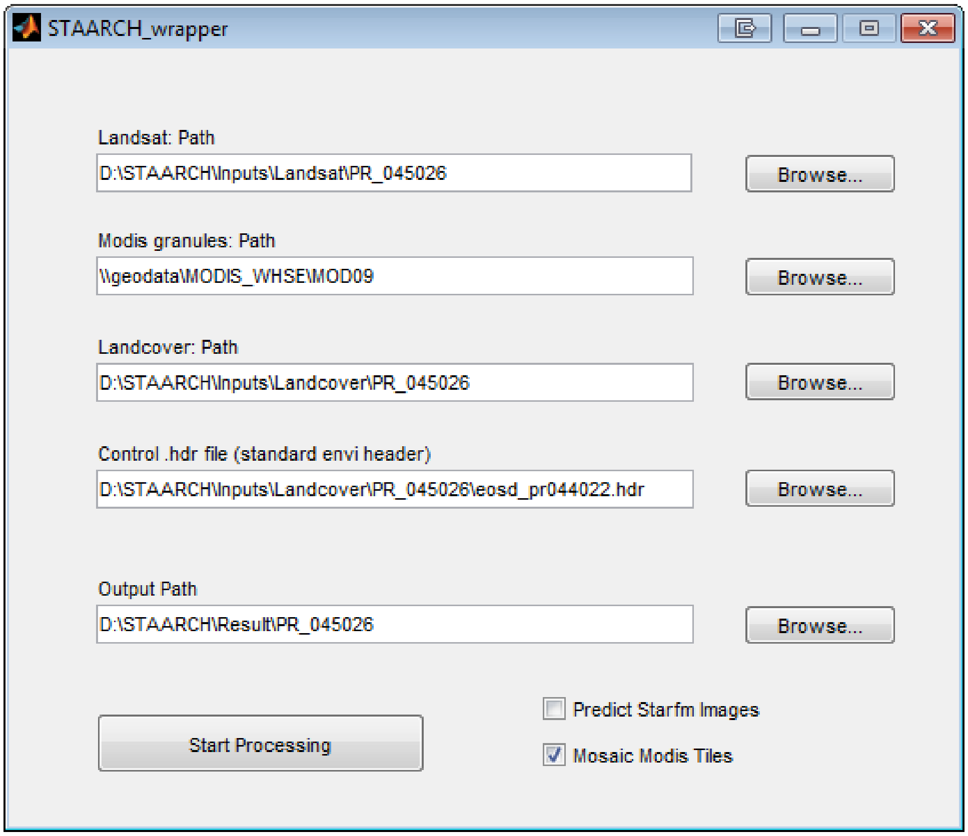
A new addition to the remote sensing dataset over the Foothills area is Laser Altimetry data. Currently the LIDAR data has been processed into 25m resolution grids of canopy metrics and topography. These layers are further discussed in work package 2.

STAARCH Processing Wrapper

The STAARCH user interface is a packaged edition to run the STAARCH algorithm directly on the archived image database in an automated fashion. The Spatial Temporal Adaptive Algorithm for mapping Reflectance Change (STAARCH) is designed to detect changes in reflectance, denoting disturbance, using Tasseled Cap transformations of both Landsat TM/ETM and MODIS reflectance data (Hilker et al., 2009). The Landsat scenes are used to delineate stand replacing changes, and the MODIS scenes from the period between the two Landsat scenes are used to determine the date of the change. The STAARCH user does all basic preprocessing of the input data required by the STAARCH algorithm, and consequently generate STAARCH parameter files. The preprocessing includes resampling and subsetting of the Landsat and landcover data and reprojection of the Modis data from the standard sinusoidal format to match the Landsat images. After the preprocessing, the user interface generates the STAARCH input parameter files to start the processing.

Interface options:
The STAARCH user interface has a simple dialog to enter the paths of the directories containing Landsat, Landcover and Modis data (Figure 2). And checkboxed to control Modis mosaicking and whether StarFM predicted landsat resolution scenes are wanted for all Modis scenes.

In addition to the data paths a control file (envi .hdr format) is needed listing the spatial extent for the whole analysis. As a default, you could select one of the .hdr files associated with the Landsat t_0 file. It is also possible to define a custom subset of the Landsat tile in this file.



Landsat: Path
D:\STAARCH\Inputs\Landsat\PR_045026

Modis granules: Path
\\geodata\MODIS_WHSE\MOD09

Landcover: Path
D:\STAARCH\Inputs\Landcover\PR_045026

Control .hdr file (standard envi header)
D:\STAARCH\Inputs\Landcover\PR_045026\eosd_pr044022.hdr

Output Path
D:\STAARCH\Result\PR_045026

☐ Predict Starfm Images
☑ Mosaic Modis Tiles

Figure 2: Screenshot of the STAARCH wrapper user interface

Results:

The STAARCH_wrapper will create all the inputs needed to run STAARCH and saves them in labeled subfolders of the Output path (Landsat, Landcover, Modis). A STAARCH Parameter file (example: 'L5045026_2620110820_parameter.txt') is created in the Output folder. . NB: especially the Modis resampling generates a considerable data volume! Reserve approximately 250Gb for a four year STAARCH run on one Landsat Tile, when predicting intermediate StarFM images it generates another 100Gb for a four year run on one Landsat Tile.

The STAARCH runtime has to be started separately, the STAARCH_Console##.exe file needs to be in the same directory as the parameter file and will write the results to '\STAARCH_Result'. The user has to select either the 32bit or 64bit version.

The outputs are:
- A mask of changed (1) \ unchanged (0) pixel

    (L5045026_02620110820_.dat.ChangeMaskLandsat__settings)

- A file containing the change dates (pixel has the nr of the corresponding modis scene as value)

    ($t_{0,}$ $t_{1,}$ $t_{2,}$ … t_n). L5045026_02620110820_.dat.ChangeSequence__settings

- If Predict Starfm Images was selected, for each input Modis scene predicted Landsat

    B1, B2 and B5. pMyyyymmdd.bc.sur_refl_b##.dat

All Output files have the dimensions indicated in the control .hdr file, and are in 32bit format.

STAARCH Disturbance Mapping

As part of disturbance mapping program in Grizzly Bear habitat from optical satellite data using high spatial and temporal resolution data, we have derived disturbance information from combined Landsat TM-5 and MODIS imagery since 2000 . We use the Spatial Temporal Adaptive Algortihm for mapping Reflectance Change (STAARCH) (Hilker *et al*. 2009)which was developed as an extended version of STARFM to allow the detection of disturbance events at spatial scales of the Landsat pixel (30m) and the temporal resolution of MODIS (16 day cloud free composites), through the generation of a spatial change mask derived from Landsat and an image sequence recording the temporal evolution of disturbance events.

Due to the malfunction in Landsat-7 Scan Line Corrector and the decommissioning of Landsat-5 there has been no new, high quality image data acquired since the growing season of 2011. This is not a significant problem however for the STAARCH program, as we can fill in this gap as soon as data becomes available from the recently launched Landsat-8 satellite. However, until then we cannot extend the timespan of the change monitoring. This year we have spent our starch efforts in improving our past products by reanalysis of tiles affected by cloud cover and by creating a continuous STAARCH product for the period 2001 – 2011.

Approach

The STAARCH runs delivered in 2011 had some gaps caused by cloud cover in the used images. To fill those gaps, we added extra imagery from 2011 and where those were unavailable from 2010. All of the images were taken during the summer months, with preference for August to avoid seasonal effects in the data. The MODIS scenes used were all acquired in March to October to avoid snowfall that would be detected as change.

The results of the STAARCH algoritm were converted to vector format with polygons attributed with the date of disturbance. As decribed in Gaulton et al. (2011) areas of disturbance smaller than 1 ha were removed from the results due to unreliable change detection often caused by slight differenes in spatial registration of the two landsat scenes. In areas where information was available from multiple scenes, the best quality scene was chosen based on the lowest cloud contaminations. Furthermore the area of detection was limited to the grizzly bear research area excluding agricultural areas (based on the agriculture land cover layer). The STAARCH result from the period 2001 – 2008 and 2008 – 2011 were merged into one data layer accounting for overlapping change area by selecting the first detected date of change.

Results

The STAARCH Change product contains polygons over the RSF area showing the changed areas and the detected date of change. Figure 3 shows two snippets of the study area as a quick look of the results.

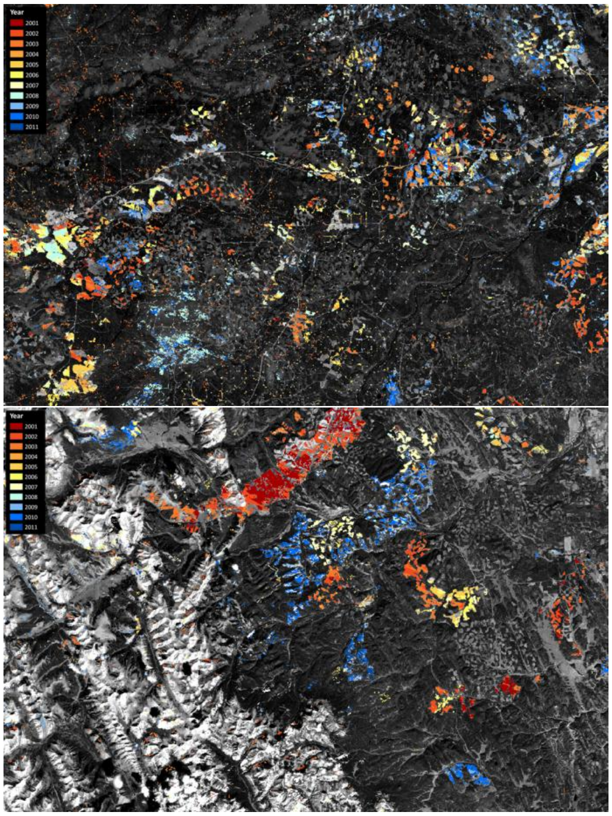


Figure 3 Quick look of the STAARCH disturbance detection results

In each of the studied years between 40000 and 90000 ha of land was detected as change, note that 2001 and 2011 were only half years and thus show lower numbers. The sum of the changed area over this decade of change detection is 5558 square kilometer which is approximately 4% of the study area (Table 1)

Table 1 Yearly and total areas of disturbance

Year	Changed Area [ha]	Percentage of RSF Area
2001	7343	0.06%
2002	39818	0.30%
2003	87898	0.67%
2004	40421	0.31%
2005	47147	0.36%
2006	41258	0.31%
2007	46988	0.36%
2008	61905	0.47%
2009	73161	0.56%
2010	72358	0.55%
2011	37496	0.29%
Total	**555794**	**4.23%**

The temporal pattern of harvesting by month is shown in Figure 4 during the whole detection period. The patterns show a concentration of harvesting in the spring and autumn seasons. It has to be noted that winter harvesting cannot be reliably detected because of snow and any harvesting during that period is thus assigned to the following spring. Figure 5 shows the changes detected across the entire study area from 2001 to 2011.

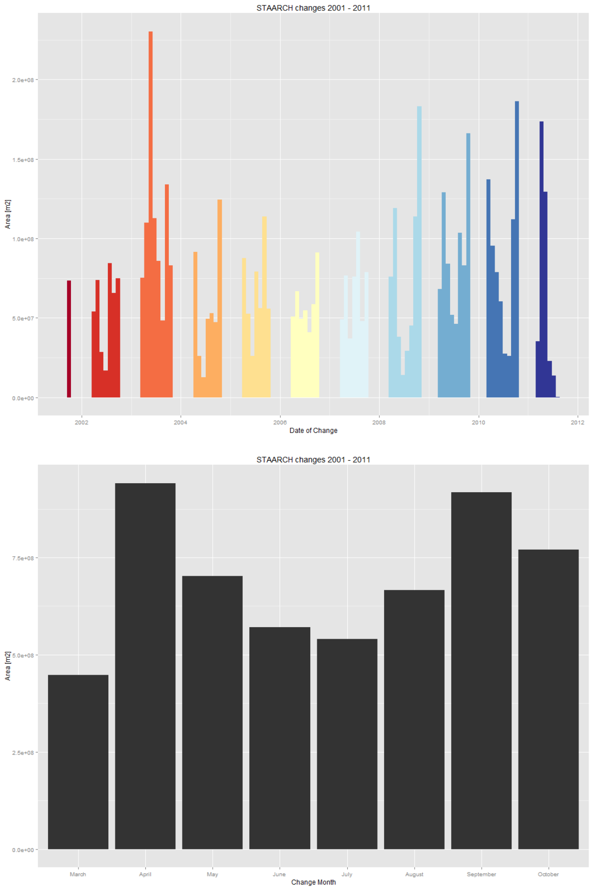


Figure 4. Top: temporal distribution of disturbed area for 2001-2011, Bottom: monthly changes over the whole study period.

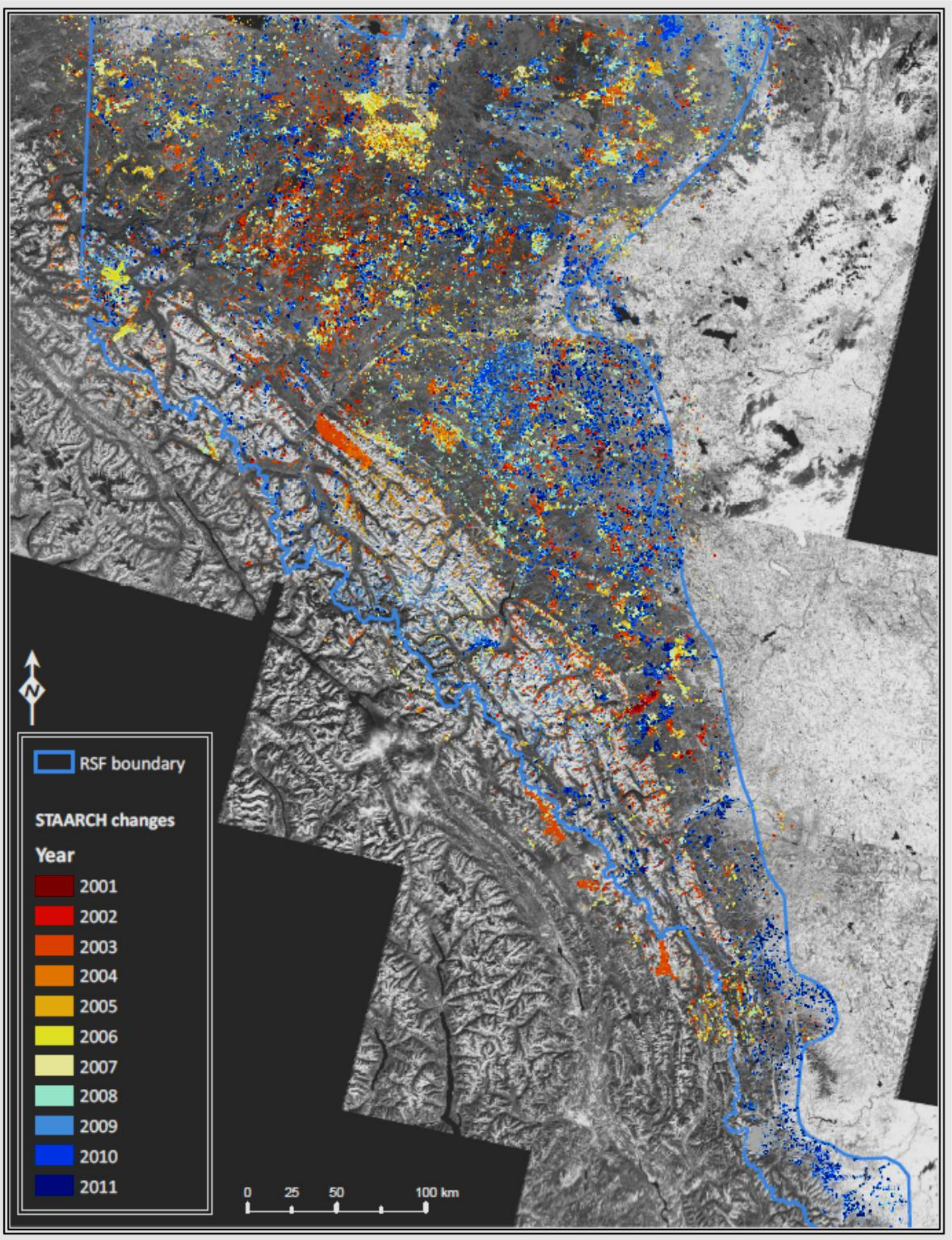


Figure 5. Overview of disturbances over the whole study area

Habitat Layer Updates.

The change layers generated by STAARCH and the 2011 Landsat data with improved coverage of the region are used to generate new updates of land cover and canopy layers which are part of the standard suite of habitat layers (Figure 6).

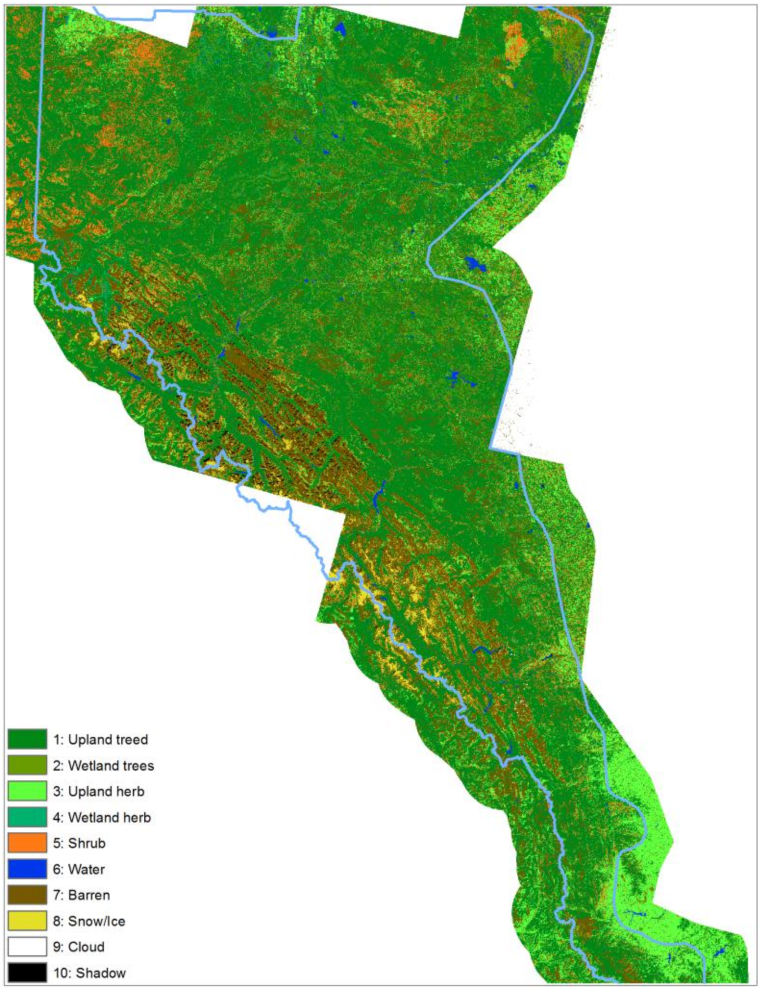


Figure 6. Quicklook on updated Landcover

Work Package 2: Habitat mapping and forest structure

Introduction

Recent efforts by the Province of Alberta in cooperation with industry partners have generated a large collection of Lidar data covering almost the entire Grizzly research area, excluding the National parks. Since bear food availability and habitat selection are strongly related to stand and canopy structural characteristics, the forest structure influences light availability for understory species and the presence of edge features or protective cover with the stand. Lidar data provides more direct measurements of structural parameters than spectral remote sensing data. To utilize this newly available data source we are processing the Lidar data as delivered to us to gridded products of canopy metrics and topography at a resolution relevant to habitat processes and in line with other current habit information.

Approach

LiDAR metrics

Lidar data was primarily available for the Yellowhead / Grande Cache region, which covers part of the Foothills area. Two Lidar products were available in 1m gridded rasters: Bare Earth elevation and Full Feature (top of canopy) elevation. To derive information on the canopy structure we use the difference between the two layers to get height above the ground surface. The heights above the ground surface on a 1 meter resolution were used to generate canopy metrics on a 25m grid. Each of the grid cells has 625 canopy points to be used to calculate grid statistics such as percentile heights, mean, and standard deviation. We have used the FUSION Lidar processing suite to calculate a suite of these Lidar grid metrics (Table 2)

Table 2 Generated Canopy Metrics

max	maximum value for cell
mean	mean value for cell
stddev	standard deviation of cell values
cv	coefficient of variation for cell
abovemean	proportion of first returns above the mean
allcover	(all returns above 2m) / (total returns)
Relief ratio	((mean - min) / (max – min))
skewness	skewness computed for cell
p05	5th percentile value for cell
p10	10th percentile value for cell
p20	20th percentile value for cell
p25	25th percentile value for cell
p50	50th percentile value (median) for cell
p75	75th percentile value for cell
p90	90th percentile value for cell
p95	95th percentile value for cell

In addition to the canopy metrics, we also used the Lidar Bare Earth information to generate a suite of topographical variables at the same 25 meter grid. The topographical variables are: elevation, slope, aspect, profile curvature, plan curvature, and solar radiation index.

<u>Canopy Information</u>

The derived Lidar metrics are the input data for regression models to predict base habitat variables over the Yellowhead-Grande Cache area. The Lidar data has shown to provide as significant improvement in explaining power. Models relating the Lidar derived structure in combination with climate data directly to understory species that are recognized as important for Grizzly Bear are currently under development.

Results

All generated Lidar metrics are delivered as grid files. Figures 7-9 show a quick look at some of the most important variables.

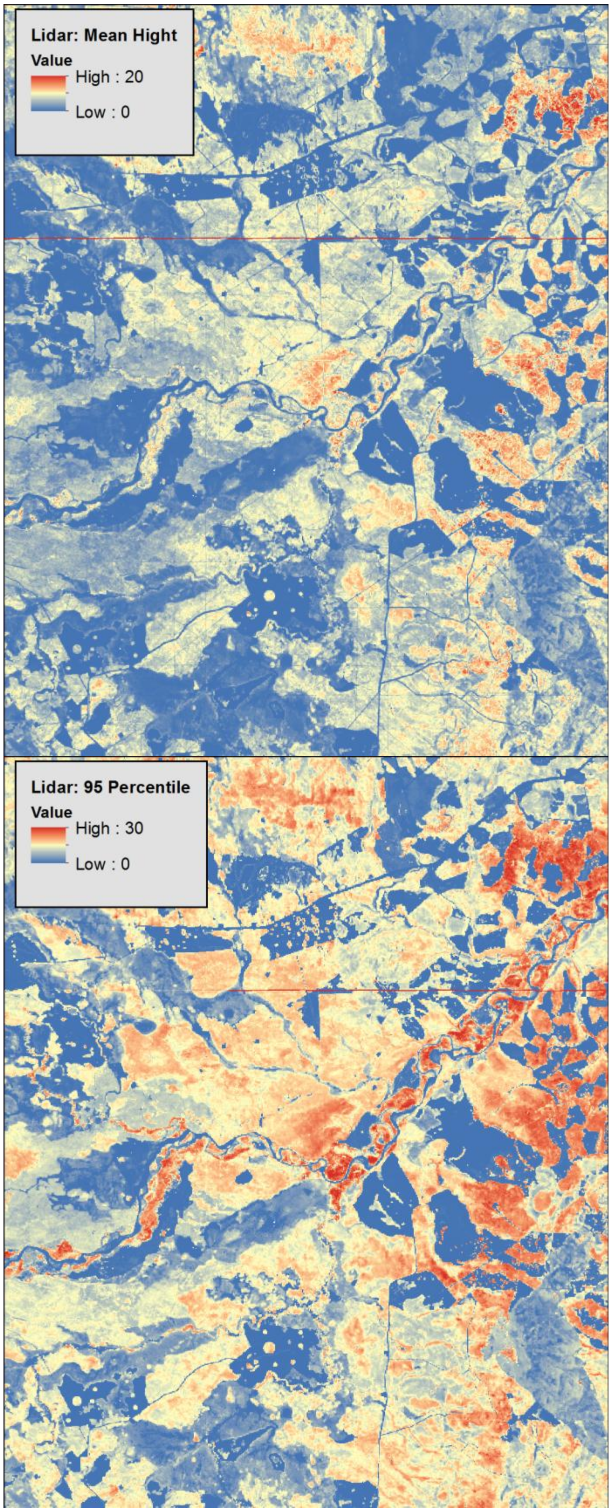


Figure 7. Example of lidar metrics, Top: Mean Height, Bottom: 95percentile

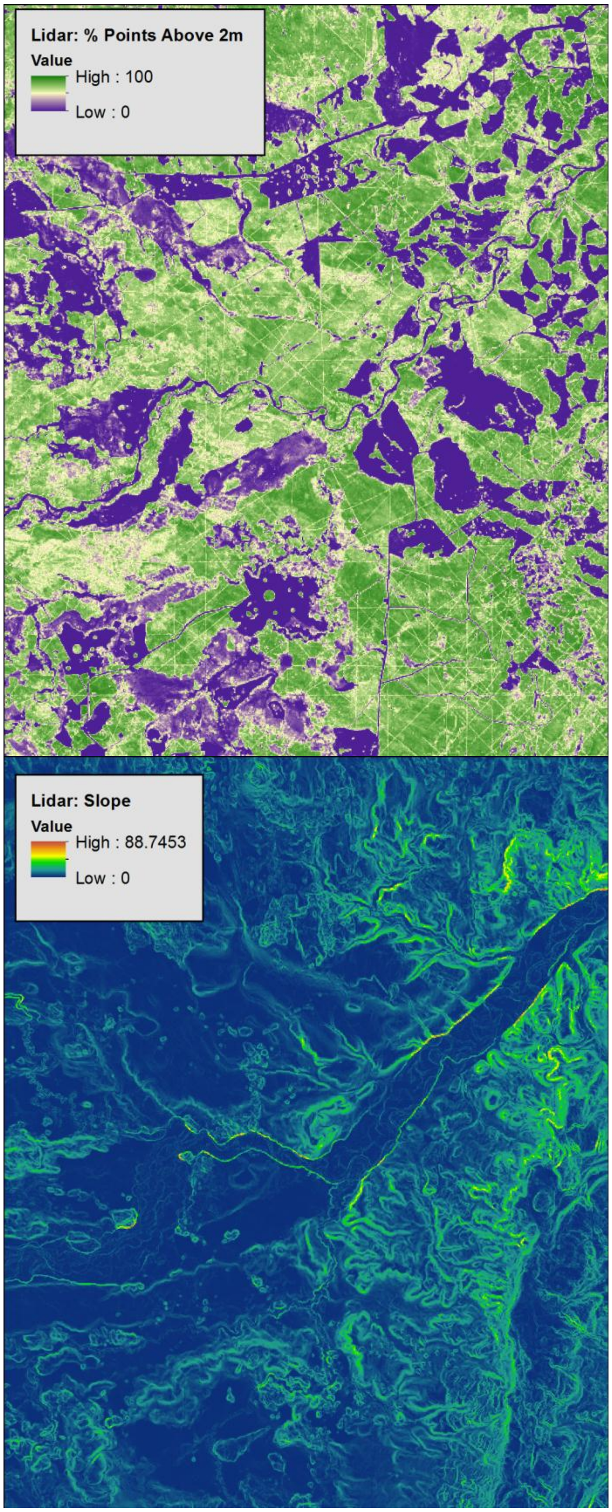


Figure 8. Example of lidar metrics, Top: Percent Points above 2m, Bottom: Slope,

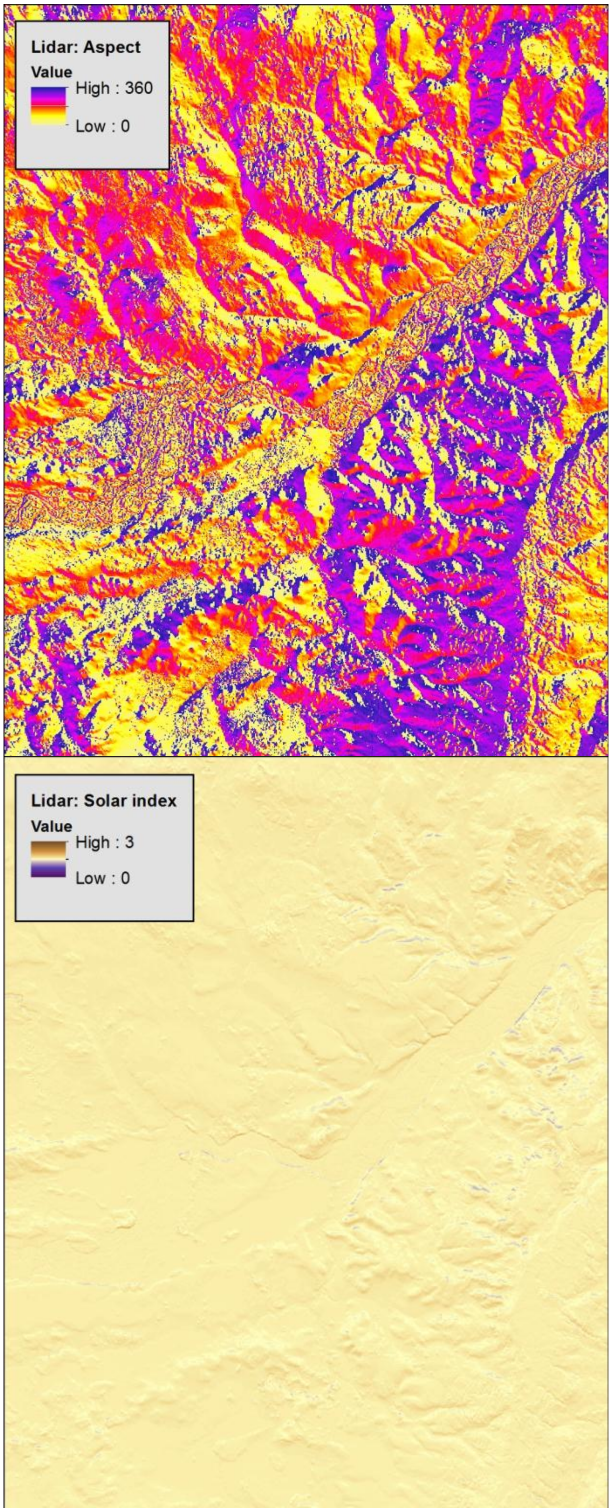


Figure 9. Example of lidar metrics: Top: Aspect, and Bottom: Solar Radiation Index

Lidar based regression models show a significant improvement over the currently used predictions that are derived from optical satellite images. The explaining power of the newly developed model is twice that of the currently used models based on optical data

(Figure 10). The Canopy Closure modes from the Lidar data is based on the p95 (95th percentile height) and the percentage of points recorded above 2m. Figure11 provides a quick look to show the increased detail of the Lidar base map

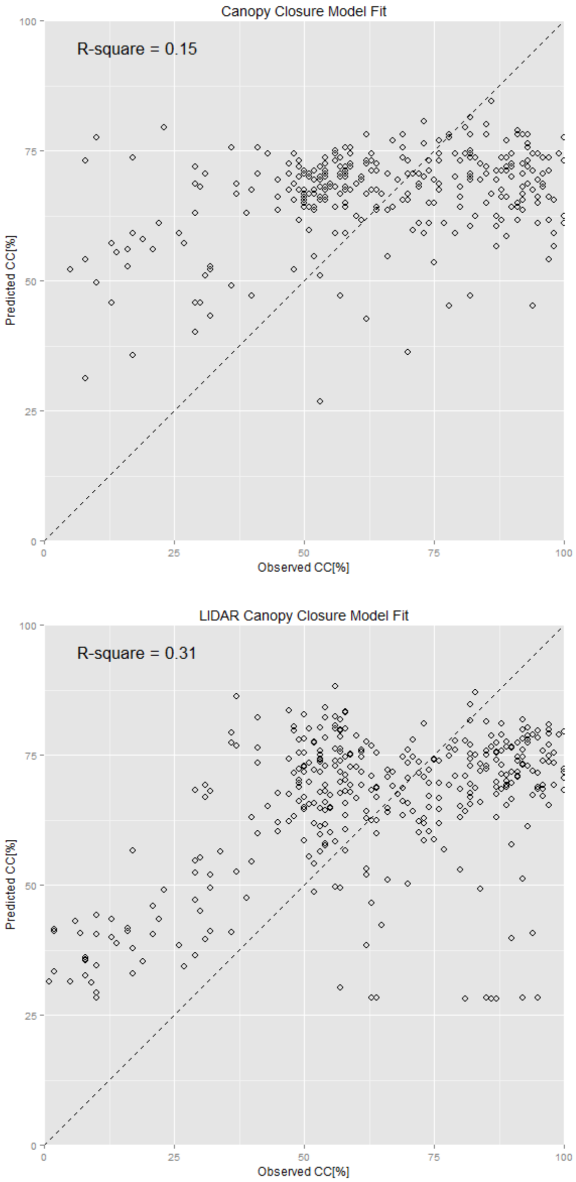


Figure 10. Scatterplots of regression model fits against the field data for Top: the currently used canopy closure layers and Bottom: Improved model based on lidar data.

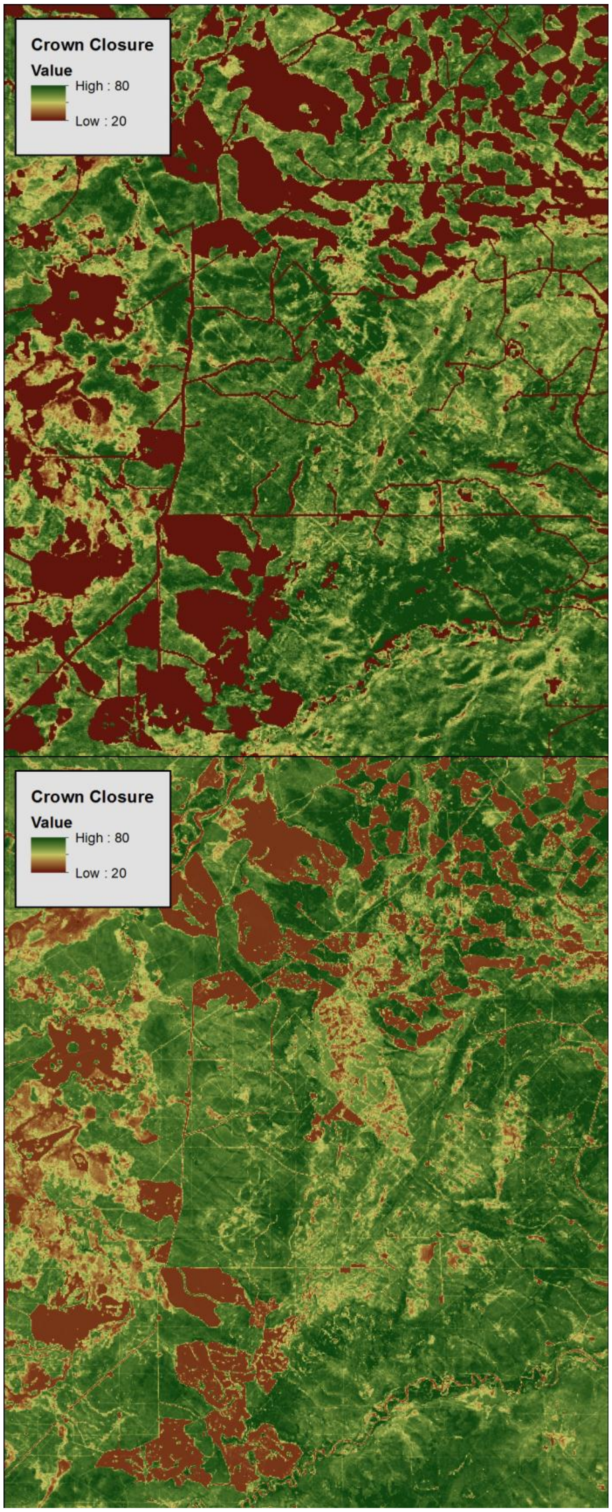


Figure 11. Canopy closure map base on Top: Optical data and Bottom: Lidar data.

Work Package 3: Ongoing Climate and Landscape Layers Generation

Tree Species Vulnerability

Introduction:

In order to produce species maps across the Grizzly bear study region, we utilized a new approach which combined the use of a process based models as well as bioclimatic species distribution modeling approached, developed by Coops et al (2009). First, a process-based growth model (3-PG, Physiological Principles Predicting Growth) developed by Landsberg & Waring (1997) was used to evaluate the extent that four climatically-related variables limit photosynthesis for Douglas-fir (Pseudotsuga menziesii), one of the most widely distributed tree species in western North America. Secondly, we related the relative limitations on Douglas-fir photosynthesis to field observations of the distribution of other tree species using an automated decision tree analysis (Coops et al. 2009). As a result of such analyses, we can appreciate why more favorable growth conditions for subalpine species might still lead to their eventual replacement by more temperate tree species. Similarly, because process-based models calculate a soil water balance that is linked to the canopy leaf area, they explain why an open ponderosa pine forest may experience less constraint on photosynthesis and transpiration during a summer drought than denser stands growing in areas receiving significantly more precipitation (Runyon et al. 1994, Law et al. 2001).

Approach:

Mean monthly climate spatial surfaces were generated using ClimateWNA, which downscales precipitation and temperature data generated at 2-4 km by PRISM (Parameter-elevation Regressions on Independent Slopes Model, Daly et al. 2002) to 1 km. The downscaling is achieved through a combination of bilinear interpolation and elevation adjustment (see Wang et al. 2006). To provide the required elevation data for ClimateWNA at 1 km a 90m Digital Elevation Model (DEM) was resampled from the Shuttle Radar Topography Mission (SRTM). Mean monthly atmospheric vapor pressure deficits (VPD) for daylight periods were estimated by assuming that the water vapor concentration throughout the day was equivalent to that held at saturation for the average monthly minimum temperature (Kimball et al. 1997). The number of days per month with subfreezing temperatures (less than -2°C) was estimated from empirical equations with mean minimum temperature (Coops et al. 1998).

Monthly estimates of total incoming short-wave radiation were calculated following a modeling approach detailed by Coops et al. (2000) that first calculates the potential radiation at the top of the atmosphere then adjusts for slope, aspect, and elevation (Garnier & Ohmura 1968; Swift 1976), and finally for variation in water vapor and the effects of clouds on the fraction of diffuse to direct beam incoming radiation (Running et al.

1987) based on a previously published relationship with the difference between mean daily maximum and minimum temperatures and latitude (Coops et al. (2002)). The latter conversion takes advantage of a correlation between monthly mean temperature extremes and the transmissivity of the atmosphere (Bristow & Campbell 1984). The modeling approach, when compared with direct measurements, predicted both the direct and diffuse components of mean monthly incoming radiation with 93 - 99% accuracy on flat surfaces, and on sloping terrain accounted for >87% of the observed variation with a mean error less than 2 MJ m-2 day-1 (Coops et al. 2000).

Species occurrence data

Across the Pacific Northwest, tree species presence / absence data were assembled from a number of sources. For British Columbia, tree species were taken from the centroids of stand-level polygons located in protected forested areas and from vegetation resource inventory plots collected across all forest lands using a three-phase, photo and ground based sampling design (Schroeder et. 2010). The spatial accuracy of the plot coordinates was estimated at roughly ± 500 m. Species data for Alberta was extracted from the Alberta ESIS and Forestry PSP/TSP data provided by the "Alberta Environment and Sustainable Resource Development" and Andres Hamann (University of Alberta).

In the United States, tree species data were acquired from U.S. Forest Service, Forest Inventory and Analysis (FIA) surveys. Plot data are recorded on a permanent sampling grid established across the conterminous United States at a density of approximately one plot per 2,400 ha (Bechtold & Patterson 2005). Only trees with DBH > 2.54 cm were considered in the sample. As actual FIA plot locations are confidential, we used the publically available coordinates which have similar spatial accuracy as the Canadian data (i.e., ± 500 m). Additional information on the FIA data sets is available in Schroeder et al. (2009).

A process based approach

The 3-PG model contains a number of simplifying assumptions that have emerged from studies conducted over a wide range of forests types and include the use of monthly climate data (rather than daily or annual) with little loss in the accuracy of model predictions. Each month, the most limiting climatic variable on photosynthesis is selected, based on departure from conditions that are defined as optimum (expressed as unity) or completely limited (expressed as zero) for a particular species or genotype. The ratio of actual/potential photosynthesis decreases in proportion to the reduction in the most limiting environmental factor. The fraction of production not allocated to roots is partitioned among foliage, stem and branches based on allometric relationships and knowledge of annual leaf turnover (Landsberg et al. 2003).

The basic model works as follows: Absorbed photosynthetically active radiation (APAR) is estimated from global solar radiation and LAI; and the utilized portion is calculated by reducing APAR by an amount determined by a series of modifiers that take values between 0 (system 'shutdown') and 1 (no constraint) to limit gas exchange via canopy stomatal conductance (Landsberg & Waring 1997). The monthly modifiers include: (a) averaged day-time vapor pressure deficits (VPD); (b) the frequency of subfreezing conditions, (c) soil drought and (d) mean daily temperature. Drought limitations are imposed as a function of soil properties and a simple water balance that calculates when soil water supply is less than transpiration estimated with the Penman-Monteith equation. In the current format, we did not separate precipitation as rain from snow because such a separation is best achieved at daily rather than monthly time steps (Coughlan & Running, 1997).

A major simplification in the 3-PG model is that it does not require detailed calculation of autotrophic respiration, assuming that it is a fixed fraction (0.47, SE ± 0.04) of gross photosynthesis (Landsberg & Waring 1997; Waring et al. 1998; Law et al. 2001).

We further simplified the approach by selecting Douglas-fir, the most widely distributed species in the region, to characterize the importance of climatic constraints on photosynthesis and growth across all forested environments, as we have done previously for other purposes (Swenson et al. 2005; Waring et al. 2005; Coops et al. 2007). We make the implicit assumption that a species presence or absence at a given site is a function of integrated physiological responses to climatic variation that cause relative differences in the growth rates of competing species. We do not assume that Douglas-fir physiological tolerances exactly match those of other species. Instead, once we characterize geographically the relative important of seasonal climatic constraints on Douglas-fir photosynthesis, we translate these limitations for other species in reference to how they depart from conditions favorable for Douglas-fir. The parameter values for Douglas-fir matched those reported in Waring & McDowell (2002), with a few exceptions. To limit the analysis to climatic effects, we set the available water holding capacity at 200 mm for a sandy loam soil throughout the region, which through sensitivity analysis is a value that will capture the effect of seasonal drought (Nightingale et al. 2007).

Decision tree modeling for individual species

We applied the 3-PG model across the region using the spatial climate layers to predict coverages of stand growth and LAI, using the mean climate derived from ClimateWNA from 1950 – 1975. Model simulations were run for 50 years of stand development by which time stands have obtained maximum LAI and maximum canopy closure (Waring & Coops 2011). The 3PG model was then stopped and at each of the plots the monthly climatically-restricting modifiers to photosynthesis were extracted for each of the four climatic modifiers (12 * 4 = 48). We derived seasonal averages and an annual extreme from these monthly climatic modifiers for modeling. To assess the extent that the 3-PG physiological modifiers might serve to predict presence or absence of each of the tree species, a decision tree analysis, similar to that developed by Coops et al. (2009) was applied to predict presence and absence for each species, based on the maximum constraints that each of the four climate modifiers imposes on photosynthesis throughout the four seasons, as well as the maximum constraint throughout the entire year.

The Kappa (k) statistic has been recommended as a metric to assess the accuracy of the developed models and is useful particularly in ecological research (see review by Monserud & Leemans 1992).This statistic calculates the proportion of specific agreement across categories (classes) and meets most of Forbes's criteria. If the prediction is in complete agreement with observed, then κ = 1; if there is no agreement (other than what would be expected by chance) then κ = 0. In cases were one class size significantly exceeds the other (as is often the case in vegetation distribution modelling) the maximum kappa achieved for perfect agreement will be less than 1, when this happens, the Kappa statistic can be rescaled based on the observed marginal frequencies (Ben-David 2008; Vach 2005).

Results

Accuracy of tree models

Species	Presence Accuracy (%)	Absence Accuracy (%)	Overall average (%)	κ
Lodgepole pine	68	78	70	0.6258
Douglas fir	74	80	78	0.5985
Subalpine fir	95	62	79	0.8555
Engelmann spruce	84	72	78	0.8872
Whitebark pine	91	81	86	0.8053
Quaking aspen	82	71	77	0.8947
Rocky mountain juniper	90	82	86	0.7837

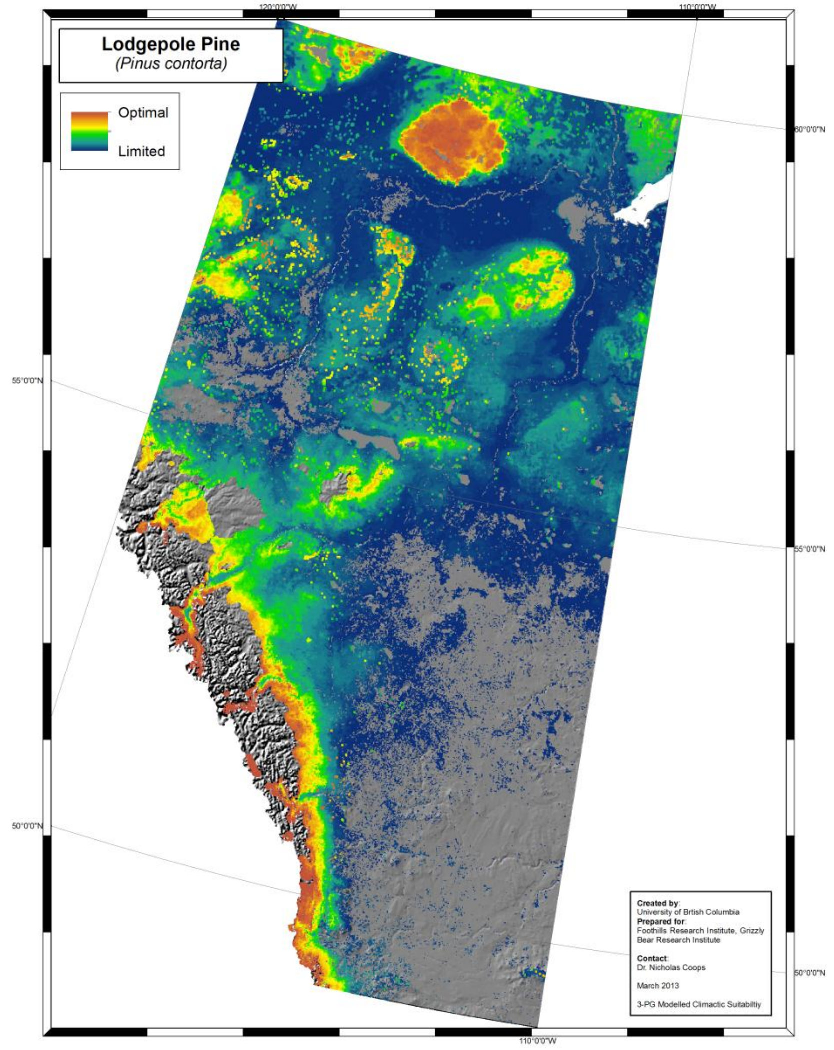


Figure 12. Example Map of Climatic suitability for Lodgepole Pine

Landis-II Landscape Simulations

Projecting 100 Years of Change Based on Three Different Historical Periods

This document and the files bundled with it from the Integrated Remote Sensing Studio at University of British Columbia describe the initial results of our forest ecosystem simulation work in the Phase 7 Study Area. For the work, we utilise the latest Landscape Disturbance and Succession Model, LANDIS-II v6.0 Release Candidate 3, using powerful computational resources to run the simulations across an area 25,223,628 hectares in size at 100-meter resolution – a task recently only recently made possible. The data and presentations (Figure 13) provided herein represent our preliminary results and are intended to be interpreted as such. We continue to work to refine model parameterisation through using the most accurate and scale-appropriate data currently available.

For the included initial LANDIS-II simulation results, we projected the future effects of the continuation of three different historical 30-year patterns in forest fire distribution (e.g., fire frequency, mean fire size, maximum fire size, minimum fire size, annual area burned) and climate change (maximum temperature, minimum temperature, and precipitation). We used novel methods to parameterise the model, including a method utilising soils and climate data currently available Canada-wide to parameterise the Tree and Climate Assessment Germination model, TACA-GEM, to allow changing species establishment probabilities within LANDIS-II. We conducted a rules-based classification of a recent bioclimatic envelope model , also known as a species distribution model, which uses ClimateWNA (Wang et al. 2012) to estimate species distributions based on their realised niche (Gray and Hamann 2013), using the same 30-year climate average data, kept static as a control.

The age class distribution of the species at each site was also held as constant for the initial landscape in order to exhibit the effects of inter-regional heterogeneity in changing landscape patterns as a result of climate and fire regime parameterisation. Species life history attribute data for thirteen primary tree species in the Phase 7 Study Area was gathered from primary source peer-reviewed literature and secondary source published tree species compendiums. The ecological regions of the study area are based on the biogeoclimatic Natural Subregions of Alberta (Alberta ESRD 2005), which was deemed an appropriate initial approximation and scale for species establishment and forest fire statistical distributions, based on a preliminary assessment.

Bundled with this document is an ArcGIS Map Package file (*LANDIS_Results_Erickson.mpk*) and a folder containing four PDF files summarizing the LANDIS-II simulation results using five key metrics: (1) Stand Age; (2) Species Change; (3) Fire Severity; (4) Species Richness; (5) Age Class Evenness. Each of the metrics is shown in the Table of Contents of the ArcMap .MXD file for closer analysis. Future published results will include the analysis of fire regimes and climate change for each Natural Subregion, which is nearing finalisation.

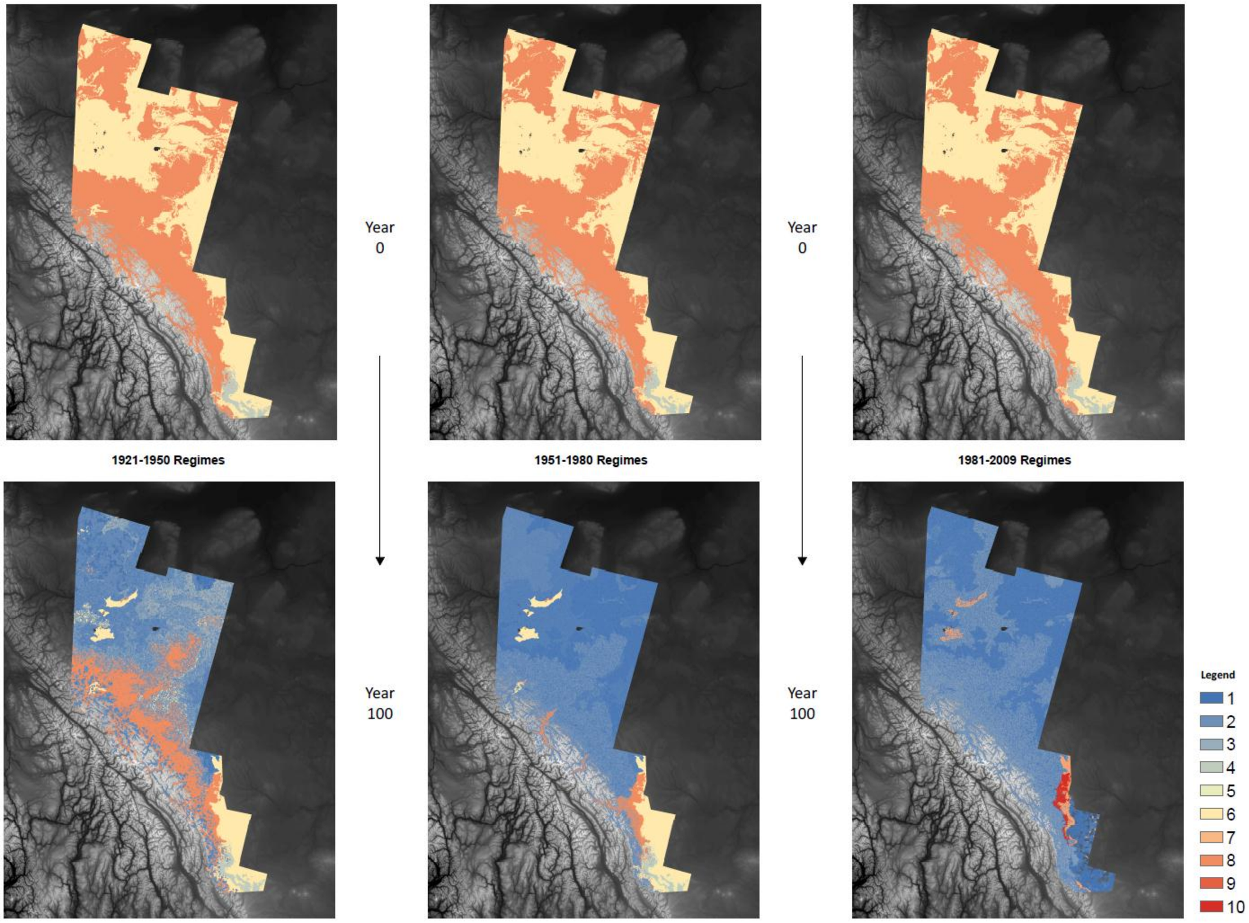


Figure 13. Example result of LANDIS simulations, Species Richness

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4.3. Population Recovery Targets For Grizzly Bears In Alberta: A Biologically-Based Bottom-Up Approach To Estimating Carrying Capacity To Inform Recovery

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Executive Summary

In 2010 Grizzly bears were listed as a threatened species in Alberta. Although a recovery plan is in place, there is no current estimate of what recovery targets should be to define recovery success. This report (year 1 of 3) outlines a spatially-explicit, biologically-based approach to estimating recovery targets based on predictions of food resource supply using field plot data, statistical modeling of critical grizzly bear food items (occupancy, abundance, biomass and energy), and a bioenergetic model that estimates total energy (kCal) demands per year. We illustrate this 'bottom-up' approach to estimating recovery targets for provincial lands within the Yellowhead population unit south of Hinton, Alberta where populations occur at the lowest documented densities in the province at 5 bears per 1000 km^2. Food supply models and simulations of energy demands by bears suggest a total maximum population size of 200 bears over a 19,945 km^2 (10 bears per 1000 km^2) or within the core and secondary conservation zones of the population unit of 139 bears (11.7 bears per 1000 km^2). In some core conservation zones near the upper Greg River drainage, potential bear densities without human displacement or mortality were estimated at up to 35 bears per 1000 km^2. We are currently examining model sensitivities and thus recommend that these recovery numbers be considered preliminary. These estimates also do not consider what is socially acceptable. Biological targets could therefore be considered the maximum possible with social carrying capacity reducing targets to that which is achievable given current land uses and human-bear conflict.

Background

In 2010, Alberta officially listed grizzly bears as a threatened species following population estimates that placed total population size for the majority of currently occupied habitat on provincially managed lands (plus Waterton National Park) at 691 bears (Alberta Sustainable Resource Development and Alberta Conservation Association 2010). Since only half of this estimate would typically be considered breeding animals, the total number of bears is far fewer than the minimum of 1000 breading animals used by the IUCN and the Alberta Conservation Committee to define secure populations of a species. Although grizzly bears in Alberta are connected to populations in

British Columbia and Montana that would exceed this population size, the jurisdiction in which wildlife are managed and regulated in Alberta under the Wildlife Act is Alberta, not North America.

Given the recent designation of threatened status, any recovery first requires that population recovery targets within local population units are defined. Although recovery plans for grizzly bears in Alberta have suggested specific actions for recovery, including defining core and secondary conservation areas based on road density thresholds of 0.6 and 1.2 km/km^2 respectively (Nielsen *et al*. 2009), actual recovery targets were not identified, nor were suggestions made on how to estimate those targets. One option is simply defaulting to the IUCN criteria of 1000 breading adults at provincial scales rather than population units. Biologically and in particular socially, such recovery targets may not be feasible or desirable for local management at the scale of population units. Alternative approaches to defining recovery targets are therefore needed, as well as management actions to facilitate that recovery and methods for monitoring populations to identify when populations are recovered.

To date, socially-based recovery targets have largely been inferred as default targets for defining recovery of populations within Alberta, acknowledging limitations in recovery based on the realities of current land use activities. This is particularly evident as it relates to ranching in the far southern Castle population where human-bear conflict rates are high and recent eastern expansion of populations observed (Northrup *et al*. 2012). Knowledge of biological targets would be, however, helpful to identify deficits between social and biologically-based recovery targets or in areas with fewer human-bears conflicts, targets that are based more around biological potential (i.e., carrying capacity).

Here we outline an approach for estimating biologically-based targets for recovery of grizzly bear populations in Alberta based on food resource supply. This approach assumes that populations of bears are limited by food resource supply (bottom-up regulation). Although most would agree that top-down factors regulate populations of grizzly bears in Alberta due to human-caused mortalities (Benn 1998; Benn & Herrero 2002; Nielsen *et al*. 2004a; Nielsen 2011), there is also evidence that populations are also limited by food supply. For instance, grizzly bear body size and reproduction is among the lowest reported for this species in Banff National Park where bears are protected, but have access to limited food resources and short growing seasons (Garshelis *et al*. 2005). Indeed, when considering range-wide scales, when grizzly bears have access to marine subsidized resources body size and population density can increase over that of interior populations such as Alberta by a factor of 10 and 100-fold respectively.

This report summarizes our progress to date (year 1 of 3) on defining population recovery targets using spatially-explicit, biologically-based food resource supply modeling of available landscape energy (kCal) or simply nutritional landscapes for a single component - energy. Below we outline our methods and initial results for one population unit in Alberta – the Yellowhead ecosystem south of Hinton, Alberta.

Methods

Study area

The study area used to define biologically-based recovery targets for grizzly bears were the provincial Crown lands occurring within the Yellowhead population unit south of Hinton, Alberta (Figure 14). This region is located between Highways 14 and 16 in the south and north respectively and east of Jasper National Park totally 19,942 km^2. Current population estimate of grizzly bears based on hair-snag DNA mark-recapture methods is approximately 5 bears per 1000km^2 (Boulanger et al. 2005). The area is characterized by lower and upper foothill forested ecosystems (natural subregions) with some local areas of sub-alpine and alpine in the far southwest of the study area (Figure 14). Resource extraction associated with forestry and mining (coal, natural gas, etc.) are common throughout the area. This area was selected to estimate recovery targets given the long history of research in the area on grizzly bear habitats (Nielsen et al. 2004b; 2006; 2008; 2009), diets (Munro *et al*. 2006), and food resource distribution (Nielsen *et al*. 2003, 2004c, 2010; Roever 2008a, 2008b; Coogan *et al*. 2012). It also contains the lowest density of grizzly bears in the Province making it an area of high priority for recovery (conservation).

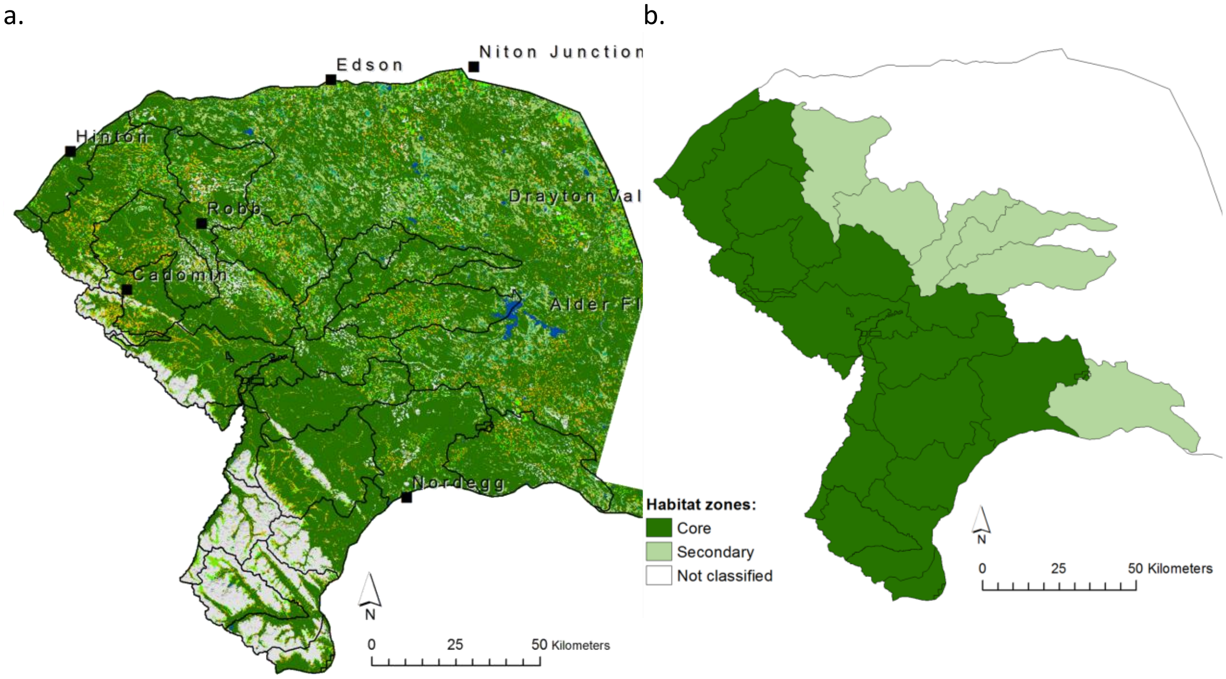

Figure 14. Study area map illustrating the region from which models and estimates of potential carrying capacity were based. Main study area towns, land cover (green is forest, gray is non-vegetated), and watershed recovery zones (see Nielsen et al. 2009) are shown in a. Watershed zones mapped by grizzly bear habitat recovery class (i.e., core, secondary, not classified) shown in b.

Field measures of food resource supply

Between 2001 and 2007, 2,782 field plots were completed over the northwest part of the study area (Figure 15), as well as parts of the Swan Hills and Grande Cache population units to the northeast and northwest. At each field plot, vegetation characteristics, including presence and abundance (cover or density) of critical grizzly bear foods, were measured (Table 3).

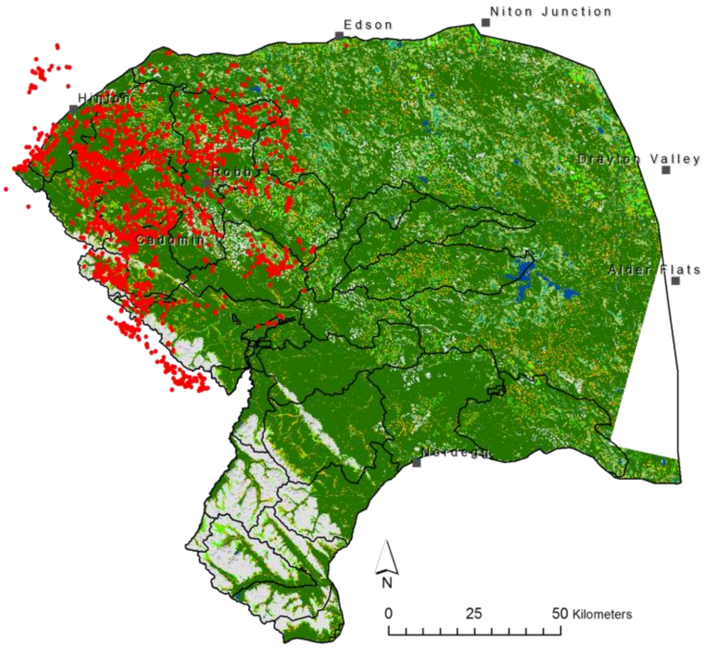

Figure 15. Location of field plots used to estimate presence, cover, and in some cases biomass of individual grizzly bear food items.

Table 3. List of critical grizzly bear food resources (based on Munro et al. 2006) considered in models of local food supply in the Yellowhead ecosystem.

Food Resource	Code	Food type
Shepherdia canadensis (buffaloberry)	SHCA	Fruit
Hedysarum alpinum (alpine sweetvetch)	HEAL	Root
Heracleum lanatum (cow parsnip)	HELA	Herbaceous
Vaccinium membranaceum (huckleberry)	VAME	Fruit
Vaccinium vitis-idaea (lingonberry)	VAVI	Fruit
Vaccinium scoparium (grouse whortleberry)	VASC	Fruit
Equisetum spp. (horsetail)	EQSP	Herbaceous
Trifolium spp. (clover)	TRIF	Herbaceous
Amelanchier alnifolia (saskatoon berry)	AMAL	Fruit
Arctostaphylos uva-ursi (bearberry)	ARUV	Fruit
Fragaria virginiana (strawberry)	FRVI	Fruit
Ribes spp. (currents)	RIBE	Fruit
Rubus idaeus (raspberry)	RUID	Fruit
Taraxacum officinale (dandelion)	TAOF	Herbaceous
Viburnum edule (highbush cranberry)	VIED	Fruit
Hymenoptera; Formicidae (ants)	UNGU	Animal
Ungulates (mostly moose *Alces alces*)	ANTS	Animal

Statistical models of food resource distribution and abundance

We used a multi-stage statistical modeling approach whereby resource distribution (presence of each species) and abundance (cover or density of each species) where present were modeled using generalized linear models (GLMs) with the response variable representing field data and environmental predictors derived from a GIS. Predictor variables include: landcover, climate, terrain, soils, and forest stand measures (Table 4), which were found to previously be important in predicting their distribution and abundance (Nielsen *et al*. 2003; 2004c; 2010; Coogan *et al*. 2012).

Table 4. Environmental GIS predictors used to model food resource distribution and abundance.

Variable theme and measurement variables	Abbreviation
1. Landcover	
Conifer	Conifer
Mixedwood	Mixedwood
Deciduous	Deciduous
Treed wetland	Treed wetland
Shrub	Shrub
Herb	Herb
2. Climate	
Mean annual temperature	MAT
Mean annual temperature (quadratic)	MAT^2
Growing season precipitation	GSP
Growing season precipitation (quadratic)	GSP^2
3. Soils	
Soil pH	soil_pHca
Soil pH (quadratic)	soil_pHca^2
Sand content	soil_tsand
4. Forest stand	
Canopy cover	Canopy
5. Terrain	
Compound topographic index (100m)	Wetness
Compound topographic index (100m; qaudratic)	Wetness^2
Solar flux	Solar
6. Interactions	
Climate interaction	MAT:GSP
Canopy cover-wetness interaction	Canopy:Wetness
wetness-solar interaction	Wetness:Solar
canopy cover-solar interaction	Canopy:Solar

Occupancy (distribution) models for grizzly bear foods. We used logistic regression (generalized linear model (GLM), family = binomial, link = logit) to estimate the probability of occurrence of major grizzly bear foods based on environmental site conditions. Fourteen candidate models were created using a combination of variables (multivariate and interaction terms). All model variables were uncorrelated (Pearson $|r| < 0.7$). Models were selected for species based on ΔAIC > 2 for the top ranked (lowest AIC) candidate model. In cases where the global model was the top model by < 2 ΔAIC, or within ΔAIC of the top model, the global model was chosen as the top model without model averaging. Top candidate models for each species were evaluated for model accuracy using the receiver operating characteristic (ROC) area under the curve (AUC) statistic. Optimal probability thresholds for classifying presence-absence of individual food resource patches were estimated by calculating the minimum absolute difference between sensitivity and specificity values. Occupancy model estimates were mapped in a GIS, where species occurrence probabilities were re-classified to binary presence-absence resource patches (30-m pixel) using the optimal probability thresholds.

Abundance models for grizzly bear foods. Abundance models were estimated for each food item, again using generalized linear models (GLMs) but instead using a Gaussian family and identity link function and excluding observations where it was absent (i.e., abundance where present models). Response variables included percent cover of groundlayer species or the density of food items including shrubs, distinct herbaceous items or fruit. Cover values were converted to proportions and transformed to logit values prior to fitting GLMs. This ensured that extrapolations to new environmental space within the GIS didn't result in cover predictions that were less than 0 or greater than 100. Densities of items (shrubs, fruit or distinct herbaceous items like cow parsnip) were log transformed with a constant of 1 added prior to fitting GLMs. These transformations normalized the data. Like occupancy models, model selection for shrub and distinct herbaceous items was based on AIC and included the same set of 14 candidate models used for occupancy modeling. Candidate models for fruit density were, however, based only on two factors: shrub density or cover and canopy (including non-linear responses for canopy).

Models estimating population density of five common ungulates (moose, elk, bighorn sheep, white-tailed deer, and mule deer) were based on aerial survey data collected and provided to us by Alberta Sustainable Resource Development. Aerial surveys represented only a fraction of the total 'blocks' within the study area. To estimate abundance of ungulates across the entire landscape, generalized linear models (GLMs) were fit to abundance estimates within sampled blocks to environmental factors in that block that related to landcover, landuse, and terrain. Biomass estimates of each species, including neonates, were based on a literature review.

Biomass estimates for herbaceous foods based on percent cover

We used ocular estimates of percent ground cover of herbaceous bear foods — horsetails (*Equisetum* spp.), cow parsnip (*Heracleum lanatum*), dandelion (*Taraxacum officinale*), and clover (*Trifolium* spp.) — within 1 m^2 circular quadrats from two study areas (Kakwa and Crowsnest Pass) during the summer of 2012. Herbaceous bear foods were collected for above-ground biomass estimation by clipping the aboveground part of each herbaceous species. Biomass clipping were collected in paper bags and allowed to air dry while in the field and field camp prior to laboratory analysis (some samples were also frozen until return to the lab). Biomass samples were oven-dried at 60°C for 48 hours in the laboratory, and weighed to a constant weight.

We used the *lmer* function from the package *lme4* in the Program R (Version 2.15.2) to create allometric generalized linear mixed-models (GLMMs; family=Gaussian, link=identity) relating dry herbaceous biomass to percent ground cover estimates. All models were regressed through the origin (i.e., intercept at zero) so that biomass estimates > 0 would not be given when absent (percent cover was zero). Models regressed through the origin were checked against models with intercepts to ensure that the model functions were similar. We used a random effect for sample plot to account for multiple samples per plot. We compared three candidate models using AIC: 1) null model (mean value); 2) biomass as a function of percent cover; and 3) biomass as a function of percent cover plus day past June 1^{st} to account for the influence of collection date on biomass and percent cover. Allometric models were selected for species based on ΔAIC > 2 for the top ranked (lowest AIC) candidate model.

Biomass to energy conversions

We combined literature from grizzly bear food studies (Hamer & Herrero 1987; Pritchard & Robbins 1990; Noyce *et al*. 1997; Welch *et al*. 1997; Swenson *et al*. 1999; Rode *et al*. 2001; Mattson *et al*. 2004) with laboratory measures of foods collected from the Yellowhead ecosystem between 2008 and 2010 (Coogan 2012; Coogan *et al*. in preparation) to estimate energy digestibility (kcal) per dry weight gram of each food resource based on relationships from Pritchard and Robbins (1990). Energy and energy digestibility estimates for food items were based on single-sourced estimates or averaged across studies (methods are presented in detail in Lopez *et al*. in preparation).

Bioenergetic model to estimate total annual energy (food resource) demand

We used a bioenergetic simulation model of grizzly bear growth to estimate total annual energy requirements for an average female grizzly bear. The model simulates the energy (kcal) requirement of active bears by integrating the main metabolic mechanisms that determine maintenance, reproduction, movement and growth costs for non-lactating and lactating bears. The model was developed in Stella 10 (Isee Systems, Inc., 2006) using a daily time step. We assumed 180 days of active period. Day one corresponds to den emergence and the final model simulation day corresponds to den entry.

Maintenance cost is a function of the body mass (BM in Kg, equation 1). Initial body mass for female was 102 kg and the denning body mass was 153 kg. Initial body mass for male was 195 kg and denning body mass was 225 kg. We assumed spring body fat content of 15% for all bears.

Eqn. 1: Kcal/day = 61.9*BM0.77 McNab (2008)

For a lactating female we assumed that she has two cubs of 60 days at emergence. Milk production cost was added based on Farley and Robbins (1995) study.

Movement cost is a function of the daily movement distance (km) and body mass (equation 2). Movement rates were estimated from McKay et al. (2011), thus for females daily movement was estimated randomly from 3.5 km to 12 km and from 4.5 km to 9.5 km for males.

Eqn. 2: Kcal/kg/km = 2.57*BM-0.316 Robbins (1993)

Growth cost depends on the denning body mass reserves necessaries to support maintenance and reproduction cost during hibernation. For non-lactating females was assumed that they will reproduce during hibernation, consequently they need more body mass reserve to sustain reproduction. Therefore target body mass for non-lactating female is higher than for lactating females. Denning body fat mass for non-lactating female was 28% and for lactating female was 22%.

Spatial bioenergetics to recovery targets (carrying capacity)

Spatial predictions of available energy (kCal) for each species of food item were estimated for the study area using a 30 m resolution (900 m^2 pixel). Recovery zones (watersheds) were used to summarize total available energy per management zone per species. Food item consumption rates were then fit for each food item to reflect the fact that bears don't consume everything that is available. This ranged from 1% to 25% (neonates) of its availability.

Results

Food resource distribution and abundance

Numerous occupancy and some abundance models contained all variables and interactions terms (global model) (Tables 5 & 6). Forest stand (canopy) and soil variables were the most commonly omitted variables in occupancy models and the occupancy model for lingonberry contained the least complex model in number of predictor variables. Fruit abundance was predicted by canopy cover at the site and shrub abundance (Table 7).

Figure 16 illustrates spatially the model predictions for estimates of occupancy for one of the species – buffaloberry (*Shepherdia canadensis*). This includes the original probability of occurrence by pixel (Fig. 16a) and presence/absence maps (Fig. 16b) that used the optimal probability cut-off threshold using model sensitivity and specificity. In contrast, Figure 17 illustrates spatially the model predictions for buffaloberry shrub density (Fig. 17a), fruit density (Fig. 17b), and energy (Fig. 17c). Patterns of fruit density and energy look similar to shrub abundance since fruit density was predicted from shrub abundance and canopy cover, while energy is a straight conversion of dry weight biomass to energy based on number of fruit predicted to a site.

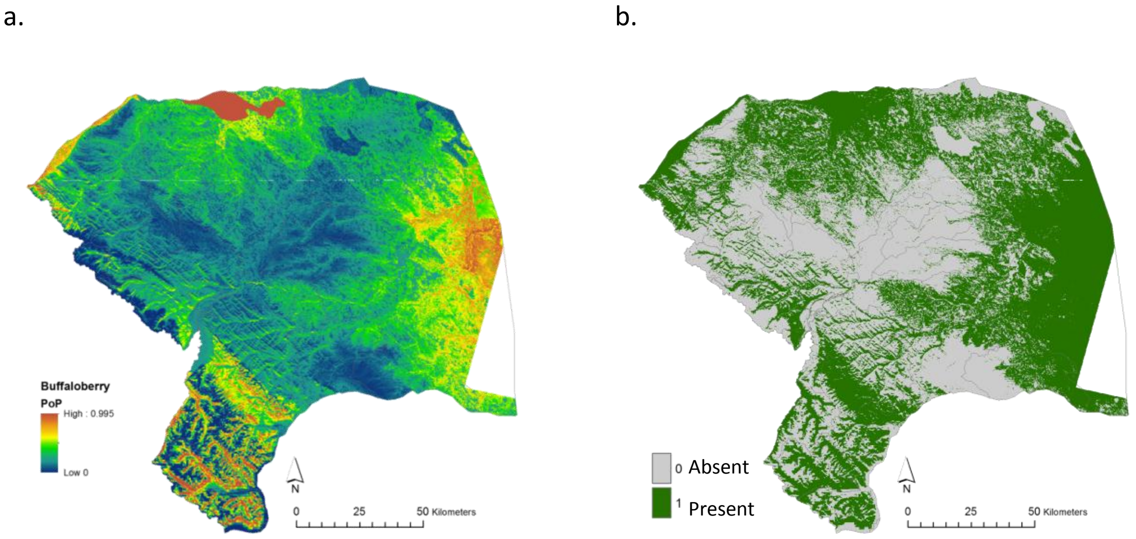

Figure 16. Example models for a critical food resource – buffaloberry (*Shepherdia canadensis*). Map a represents the probability of occurrence of buffaloberry, while b represents the predicted presence of buffaloberry based on an optimal classification threshold of probability of occurrence.

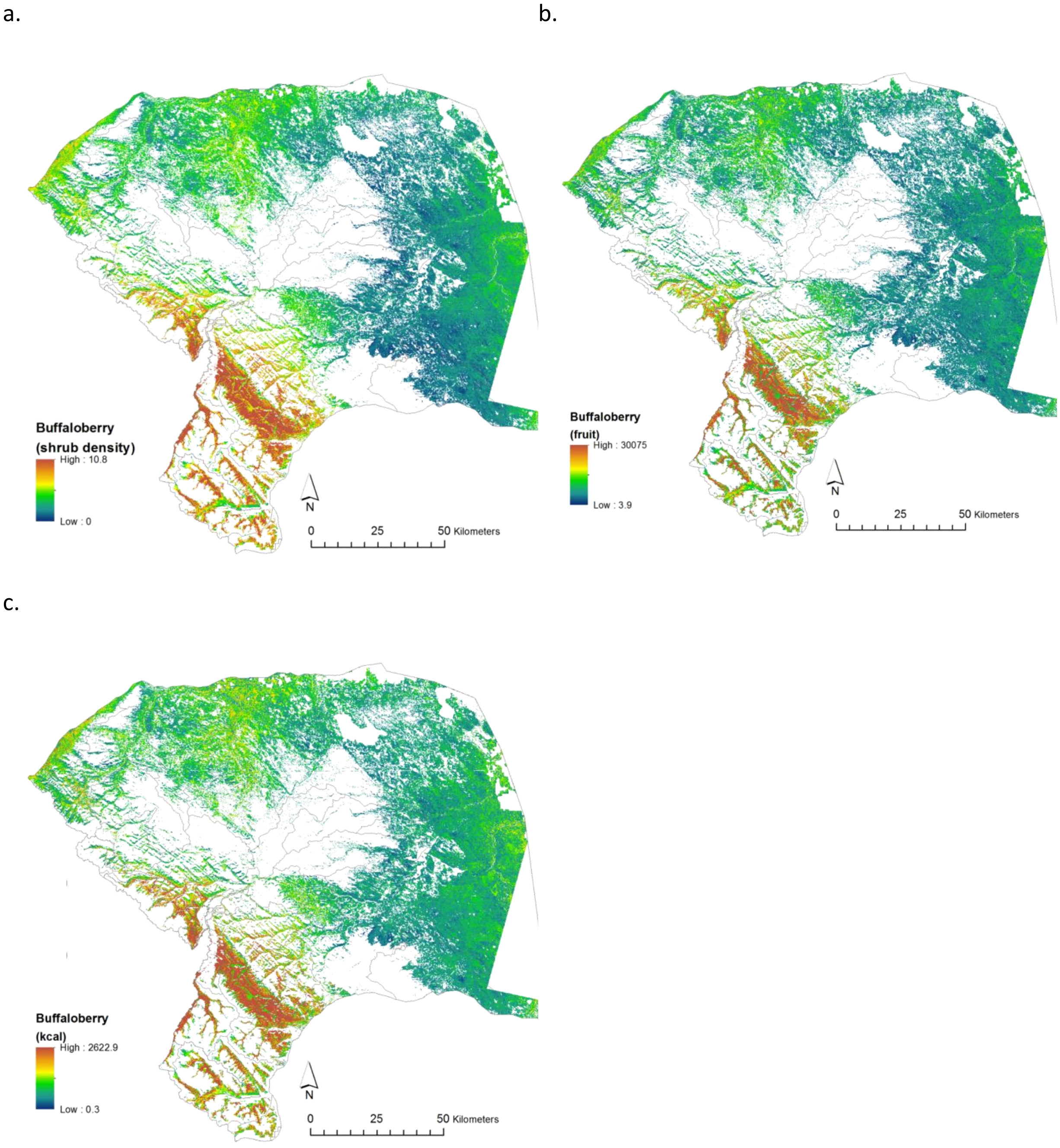

Figure 17. Predicted shrub density (a), fruit density (b), and energy [kcal] (c) for buffaloberry (*Shepherdia canadensis*) based on models of shrub density from field measures and environmental data, relationships between fruit abundance from field measures and shrub density and canopy, and energetic conversions of fruit to kcal of energy based on lab analyses and literature.

Figure 18 illustrates spatially the model predictions for estimates of ungulate biomass for the species of moose (Fig. 18a), elk (Fig. 18b), bighorn sheep (Fig. 18c), mule deer (Fig. 18d), and white-tailed deer (Fig. 18e). Figure 18f and 18g illustrate patterns of biomass pooled across species, but separated between adults and neonates.

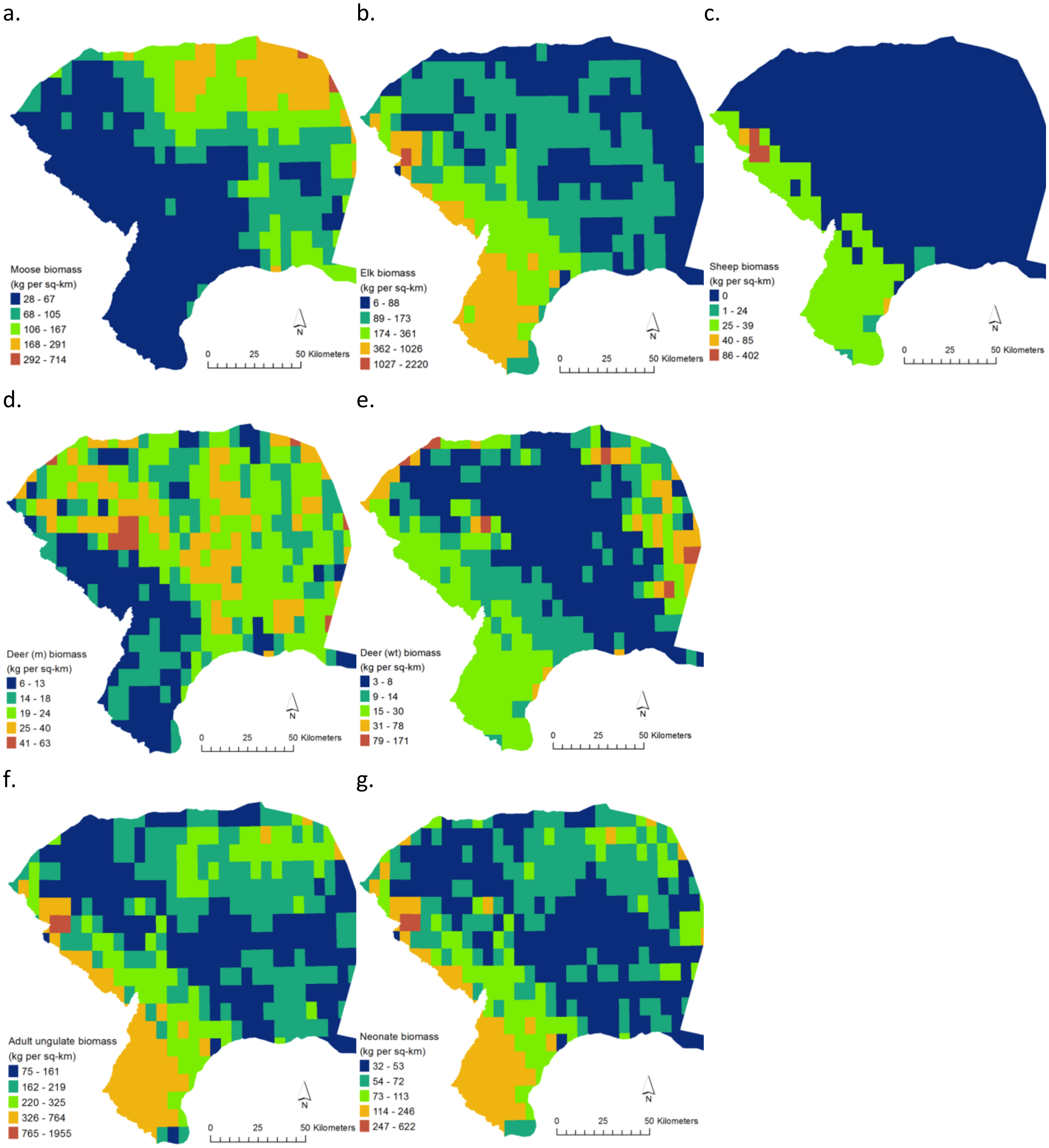

Figure 18. Predicted ungulate biomass (fresh weight) for moose (a), elk (b), bighorn sheep (c), mule deer (d), and white-tailed deer (e) based on aerial survey data and models relating local habitat to density of ungulates. Total biomass of ungulates as adult (f) and neonates (g) are shown. Biomass conversions from density and number of neonates per ungulate were based on published body sizes and average number of neonates per species.

Allometric models of cover to biomass

We collected and weighed 130 horsetail (Kakwa *n* =110, Crowsnest *n* = 20), 10 cow parsnip (Kakwa *n* =9, Crowsnest *n* = 1), 44 dandelion (Crowsnest *n* = 44), and 13 clover (Kakwa *n* =3, Crowsnest *n* = 10) samples. Biomass as a function of percent cover (candidate model 2), was the most supported model for all herbaceous species (Table 8).

Biomass to energy conversions

Table 9 provides the biomass to energy conversions used to convert predicted biomass to kCal of energy for each food item and landscape pixel.

Bioenergetic model for annual energy demands

Energy requirements for non-lactating females were 1,975,000 kCal/bear/180days, while for non-lactating females were 2,023,000 kCal/bear/180days. Energy requirements for lactating females are higher due to cost of milk production. Energy requirements for males were 2,815,000 kCal/bear/180days. Male requirements are higher due they large body mass. For estimating energetic-based carrying capacity, we used the average of male and lactating female grizzly bear energy requirements of 2,419,000 kCal/bear/year.

Habitat carrying capacity estimates for grizzly bears

When considering the entire 19,942 km^2 Yellowhead study area that included all core, secondary and unranked conservation zones total potential carrying capacity (*K*) and thus the maximum possible biological recovery was estimated at 200 grizzly bears or a density of 10 bears per 1000 km^2 (Fig. 19). Considering only the core and secondary zones, *K* was estimated at 139 bears or 11.7 bears per 1000 km^2. Carrying capacity of bears varied substantially, however, among conservation zones with some units near the upper parts of the Greg River (including the Greg River Mine) as high as 35 bears per 1000 km^2 (Fig. 19).

Table 5. Logistic regression coefficients (β) estimating the probability of occurrence of major grizzly bear foods based on environmental conditions at a site and presence/absence of each food item.

Variables	SHCA	HEAL	HELA	VAME	VAVI	VASC	EQSP	TRIF	AMAL	ARUV	FRVI	RIBE	RUID	TAOF	VIED
Intercept (constant)	-26.59	-114.3	-84.51	-42.03	10.72	-66.92	-9.922	-182.6	-47.13	-25.68	-22.51	-3.959	4.993	-63.93	-18.66
Landcover															
Conifer	0.7455	0.7441	0.5396	0.1453	0.6185	-0.1684	0.3602	0.2524	-0.3946	0.1391	0.0049	-0.5048	-0.0639	0.0670	-0.7583
Mixedwood	1.1570	0.8777	0.9772	0.4296	0.1344	-0.2879	0.4766	0.9122	0.3172	0.3147	0.6413	-0.1894	0.4543	0.6892	0.1215
Deciduous	0.8114	0.4910	1.4190	0.0992	-0.5546	-0.5593	0.9526	0.9869	1.4060	-0.0429	0.6661	0.3285	1.2640	1.3900	0.9721
Treed wetland	-0.2038	-1.4560	0.6819	-0.3464	0.3532	-14.8400	0.9090	0.4813	0.3525	-0.6472	-0.1049	-0.7285	0.6932	0.1780	-1.1040
Shrub	0.4604	0.4569	0.8545	0.3697	0.3557	-0.6557	0.4502	0.2613	0.3310	-0.2317	0.0091	0.0655	0.2806	0.6051	-0.2389
Herb	0.0623	0.2886	1.0280	0.0954	-0.1740	-0.3930	0.2400	0.6214	0.8653	-0.4551	-0.0874	0.1505	0.1467	0.7941	0.1809
Climate															
MAT	-4.5180	4.5910	13.2300	10.3100	-6.2130	-3.3110	-0.2523	14.2100	8.6270	-4.8400	-2.8790	0.1127	0.1660	4.4130	-0.5888
MAT^2	0.3275	0.2384	-0.7208	-0.6002	0.2566	0.4257	-0.1030	-0.5018	-0.2416	0.6268	0.1826	-0.3168	-0.5216	-0.0991	-0.1517
GSP	0.1687	0.5933	0.3302	0.1227	-0.0570	0.3597	0.0314	0.8681	0.1720	0.1842	0.1328	0.0111	-0.0381	0.3128	0.0332
GSP^2	-0.0002	-0.0007	-0.0004	-0.0001	0.0001	-0.0004	-0.00004	-0.00095	-0.0002	-0.0003	-0.0002	-0.00002	0.00004	-0.0003	-0.0001
Soil pHca	-4.1920	-2.5180	2.5470		-0.1741	-6.7890	1.2940	-3.9150		-2.7720	-1.2490		0.7280	-4.0830	2.4190
Soil pHca^2	0.3881	0.2436	-0.2350		-0.0233	0.5570	-0.1088	0.3657		0.2387	0.1157		-0.0667	0.3676	-0.2194
Soil_tSand	0.0173	-0.0099	-0.0072		-0.0044	0.0542	-0.0031	0.0212		0.0091	0.0042		-0.0058	0.0175	0.0046
Forest stand															
Canopy	0.0091	-0.0263		0.0361	0.0032		-0.0184	-0.0888		-0.0327	-0.0337	0.0212	-0.0110	-0.0800	-0.0152
Terrain															
Wetness		-0.9953	0.1865	0.5553	0.2126		0.4229	-0.8885	-0.3983	-1.0230	-0.2589	0.2365	0.5438	0.1005	0.9772
Wetness^2		0.0180	0.0115	-0.0232	-0.0206		-0.0167	0.0005	0.0002	0.0122	-0.0043	0.0105	-0.0073	-0.0010	0.0108
Solar flux	6.79	-6.272	4.951	1.591	-2.184		-3.245	-11.54	5.665	-0.3464	0.9482	5.380	3.011	0.9393	15.8600
Interactions															
MAT:GSP	0.010	-0.0127	-0.0295	-0.0216	0.016	0.007	0.0008	-0.0297	-0.0166	0.010	0.0071	0.0017	0.0023	-0.0084	0.0029
Canopy:Wetness		0.0010			0.0016		0.0015	0.0004		0.0008	0.0013		0.0015	0.0019	0.0017
Wetness:Solar		1.0740	-0.6843	-0.5160	0.2137		0.0526	1.5570	0.3977	1.1430	0.5775	-0.9033	-0.7499	-0.0986	-2.4860
Canopy:Solar	-0.0112	0.0139		-0.0374	-0.0151		-0.0015	0.0970		0.0295	0.0274	-0.0259	0.0004	0.0649	0.0148
Model statistics															
Null deviance	2641.7	2240.5	1498.9	1700.0	3633.9	697.1	3847.0	2375.1	443.9	2200.0	3703.4	2647.7	3844.0	2472.3	2539.9
Residual dev.	2208.1	1582.1	1378.9	1477.4	2894.9	631.9	3623.6	1965.1	380.1	1840.6	3275.8	2473.9	3305.1	2080.8	2121.1
% deviance	16.4	29.4	8.0	13.1	20.3	9.4	5.8	17.3	14.4	16.3	11.5	6.6	14.0	15.8	16.5
AIC	2244.1	1626.1	1416.9	1513.4	2938.9	661.9	3667.6	2009.1	412.1	1884.6	3319.8	2509.9	3349.1	2124.8	2165.1
ROC AUC	0.79	0.87	0.72	0.77	0.80	0.75	0.66	0.79	0.81	0.79	0.73	0.68	0.73	0.78	0.78
Threshold prob.	0.19	0.14	0.08	0.10	0.40	0.04	0.48	0.17	0.02	0.15	0.40	0.20	0.51	0.18	0.18

Food species codes: *Shepherdia canadensis* (SHCA); *Hedysarum alpinum*, (HERA); *Heracleum lanatum* (HERA); *Vaccinium membranaceum* (VAME); *Vacciunium vitis-idaea* (VAVI); *Vaccinium scoparium* (VASC); *Equisetum* spp. (EQSP); *Trifolium* spp. (TRIF); *Amelanchier alnifolia* (AMAL); *Arctostaphylos uva-ursi* (ARUV); *Fragaria virginiana* (FAVI); *Ribes* spp. (RIBE); *Rubus idaeus* (RUID); *Taraxacum officinale* (TAOF); *Viburnum edule* (VIED).

Table 6. GLM coefficients (β) predicting cover of major grizzly bear foods based on environmental conditions at a site.

Variables	SHCA	HEAL	HELA	VAME	VAMY	VAVI	VASC	EQAR	Trifolium	AMAL	ARUV	FRVI	Ribes	RUID	TAOF	VIED
Intercept	0.74	-43.35	-86.39	-9.5135	1.5562	-6.4007	-0.6091	-1.9072	-2.9694	1372.113	-10.9221	-1.8007	-10.3469	0.987	-9.9861	-3.845
Landcover																
Conifer		-0.259	0.0973		-0.7313	0.2785		-0.2504			-0.6481	-0.1029	0.3023	-0.7989		
Mixedwood		-0.0813	0.2824		-0.2681	0.254		-0.0893			-0.4157	0.2466	0.206	-0.5529		
Deciduous		0.2108	0.6218		-0.5908	-0.1403		-0.3584			-0.9851	0.324	0.1986	-0.1313		
Treed_wetland		0.2452	-0.3624		-0.509	0.1476		0.1967			-0.6343	0.075	0.6143	0.71		
Shrub		-0.2024	0.6714		-0.223	0.0313		-0.1631			-0.5083	0.1475	-0.0679	-0.3333		
Herb		0.0744	0.6472		-0.4481	-0.4852		-0.157			-1.0666	0.1477	-0.0522	0.0732		
Climate																
MAT			4.6237	11.4303	1.0221	6.1023	-0.4553		3.1238		-7.0648	2.4777	1.724	2.7399	2.246	3.1859
MAT^2			-0.1411	-0.0036	-0.1124	-0.4928	0.002		-0.3034		-1.4415	-0.0099	-0.1287	-0.3722	-0.4602	-0.059
GSP			0.1765	0.378	0.0178	-0.0758	-0.0178		-0.0382		-6.0693	0.032	-0.0095	0.0428	-0.0036	0.0187
GSP^2			-0.0002	-0.0004	-0.0000079	0.0001209	0.000018		0.0000467		0.0066802	-0.0000385	0.0000114	-0.0000507	0.0000054	-0.0000148
Soils																
Soil pHca	-1.416				1.1867	0.6202	1.1717	1.2107								
Soil pHca^2	0.1268				-0.0861	-0.0718	-0.1065	-0.0999								
Soil_tSand	0.0092				-0.0011	-0.0091	-0.0311	-0.0034								0.0118
Forest stand																
canopy		-0.0173	-0.0448					-0.043	-0.0314		-0.0044	-0.0082	-0.0316			-0.0605
																0.0005
Terrain																
Wetness						0.4816	-0.0838	0.7058						-0.467		
Wetness^2						-0.0056	-0.0327	-0.0051						0.0139		
Solar flux		0.4473	-7.1616			8.3799	-16.1661	3.3822	-0.4864		2.5104	-0.7814	-4.3361	-3.859		
Interactions																
MAT:GSP		-0.0104	-0.0261	-0.0029	-0.0097	0.0016		-0.0068		0.0235	-0.0059	-0.0035	-0.0057	-0.0028	-0.0069	
Canopy:Wetness								0.0011								0.0028
Wetness:Solar						-0.5927	1.3395	-0.8989						0.162		
Canopy:Solar		0.0191	0.0732					0.0539	0.023		-0.0046	0.0081	0.045			

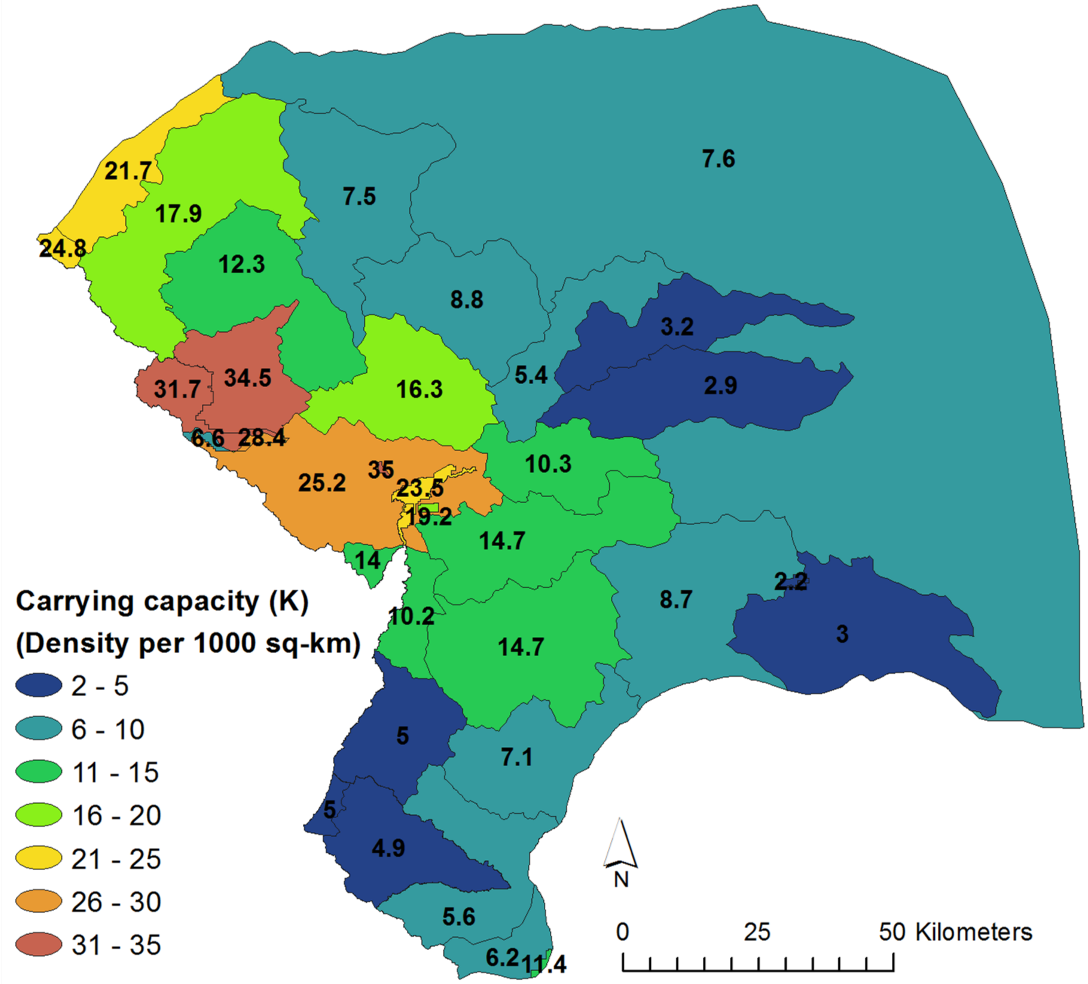

Figure 19. Predicted carrying capacity (*K*) of grizzly bear recovery zones for the Yellowhead ecosystem of Alberta.

Table 7. GLM coefficients (β) predicting fruit cover of major fruiting grizzly bear foods based on abundance of shrubs and canopy cover.

Variables	SHCA	Ribes	RUID	VIED
Intercept (constant)	-6.1530	-6.6260	-7.1710	-6.3067
Abundance (density / cover)	0.0798	0.1445	0.1980	0.1253
Canopy cover	0.0474		0.0220	
Canopy cover^2	-0.000622		-0.000294	

Table 8. Allometric generalized linear mixed-model regression through the origin coefficients (beta) estimating the biomass (dry weight grams) of major herbaceous grizzly bear foods based on percent cover estimates. Plant foods include horsetails (EQSP), cow parsnip (HERA), dandelion (TAOF), and clover (TRIF).

Variables	EQSP	HERA	TAOF	TRIF
Intercept (constant)	N.A.	N.A.	N.A.	N.A.
Cover	0.4499	0.4901	0.3819	0.4640
Model Statistics				
Standard error	0.0498	0.1241	0.0306	0.2663
t value	9.026	3.949	12.48	1.742
AIC	991.5	55.7	180.33	41.66
logLik	-490.8	-22.85	-90.74	-15.83
deviance	977.4	43.31	176.3	30.81

Table 9. Digestible energy (kCal per gram dry weight) and crude protein digested (gram per dry weight gram food item) of bears foods, dry weight (g) per berry, and average dry weight (g) per root of *Hedysarum sp*. used to estimate nutritional landscape values available to grizzly bears in Alberta.

Estimate	**SHCA**	**HEAL**	**HELA**	**VAME**	**VAVI**	**VASC**	**EQSP**	**TRIF**	**AMAL**	**FRVI**	**RIBE**	**RUID**	**TAOF**	**VIED**	**VAMY**	**UNGU**	**ANT**
Digestible energy§	2.7	1.6	0.6	2.5†	2.6	2.7	1.3	1.8	2.6†	2.6†	2.6	2.6†	1.8	2.6†	2.5	***6.8***	0.88
Crude protein digested§		0.103	0.087				0.146	0.115					0.115			55%	34%
Dry weight (g) per berry*	0.0323			0.0389†	0.0320	0.0149			0.16352	0.04	0.0321	0.0400		0.06328	0.0389		
Average dry weight *Hedysarum* spp. root±		1.19															

† Values were assumed. See Table 6 for assumptions.

§ See Lopez Appendix for sources of digestible energy and protein digested values.

*Coogan 2012; Welch *et al*. 1997

± Hamer 1999.

Discussion and next steps

Recovery targets based on food resource supply suggest that currently defined grizzly bear conservation zones in the Yellowhead population unit could biologically support about two-times the current number of bears in the area at 11.7 bears per 1000 km^2. Areas of very high predicted carrying capacity included the upper Greg River at 35 bears per 1000 km^2.

These estimates also do not consider what is socially acceptable. Biological targets could therefore be considered the maximum possible with social carrying capacity reducing targets to that which is achievable given current land uses and human-bear conflict.

These models are also based on a number of assumptions that require further testing and thus should be considered preliminary. Work in year 2 will focus on sensitivity analyses of inputs and parameters and the potential to use a reference population at carrying capacity, such as the Willmore Wilderness, to estimate relationships between predicted energy and population density.

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CHAPTER 5: POTENTIAL IMPACTS OF CLIMATE CHANGE ON CRITICAL GRIZZLY BEAR FOOD RESOURCES IN ALBERTA

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Introduction

Grizzly bears (*Ursus arctos*) inhabiting seasonal latitudes, such as Alberta, possess habitat-use patterns that are clearly driven by the timing and availability of high-nutrition food-plants (Munro *et al.* 2006; Hamer and Herrero 1987). As the season progresses, bears will move throughout their home-range in search of quality forage. As a result, grizzly habitat is not contained within a static boundary, but rather, is very dynamic in response to marked pulses of nutrition across the landscape (Nielsen *et al.* 2010). The study of the annual timing of recurring biological events is termed phenology, and provides a dynamic, integrative approach to ecological research (Post and Inouye 2008). A major driver of plant development is temperature (Slafer and Savin 1991), as plants accumulate exposure to heat they will predictably move from one life-cycle event to the next – these events are called phenophases. Global climate-change threatens to affect regional seasonal temperatures, with a predicted increase in mean annual temperature across Alberta and western Canada (Mbogga *et al.* 2009; IPCC 2001). These changes will directly impact the timing and distribution of critical food-plants, and potentially impede germination success, and increase early season frost risk (Bennie *et al.* 2009; Inouye 2008; Myking 1997). Such climatic influences on vegetation will have cascading effects throughout the ecosystem (Parmesan and Yohe 2003; Parmesan 2006), ultimately affecting the abundance and quality of critical habitat for grizzly bears within the province. Often, habitat models rely too heavily on simplistic environmental surrogates that remain static through time (Schlossberg and King 2009). Therefore grizzly bear management in Alberta would benefit from a deeper understanding of the timing and location of high quality food resources and how these may be affected by shifting climate.

This research project aims to quantify and visualize the potential impact of climate-change on the timing and distribution of critical bear food-plants within the province. Over two consecutive seasons (2011-12) direct field observations of plant phenology have been made using a network of time lapse-cameras, meteorological equipment, and site visits by personnel throughout five elevational transects in the Rocky Mountain foothills of Alberta. These observations will provide the baseline phenological progression and minimum-temperature developmental thresholds (biofix) of the food-plants under investigation. These focus species include: Buffaloberry (*Shepherdia candensis*), a fruiting plant; cow parsnip (*Heracleum lanatum*), a herbaceous food; and alpine sweet vetch (*Hedysarum alpinum*), which has an edible root. The field observations will be linked to daily overhead spectral and temperature data collected by the *Moderate Resolution Imaging Spectroradiometer* (MODIS), mounted on the Terra and Aqua satellite platforms. The combination of ground data and satellite imagery will produce a series of dynamic 'phenology' maps expressing land-surface heat accumulation, or growing degree days (GDD), that will clearly exhibit the baseline phenological progression of the focus species.

The potential impact of changing climate on this baseline phenological progression is currently being assessed within climate-controlled growth chambers at the Alberta Innovates Technology Futures Bioresource Center in Vegreville (AITF). Here, the phenological development of the focus species can be altered in a managed, limited-variable environment. The climate scenarios that will be simulated include: i) the climate normals of the study area (a validation of the baseline phenology maps created from field observations), ii) a climate warming scenario based on IPCC forecasts, and iii) a simulation of regional cooling. The experimental chamber results will be used to adjust the baseline maps to display the impacts of climate change on food-plant phenophase timing and distribution. The goal of this research is to develop spatially explicit empirical models that provide wall-to-wall dynamic estimates of phenophase timing throughout the season, and into the future, across grizzly bear habitat in Alberta.

Objectives

- Determine phenological development of *Shepherdia canadensis*, *Heracleum lanatum*, and *Hedysarum alpinum* through field observations.

- Derive phenology maps displaying the seasonal development of the focus species across grizzly habitat in Alberta (baseline phenology maps).

- Determine shift in timing of phenological development using growth chamber observations of simulated climate scenarios.

- Derive phenology maps which display the spatio-temporal shift in plant development under various climate change scenarios across grizzly habitat in Alberta (future phenology maps).

Study Area

The study area encompasses the extent of grizzly bear habitat along the front ranges of the Alberta Rocky Mountains, including the home ranges of the Foothills Research Institute's (FRI) core population of grizzly bears near Hinton. This area offers a long history of GPS telemetry data and knowledge regarding animal foods and diet (e.g. Nielsen and Boyce 2005). Observations of focus species phenology was made along six transects extending across topographical gradients that are perceptible with MODIS imagery. The notion being that phenophases are delayed at higher elevations, where temperatures are cooler, and GDD accumulation is prolonged (Hopkins 1918). This ultimately lends to the differential habitat-use strategies observed in grizzlies as a response to the timing of food availability (Hamer and Hererro 1987). Each east-west transect extends an average of 75km in length, and spans a latitudinal range of nearly five degrees, or 550km (Lat: 54°37' to 49°85').

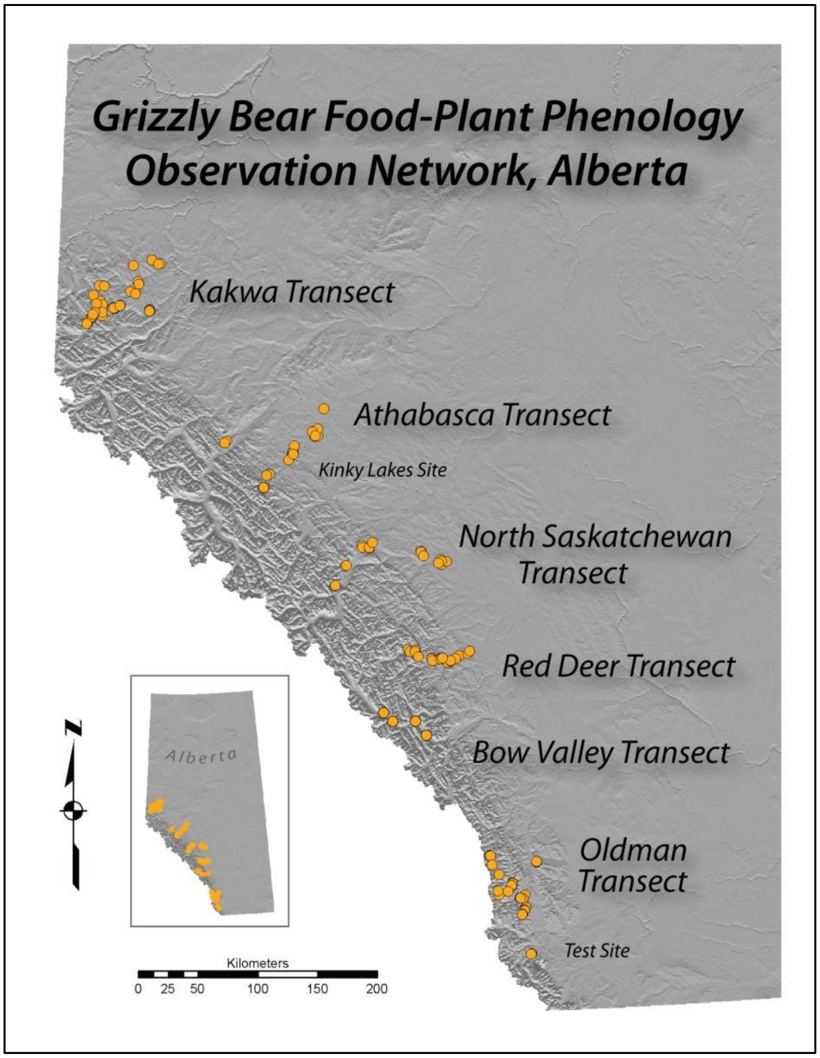

Figure 1. The phenology project study area.

Methods

Field Observations

Development of the focus species was monitored in 250m x 250m (MODIS spatial resolution) sites by field crews every 16 days, to match the temporal resolution of MODIS. Personnel would sample two random 250m transects (500m) bisecting the sites and note the phenophase of any focus species encountered (e.g. Table 1.). These observations were made over seven months to capture the entire growing season. For continuous observations between crew visits, sites were monitored by 85 phenology cameras (daily picture) and 120 temperature loggers (hourly) for GDD accumulations.

Table 1. Phenophase codes of deciduous trees and shrubs (Dierschke, 1972).

Code	Phenophase
0	Closed bud
1	Green leaf out, but not unfolded
2	Green leaf out, start of unfolding
3	Leaf unfolding up to 25%
4	Leaf unfolding up to 50%
5	Leaf unfolding up to 75%
6	Full Leaf unfolding
7	Stem/first leaf fading
8	Yellowing up to 50%
9	Yellowing over 50%
10	Dead

Temperature loggers were geometrically distributed across sites to record temperature at the scale of a MODIS pixel (250m). Each plant that was monitored by a phenology camera also had a temperature logger at the height of the developing buds and shoots (1m). The forest structure at different sites will affect the understory temperature regime. Forest structure was therefore characterized by field crews to determine the relationship between land surface (canopy) temperature as measured by MODIS, and understory temperature measured by the temperature loggers. Along two random 250m transects 60 hemispherical images were taken systematically to calculate crown closure which correlates to forest density. At these same sites 12 basal area factor prism-sweeps were performed to sample the tree species composition of the forest.

A series of validation sites were set up to measure ground temperature at non-forested, homogenous open sites to control for the effects of forest canopy attenuation. In 2011 three sites were established in large, flat agricultural pastures SW of Calgary. In 2012 a single site was set up at the Suffield military base in SE Alberta which has the largest, undisturbed, homogenous landcover in the province – temperature measurements at this site are ongoing.

Growth Chamber Observations

The growth chambers at the AITF provide control of temperature, photoperiod duration, light intensity, light frequency, and atmospheric gas mixture (atmospheric control not employed for this study)(Figure 2.) *Heracleum lanatum* and *Hedysarum alpinum* seeds were collected from different elevations and latitudes throughout the study area to account for phenotypic variations. The seeds were scarified to promote germination, inoculated with mycorrhizae, and stratified to simulate winter chill days. In addition, adult plants were dug from disturbed sites (i.e. cut blocks) throughout the study area to ensure a viable growth chamber study population. *Shepherdia canadensis* matures after 4-5 years and could not be grown from seed. A number of individuals from a nursery at the AITF and near Smoky Lake were dug and potted.

Figure 2. Climate controlled growth chambers and focus species at AITF.

The study plants were divided into three groups and placed into chambers simulating three climate regimes: i) *Climate normals* estimated using 30 year daily high and low temperature averages for the study area. ii) *Climate warming* based on current IPCC projections and forecasts for western Canada (Mbogga *et al.,* 2009) that predict a high scenario of 4°C warming (*likely* range of 2.4 to 6.4°C) over the next 100 years, and iii) *Climate cooling*, where climate change can manifest as a regional cooling, this chamber will slow plant development by dropping the 'normal' seasonal temperature profile by 4 degrees to mirror the warming forecast. Any climate scenario can be mapped knowing the phenological progression of the focus species under different temperature regimes. Observations by personnel are made three times a week, phenology cameras in the chambers take daily pictures, and temperature is logged hourly.

Progress To Date

Season 1, 2011

Field observations 2011 were successfully made for *Shepherdia candensis*, *Heracleum lanatum*, *Hedysarum alpinum* (Figure 3). A clear temporal lag in phenological development was observed across elevations for all focus species – this will be quantified in upcoming manuscripts submitted to the FRI as a deliverable. The phenological development of *Shepherdia* was remarkably distinct, with an unmistakable 'pulse' of nutrition of berry ripening visible with phenology cameras. As a diaceous species, the flowering of *Shepherdia* was clear in the imagery as well; in most cases the sex of the plant was apparent (flowers are 2-5mm). By the completion of *season 1* it was apparent that *Heracleum* and *Hedysarum* grow too quickly to be monitored continuously with phenology cameras. The developing embryonic shoots and flower buds are carried out of the field of view (FOV) by the quickly growing stalk. The image record is still nearly complete, as the camera FOV was reset during sites visits. The benefit of using phenological camera monitoring was two-fold. Firstly, they fill the temporal gaps between field visits to ensure no significant developments were missed, and second, it was found that by using two cameras per plant (wide and narrow FOV), visitation by crews could be reduced substantially in *season 2*. Temperature accumulation was successfully recorded at all sites for deriving GDD calculations.

Sugar content – Along the Athabasca and Red Deer transects, measurements of *Shepherdia* berry sugar content were made every 8-10 days, sampling from the same individuals – two per site. Measurements were made using a brix refractometer which derives percent dissolved sugar in solution. Early season values begin at 5-6% soon after the flowers have desiccated and the ovaries have begun to swell. At peak ripeness (variable over elevation) sugar content exceeded 30%. There was is a marked lag across the elevational gradient, where low elevation plants at some sites had complete dispersal of berries, where some high elevation plants still had unripe berries at the point of first snowfall.

Growth chamber observations 2011– The *Shepherdia* plants were observed for 4 months after being transplanted into pots and were then successfully artificially stratified to trigger dormancy. However, during the overwinter period, the plants experienced excess evapotranspiration, damaging all of the reproductive and vegetative portions of the plant. This delayed growth chamber observations for an entire season until more naturally dormant plants could be potted. Germination success in *Hedysarum* was 90%, with multi-stem potted plants put through an abbreviated growing season to accelerate maturing. *Heracleum*, being biennial, required extended periods of cold stratification in excess of 150 days. To shorten this duration, it was attempted to reduce the amount of dormancy hormone within the seeds - germination was unsuccessful. All mature, potted *Hedysarum* and *Heracleum* also experienced the same extensive cold stratification damage as the *Shepherdia*. A different stratification unit was used during *season 2*, and this problem did not reoccur.

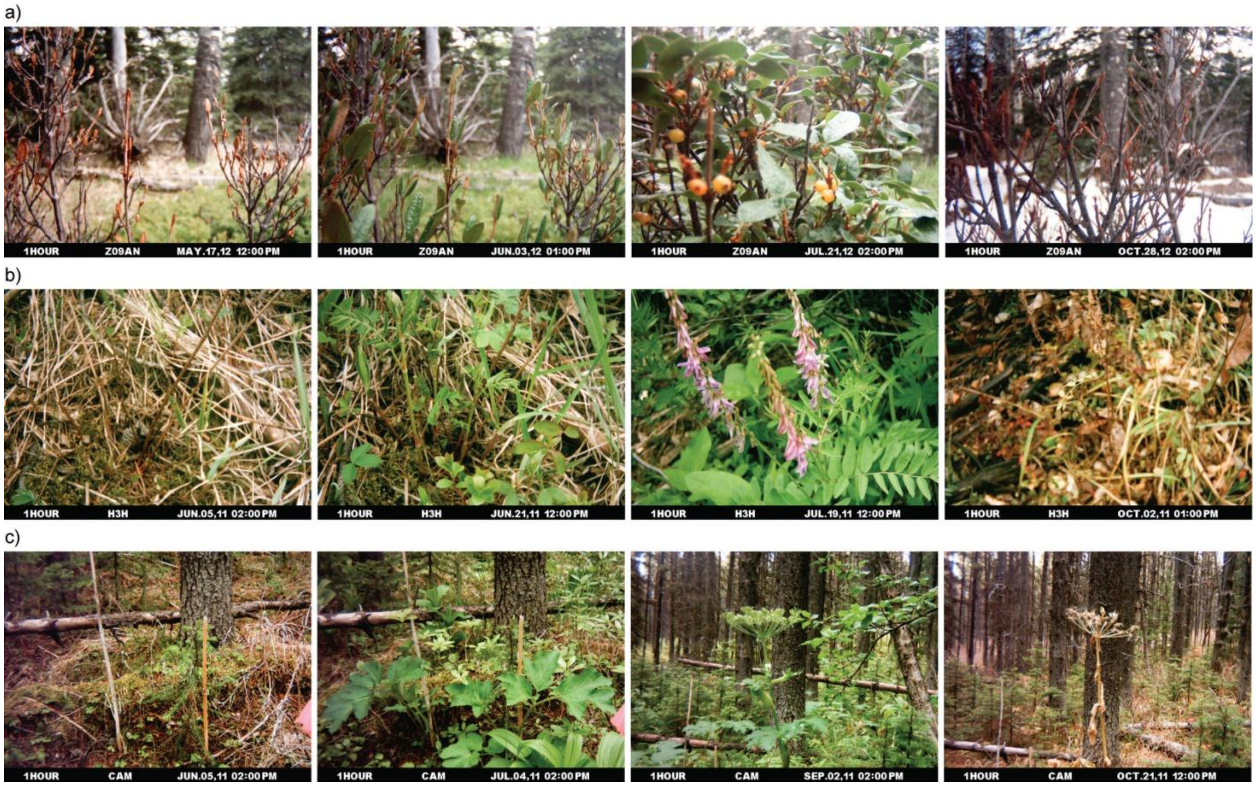

Figure 3. Select phenophases of the three focus species. a) *Shepherdia*, b) *Hedysarum*, and c) *Heracleum.*

Season 2, 2012

Field observations 2012 – The major focus of this field season was to make ground observations specific to building models between understory temperature (where the plants grow) and observations made by the satellite platform MODIS. Additional field sites were selected for this purpose, including a new transect in the Bow Valley. Sites are broad and flat to avoid topographic effects (shadow), with each site having continuous (as heterogeneous as possible) cover of a single forest type, which included: deciduous, coniferous, mixed, and all combinations of open and closed canopy. These sites were successfully characterized by ground crews who measured crown closure and trees species composition.

Every site in 2012 was monitored by phenology cameras observing *Shepherdia* only, for a few reasons: As mentioned earlier, observations of *Heracleum* and *Hedysarum* are difficult using phenology cameras due to their rapid growth, while *Shepherdia* is relatively stationary. The phenophases of *Shepherdia* are much more distinct than the other two species. When considering plant phenology in relation to grizzly ecology, all of these species provide critical nutrition. However the growth and developmental steps of *Heracleum* and *Hedysarum* are very broad, overlapping and difficult to categorize objectively. The marked 'pulses' when *Shepherdia* blooms, or berries ripen, provide temporally discrete anchors ideal for this type of modeling. This ultimately makes observation of *Shepherdia* phenology much more straightforward, and will increase the predictive accuracy of the resulting statistical models. Considering the goal of mapping GDD accumulations and the timing of key pheonological events across the extent of grizzly habitat in Alberta, the distribution of *Heracleum* and *Hedysarum* was found to be too dependent on topographic micro-features, such as moist depressions and gullies for *Heracleum*, and slopes and exposed ridges for

Hedysarum. *Shepherdia* has a much more consistent and broad distribution throughout a variety of habitats. Considering these practical observation concerns, limited observation seasons and equipment, all of the cameras were allocated to observations of *Shepherdia* in *season 2* (as well as forest canopy phenology for training the MODIS models). *Season 1* provided complete phenology datasets for both *Hedysarum* and *Heracleum* and phenological maps will be made for these species nonetheless.

Growth chamber observations 2012 – A new sample group of *Shepherdia* plants were dug and potted for a total of 35 individuals (twice the original number), 3 groups of 11 females for each experimental climate scenario, and an associated male in each group for pollination. The plants were set dormant naturally, and then stratified artificially in refrigerated warehouses (-5°C) at the Smoky Lake Nursery. The plants are currently growing under their respective climate regimes, and observations will continue for the remainder of *season 3* (2013). To maximize the sample population, only *Shepherdia* is being observed in the growth chambers. There is no field campaign for 2013 aside from temperature observations at the MODIS control site at the Suffield Base.

Manuscript: Temperature dependant development in *Shepherdia canadensis*.

As an initial inquiry, a predictive phenology model is being developed using existing phenological data collected by FRI biologists from 2008-2010. This manuscript is looking to predict the timing of phenophase events for *Shepherdia* at various elevations using broad-scale climate data from off-site meteorological stations. The explanatory variables include general GDD accumulations for the area, Julian day, and underlying climate signals from broad controllers such as the Pacific Decadal Oscillation and the El Nino Southern Oscillation. The model was unable to predict individual phenophase events, such as flowering or leaf out, but it was able to identify a developmental lag of nearly two weeks between the lowest (950m) and highest sites (1750m). This paper provides a foundation to develop the more refined, at-site GDD models that will be produced from the 2011 and 2012 phenology (and MODIS) observation data.

Deliverables

It is the intent of the research team that all work associated with this project will be published in peer reviewed scientific journals.

The goal of this research project is to develop a series of dynamic phenology maps of grizzly bear habitat in Alberta. These maps will assist managers in identifying the timing of particular nutritional events, define areas of critical habitat, assist in the calculation of carrying capacity, and provide a better understanding of available resources and energetics. The key deliverables are the results of obtaining the project objectives:

- Develop spatially explicit empirical models (phenology maps) displaying the seasonal development of critical grizzly bear foods: *Shepherdia Canadensis*, *Heracleum lanatum*, *Hedysarum alpinum* across grizzly habitat in Alberta (baseline phenology maps).
- Develop spatially explicit empirical models for *Shepherdia Canadensis*, displaying the spatio-temporal shift in phenophase under various climate change scenarios for both increasing and decreasing mean annual temperatures, as well as long term climate forecasts for the region.

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APPENDIX 1: LIST OF PROGRAM PARTNERS (1999 – 2012)

- Ainsworth Lumber Co. Ltd.
- Alberta Advanced Education and Technology - (formerly Innovation and Science)
- Alberta Conservation Association
- Alberta Environment and Sustainable Resource Development
- Alberta Fish & Game Association
- AB Innovates Biosolutions
- Alberta Newsprint Company
- Alberta Summer Temporary Employment Program
- 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 AllianceCanada (PTAC)
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  - (formerly Canadian Hunter Exploration Ltd.)
- Conservation Biology Institute
- Daishowa Marubeni International Ltd.
- Devon Canada Corp
- Enbridge Inc.
- Encana Corporation
- ENFORM
- Foothills Research Institute
  - (formerly FoothillsModelForest)
- Forest Resources Improvement Association of Alberta (FRIAA)
- G&A Petroleum Services
- GeoAnalytic Inc.
- Government of Canada
  - CanadianForest Service, Natural Resources Canada
  - Canadian Wildlife Service
  - Environment Canada – HSP
  - Human Resources and Skills Development Canada (CSJ)
  - Natural Sciences and Engineering Research Council of Canada (NSERC)
  - Parks Canada
    - BanffNational Park
    - JasperNational Park
- Grande Cache Coal Corporation
- Hinton Fish and Game Association
- Hinton Training Centre
- Husky Energy Inc.
- Komex International Ltd.
- Lehigh Inland Cement Limited
- Luscar Ltd.
- Gregg River Resources Ltd.
- Manning Diversified Forest Products Ltd.
- Manning Forestry Research Fund
- Millar Western Forest Products Ltd.
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- Mountain Equipment Co-op
- Nature Conservancy
- Natural Resources Canada
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- Petro Canada Ltd.
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- Precision Drilling Corporation
- Progress Energy Resources Corp
- Rocky Mountain Elk Foundation - Canada
- Shell Canada Limited
- Sherritt International – Coal Valley Resources
- Slave LakeDivision – Alberta Plywood
- SprayLake Sawmills Ltd.
- Suncor Energy Inc.
- Sundance Forest Industries Ltd.
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- World Wildlife Fund Canada
- Yellowstone to Yukon

APPENDIX 2: LIST OF PROGRAM PARTNERS (2012)

Alberta Innovates Biosolutions
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Alberta Summer Temporary Employment Program
Alberta Upstream Petroleum Research Fund
Canadian Cooperative Wildlife Health Centre
Canadian Natural Resources Limited
Canfor Forest Products
Conoco-Phillips
Devon Canada
Encana
Foothills Research Institute
Forest Resources Improvement Association of Alberta
Grande Cache Coal Corp
Human Resources and Skills Development Canada – Canada Summer Jobs
Husky Oil
Millar Western
Millennium – EMS solutions Ltd.
Natural Resources Canada
Parks Canada
Pembina Pipelines
Progress Energy Resources Corp.
Shell Canada
Sherritt International. – Coal Valley Resources Inc
Spray Lakes Sawmills
Suncor Energy
Sundance Forest Industries Ltd.
Talisman Energy
Teck Coal
TransCanada Pipelines
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University of British Columbia
University of Calgary
University of Victoria
West Fraser Ltd.
Weyerhaeuser Ltd
Yellowstone to Yukon

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