New Tools to Map, Understand and Track Landscape Change and Animal Health for Effective Management and Conservation of Species at Risk.
Innovation Program Project #06-025-SE
Progress Report

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CHAPTER 1: Introduction

The Alberta landscape continues to face pressures to meet societal needs. These needs include resource extraction activities (forestry, mining and oil and gas development) along with the mulitude of recreational activities that Albertans pursue on a year round basis. When viewed collectively these activities result in alteration to landscapes along the eastern slopes of Alberta. These areas are also home to grizzly bear populations which are a species widely recognized as an indicator of ecosystem health.

Our research team has focused efforts on developing new innovative products and techniques to investigate and understand the relationships between landscape structure, (human-caused) landscape change, and health in grizzly bears.

The results of this research effort will enable the Alberta government departments to make well informed and timely land use management decisions to maintain ecosystem health and to support sustainable development. Although this project focuses on Alberta grizzly bear populations the concepts, techniques and relationships uncovered can be applied to a variety of species at risk in Alberta and Canada. These leading edge innovative products and techniques will make Alberta a recognized world leader in ecosystem management and monitoring.

This interim report provides details of the progress of the research team during 2007. The final program report and complete data analysis will be provided in June 2008.

Working Hypothesis and Program Structure

Our research team initiated this program of study with the following working hypothesis:

"Rapid environmental change (mostly human-caused) can adversely affect performance of resident grizzly bear populations through long-term stress and impaired health in grizzly bears."

We have formed the following predictions from this working hypothesis:

a). Environmental change and condition are associated with long-term stress in grizzly bears.

b). Long-term stress is associated with impaired health (slow growth, failed reproduction, etc.) in grizzly bears.

c). Impaired health in individual grizzly bears is associated with poor population performance (lower reproductive and survival rates, decreased abundance).

In order to investigate these predictions we have divided our program into three key elements with leading scientific authorities directing integrated teams in the following areas:

Remote Sensing based habitat mapping to determine landscape structure and change (Lead Investigators: Dr. Steven Franklin and Dr. Greg McDermid)
This element will enhance geospatial tools to provide new map products for the monitoring of landscape structure over large geographic areas (>10,000 km^2) with particular emphasis on detecting changes that may be important to resident grizzly bears. These new map products will serve as the basis for the identification and management of key grizzly bear habitat in Alberta by resource managers.

Animal Health (Lead Investigators: Dr. David Janz, Dr. Marc Cattet, and Dr. Matt Viijan)
Within this program element the team will strive to develop a sensitive proteomics technique for detecting long-term physiological stress in grizzly bears based on analysis of expression profiles of multiple stress-activated proteins found in many body tissues. We will also develop Animal Health profiles for individual bears and attempt to determine relationships between long-term physiological stress and other measures of health (longevity, growth, reproduction, immunity, and activity) in grizzly bears.

Knowledge Transfer and Product Delivery (Lead: Gordon Stenhouse)
The scope and scale of delivering these new products and information to the numerous government departments and agencies is a key step within this program. It is our intention to not only provide digital files (maps, etc.) for each department but to also develop new GIS applications to enhance decision making and to provide the necessary training to enable new users to understand and maximize the use of these products in their work environments. Our research team feels that this program element is key to maximizing the benefits of this leading edge research undertaking.

CHAPTER 2: Program Activities and Achievements of 2007

Gordon Stenhouse and Karen Graham

Introduction

In order to gather the necessary samples from study animals we conduct an annual spring capture and collaring effort. This activity provides the needed animal health and movement data to relate to landscape conditions.

The 2007 grizzly bear spring capture session was the 9th conducted by the Foothills Model Forest Grizzly Bear Research Project. In 1999, our original study area encompassed 10,000 km^2 in an area south of Highway 16, between Edson and Jasper in the north and the Brazeau River in the south. In 2003 the study area expanded to include all of the grizzly bear range between the Berland River and the Montana border (62% of grizzly bear range in Alberta). In 2005, the study area expanded again to include areas between the Berland and Wapiti Rivers plus the Swan Hills. In 2006, the study area expanded northwards to include the Chinchaga River, The Hotchkiss River and the Meikle River area. We also included an area south of the Wapiti River and returned to the Swan Hills.

In 2007 our capture and collaring efforts were focused in 2 areas. We returned to the Kakwa and Nose Hill Tower areas of the Weyerhaeuser Forest Management Agreement area and the Clear Hills area north of Worsley which included the southern part of the Chinchaga area.

There were two primary purposes for capture and collaring grizzly bears in these areas. In the Clear Hills we wanted additional grizzly bear movement data for RSF (Resource selection function) map development for the north west portion of the province. In the Kakwa area our focus was to collect grizzly bear movement data that will relate to ongoing mountain pine beetle activities and ongoing forest management efforts in this area. Our research team has recently completed an RSF map product for the Kakwa area with grizzly bear location data obtained prior to mountain pine beetle activity in this area.

Tooth, blood and tissue samples collected from captured grizzly bears will be used to help understand population dynamics, assist in defining population units through genetic analysis, and track population health.

The goal of this years capture session was to deploy 15-20 GPS radio-collars on grizzly bears in these study areas. We also embarked on the first major deployment of new camera/sensor systems that were attached to our existing GPS collars. These new camera/sensor systems were being field tested to gather additional information on habitat use and detailed movement paths.

Study Area

Two capture areas were designated within the 2007 study area (Figure 1). These capture areas were as follows:

1. The Clear Hills area. (Figure 1)
2. The Kakwa and Nose Hill Tower area. (Figure 2)

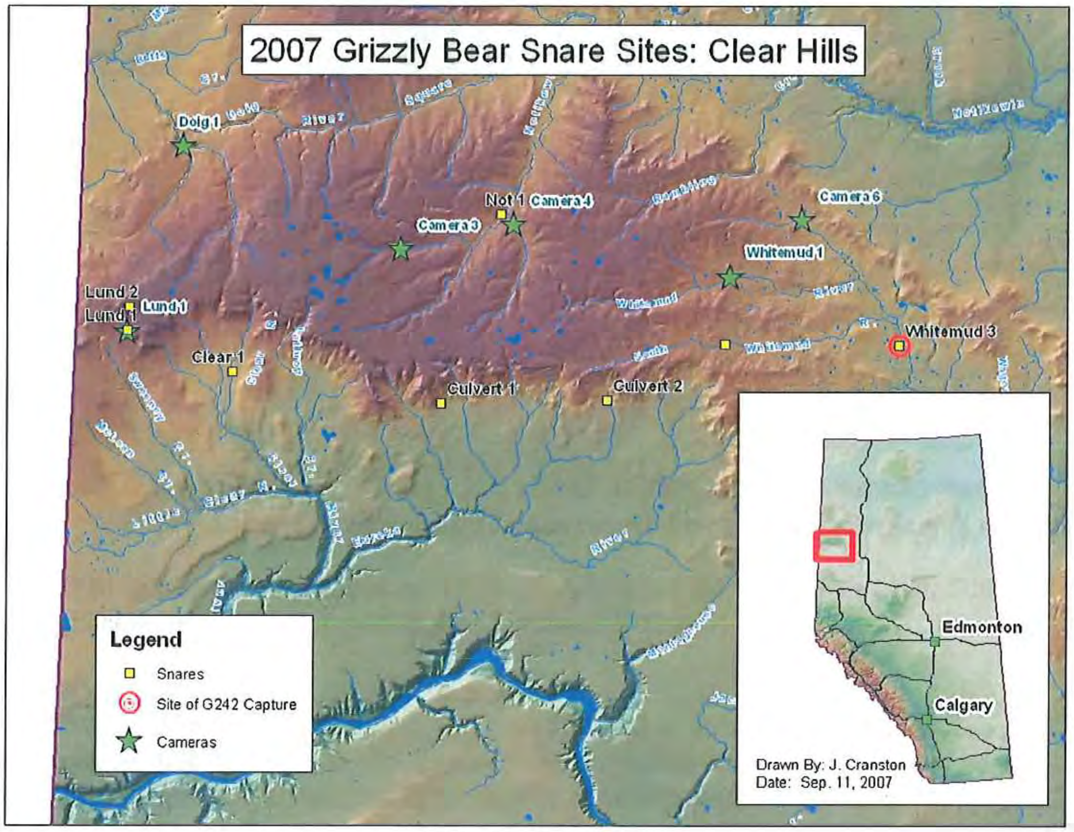

Figure 1. Clear Hills Capture area with site locations.

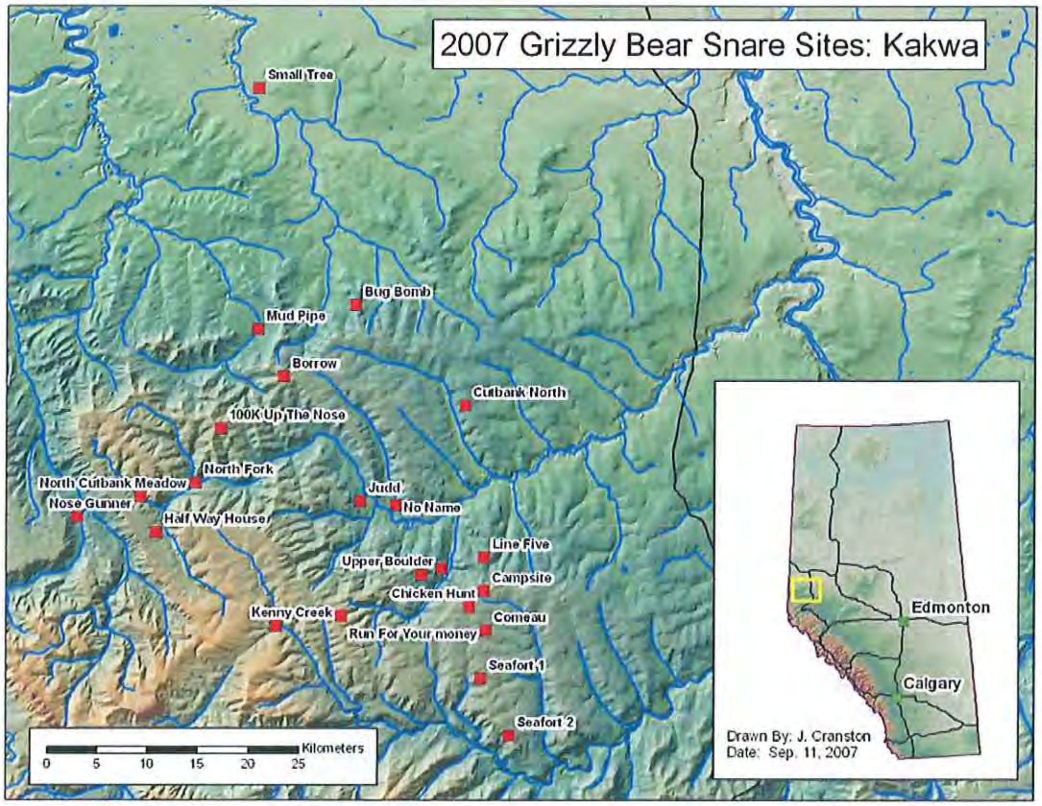

Figure 2. Kakwa and Nose Hill Tower capture area with site locations.

The 2007 study area comprised parts of provincial Bear Management Areas (BMAs) 1 (Clear Hills), and 2B (Kakwa and Nose Hill Tower). These BMAs make up approximately 66% of grizzly bear range in Alberta.

The population estimate for these BMAs, as of 2002, based on Alberta Fish and Wildlife Division projections, was 350 grizzly bears. This was 36% of the estimated Alberta grizzly bear population in 2002. These estimates of both range area and population size have not been empirically determined.

Methodology

Field capture efforts began in May this season. In May, capture operations were conducted by 1 helicopter-based crew (Clear Hills) and 1 ground-based crew (Kakwa Tower). Each crew consisted of biologists with experience in grizzly bear capture and a project Veterinarian. The Clear Hills team utilized an aerial snare line approach with daily checks on all active sites. Due to the forest cover and low elevation aerial darting was not possible. During this same time period the Kakwa based team worked exclusively along existing forest access roads to establish snaring sites.

On June 4th, after 4 weeks of continuous capture efforts, the helicopter crew moved to the Kakwa Tower area to allow capture efforts to expand beyond roaded areas. Primary capture efforts in the Kakwa were concluded at the end of June.

Bears were immobilized using a drug combination of Telazol and xylazine (XZT). The drugs were administered by rifle/pistol once the bear had been restrained in a snare, or culvert trap. Atipamazole was used to reverse the xylazine, after handling procedures were completed.

Once immobilized, grizzly bears were weighed, and measured (chest girth, zoological length, and straight-line length). Samples were collected (blood, hair, ear plug tissue and tooth). Radio-collar and ear tag transmitters were attached. Vital functions and blood-oxygen levels were monitored during the processing.

Black bears and other non-target species were marked with ear tags and released from the snare after immobilization. Vital conditions were monitored while these species were under anaesthesia but measurements and samples were not collected.

After administering the reversal, all bears were monitored until they became mobile.

As required by the Alberta SRD research permit conditions, all captured bears were checked within 24 hours of capture to ensure that they had recovered from immobilization and handling procedures.

Results

Capture Locations

In total, 14 grizzly bears and 13 black bears were captured this trapping season. Of the grizzly bear captures, only 1 was caught in the Clear Hills capture area, while 13 were caught in the Kakwa capture area (Table 1). One bear, G267 was a bear that was relocated to the Sheep Creek area in August and was collared to collect additional movement information.

Table 1. Grizzly bears captured in each capture area 2007.

Capture Area	Captured Grizzly Bear IDs
Clear Hills	G242
Kakwa Tower	G222, G223, G224, G226, G238, G260, G261, G262, G263, G264, G265, G266, G267

Sex and Age Characteristics

Of the 14 grizzly bears captured, 9 (64%) were adults, 5 (36%) were sub-adults, Nine (64%) were males and 5 (36%) were females (Table 2). Adult males made up the largest component of captured grizzly bears (50%) while sub-adult males, adult females, and sub-adult females comprised 14%, 14%, and 21% of captured grizzly bears respectively. No cubs of the year or yearlings were caught.

Table 2. Sex and age of captured grizzly bears.

Grizzly Bear IDs	Area	Age	Sex
G222	Kakwa	Adult	Male
G223	Kakwa	Adult	Female
G224	Kakwa	Sub-adult	Female
G226	Kakwa	Adult	Male
G238	Kakwa	Sub-adult	Female
G260	Kakwa	Adult	Female
G261	Kakwa	Adult	Male
G262	Kakwa	Adult	Male
G263	Kakwa	Adult	Male
G264	Kakwa	Adult	Male
G265	Kakwa	Sub-adult	Female
G266	Kakwa	Sub-adult	Male
G267	Kakwa	Sub-adult	Male
G242	Clear Hills	Adult	Male

Of the 2 captured adult females, only G223 was observed with dependant young (3 cubs).

Capture Type

Capture types were categorized as ground capture with snare, ground capture with culvert trap or helidarted. Most ground capture sites used snares in 3 different formats, pail sets, cubby sets and/or trail sets. Three new lightweight aluminum culvert traps were deployed.

Of the 16 capture events (G223 and G260 were captured twice)(Table 3), helicopter captures accounted for 6.25% (1) of captures events and ground captures accounted for 93.75% (15) of capture events. Fourteen ground-capture events involved snares and 1 involved a culvert trap.

Table 3. Grizzly bear capture types.

Grizzly Bear IDs	Capture Type	Grizzly Bear ID	Capture Type
G222	Snare	G261	Snare
G223	Snare	G262	Snare
G223 2nd capture	Helidart	G263	Snare
G224	Snare	G264	Snare
G226	Snare	G265	Snare
G238	Culvert	G266	Snare
G260	Snare	G267	Snare
G260 2nd capture	Culvert	G242	Snare

Telemetry

Fourteen radio-collars were deployed. All grizzly bears were tagged with an ear-tag transmitter. Radio-collars deployed consisted of 3 types, Tellus (including new UHF model), ATS GPS and Telonics Argos GPS. Tellus collars collect locations on the following schedule:

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

All radio-collars were outfitted with a remote release mechanism and all collars were equipped with a rot-off system as a backup in case of electronic failure.

G223s collar was replaced when she was caught the second time.

Status of Captured Grizzly Bears
Table 4 lists status of collared grizzly bears as of mid-September 2007.

Table 4. Status of 2006 research grizzly bears as of January 2008.

Grizzly Bear IDs	Fate as of January 2008
G222	Last heard 03 July 2007, collar pulled off after 24 hours.
G223	Alive, collar working.
G224	Alive, collar beaconing but not uploading.
G226	Alive, collar malfunctioned. Dropped and retrieved.
G238	Alive, collar working.
G260	Alive, collar working.
G261	Last heard 14 August 2007. Collar pulled off after 4 days.
G262	Last heard 14 August 2007
G263	Last heard 08 June 2007. Collar pulled off after 3 days.
G264	Last heard Sept 2007
G265	Alive, collar working
G266	Alive, collar working
G267	Alive, collar working.
G242	Last heard 16 June 2007.

Capture Related Mortalities
There were no capture related mortalities of either grizzly or black bears this year.

Black Bears
A total of 14 black bears were captured (7 in the Kakwa Tower area and 7 in the Clear Hills area). Adult males constituted the largest number of captured black bears (62%). adult females, and sub-adult males comprised 31% and 8% of captured black bears respectively. No cubs of the year, yearlings or sub-adult females were captured. Male/female percentages of captured black bears were 69/31 and adult/sub-adult percentages were 92/8. One black bear was caught in a culvert trap and released without handling therefore age and sex of this bear could not be determined.

Table 5. Black bear captures by sex and age classifications.

Kakwa Tower area					
Sex	Cub of the Year	Yearling	Sub-adult	Adult	Total
Male	0	0	1	3	4
Female	0	0	0	3	3
Total	0	0	1	6	7
Clear Hills area					
Male	0	0	0	5	5
Female	0	0	0	1	1
Total	0	0	0	6	6

Grizzly Bear Vs. Black Bear Captures

The numbers of grizzly bears vs. black bears captured have varied between years and areas (Table 6).

Table 6. Number of grizzly bears vs. black bears captured by year.

Year	Grizzly Bears	Black Bears	Total
1999	24	5	29
2000	25	13	38
2001	29	10	39
2002	28	5	32
2003	28	14	42
2004	25	25	50
2005	23	22	45
2006	15	38	53
2007	14	14	28

GPS Location Data

Our research team continued to collect grizzly bear movement data from collared animals up to the time of denning, which occurred this year during the first week of December. Using the exact locations of den sites we have also established weather monitoring stations at a number of grizzly bear dens to collect microsite weather data to relate to temperature data being collect from collars in dens. The objective of this data collection effort is to further investigate possible den emergence over the winter months.

Clear Hills – additional data

Since our capture success in the Clear Hills was very limited (for a second consecutive year) we undertook an effort to gather additional data on the possible distribution and number of grizzly bears in this area. In June prior to the crew departing this area, we established 6 large bait sites where we positioned remote camera systems to take pictures of all activities that would occur at these sites during a one month period (June). We now have recovered these data sets and they are being processed and reviewed. Should opportunities arise this fall to capture additional bears in this area our research team will attempt to deploy additional GPS collars.

Vegetation and Diet Data Collection

Research personnel worked in the field between May 1 and September 15, 2007 to collect comprehensive grizzly bear habitat use information and track human industrial activity. This work occurred within Weyerhaeuser Grande Prairie Forest Management Agreement Area south west of Grande Prairie, Alberta. Our vegetation sampling strategy was to visit one female grizzly bear GPS location per bear use day paired with an associated random location throughout the field season. Data collected at GPS locations included a detailed inventory of forest floor and under story vegetation, forest composition and structure, canopy cover measurements, distribution and abundance of grizzly bear foods, identification of grizzly bear and other wildlife sign, presence of human activity, habitat classification according to our remote sensing mapping criteria, and grizzly bear scat collection. Field personnel visited additional GPS locations to collect grizzly bear activity (feeding or bedding) information for those individuals using habitats in proximity to major road networks or where other industrial activities were occurring.

Scat collection and analysis followed protocols established by the Foothills Model Forest Grizzly Bear Research Program used in previous field seasons. One scat per bear use day collected throughout the field season was analyzed for content based on our ability to positively identify food matter. The percent volume of discernable food items was quantified to determine their seasonal importance value. This information will be used to link seasonally important grizzly bear foods to specific habitat attributes and model the distribution of these resources across the study area.

During the summer of 2007, 50 permanent berry plots were set-up in the Kakwa study area. These plots were built in an effort to assess yearly berry abundance and variations. Five key berry species were recognized as important bear foods (*vaccinium membranaceum, vaccinium myrtilloides, vaccinium caespitosum, vaccinium vitis-idea, and shepherdia Canadensis*) and at least 10 berry plots were set-up per species (more than one species can occur in a particular plot). In order to reduce environmental variations, plots were only set-up in the 2 most abundant habitat types within the study area (conifer forests and regenerating stands). Furthermore, to reduce variations caused by aspect, plots were positioned on slopes of less than 10°. Berry plots were visited at least once in August and September to assess berry production and timing. Once most berries within a plot were ripe, they were picked and weighted for biomass production. All plots will be revisited consistently within the next few years to assess yearly variations.

In order to assess berry species abundance and variation over the landscape, random locations were visited within conifer and regenerating stands. Locations with and without berry species were marked and a percentage of plant cover was determined if key species occurred. Once a significant number of locations are visited, an accurate measure of berry species availability over the landscape will be derived.

The habitat use information collected this field season will be used as part of our on-going effort to generate habitat classification maps. It will also be used to create and validate a Resource Selection Function model which is the probability of occurrence of grizzly bears within specific habitat types. We can then assess the current state of the landscape for grizzly bears and make predictions regarding habitat quality and quantity and if industrial activity or natural factors such as Mountain Pine Beetle and forest fires alter portions of the land base.

CHAPTER 3: Landscape Change in the Grizzly Bear Health Study Area (BMAs 3 and 4): 1998 to 2005

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Introduction

Increasing levels of human activity in west-central Alberta surrounding the timber, coal, and petroleum industries have lead to widespread growth in anthropogenic disturbance features on the landscape, and corresponding changes in land cover structure and composition. A primary goal of the mapping team in this project has involved the accurate detection, mapping, and quantification of human-induced landscape changes at a temporal resolution matching our grizzly bear health and stress data sets as closely as possible. We employed satellite imagery and change-detection procedures to generate spatially-explicit layers of land cover, vegetation, and various anthropogenic disturbance features across the Health Study Area covering BMAs 3 and 4, then quantified their annual levels and trajectories using a variety of summary statistics. An overview of these activities and their results are summarized briefly below.

Methods

We acquired a series of 22 Landsat Thematic Mapper and Enhanced Thematic Mapper Plus images to track annual change patterns across the study area from 1998 to 2005 (Table 1). Linear disturbance features (roads, pipelines, rail) were mapped primarily through manual digitizing and update of available GIS layers, while area-based features (cut blocks, mines, wellsites) were delineated primarily through change detection of co-registered remote sensing imagery. Binary change masks were created by thresholding Tasseled Cap (Crist and Cicone 1984) wetness difference images from the *base* 2003 Landsat imagery following the enhanced wetness difference index method of Franklin et al. (2001). Spectral and topographic values from within the *change* areas were imported to Definiens Professional 5.0 and segmented for further processing. We used a series of logical decision rules to classify the change objects into human disturbance categories: roads, cutblocks, wellsites, pipelines, and mines. Annual disturbance layers were visually inspected and manually corrected where necessary. Disturbance objects were then exported from Definiens Professional to ArcMap 9.2, transformed to land cover classes using decision rules (e.g. road features = barren; pipelines = herbaceous), and spatially mosaicked to create annual update layers. Finally, we overlaid the annual update layers on the co-registered 2003 base land cover map to generate updated land cover products for each year of interest (see samples in Figure 1).

The thematic accuracy of the change features were assessed at two levels: (i) change identification, and (ii) change labeling. Change identification assessed our ability to accurately separate *change* areas from *no change*, using 178 test points evaluated through manual interpretation of temporally-coincident, high-spatial-resolution orthophotos. Change labeling accuracy was determined with an additional 256 test points distributed in a stratified random sample, allocated proportionally. Results of the accuracy assessment suggested efficient thematic performance of the procedure, both in the identification (100% overall accuracy; Kappa=1.0) and labeling (93% overall accuracy; Kappa=0.889) of change features, lending good confidence to the quality of the resulting map products.

A spatio-temporal analysis of landscape structure from the period 1998 to 2005 was conducted using Fragstats 3.3. We derived the landscape metrics Mean Patch Size, Mean Nearest Neighbor Distance, and Edge Density from the ten-class landcover map for each year of interest. The same metrics were also derived from a class perspective to track the patterns of forest/non-forest through time.

Table 1: Landsat scenes acquired and processed for quantifying human disturbance, land cover, and landscape structure from 1998 to 2005.

Landsat Path/Row	Image Acquisition Date	Sensor
45/23	September 5, 1998	Landsat 5 TM
	September 8, 1999	Landsat 5 TM
	August 17, 2000	Landsat 7 ETM+
	September 14, 2001	Landsat 7 ETM+
	August 23, 2002	Landsat 7 ETM+
	September 3, 2003	Landsat 5 TM
	August 12, 2004	Landsat 7 SLC-Off
	July 22, 2005	Landsat 5 TM
44/23	August 29, 1998	Landsat 7 ETM+
	August 24, 1999	Landsat 7 ETM+
	September 27, 2000*	Landsat 7 ETM+
	September 14, 2001	Landsat 7 ETM+
	June 13, 2002	Landsat 7 ETM+
	July 10, 2003	Landsat 5 TM
	August 13, 2004	Landsat 5 TM
	September 13, 2005	Landsat 5 TM
4324	June 22, 2002	Landsat 7 ETM+
	June 17, 2003	Landsat 5 TM
	June 19, 2004	Landsat 5 TM
	August 25, 2005	Landsat 5 TM
4424	2002 N/A	-
	July 10, 2003	Landsat 5 TM
	2004 N/A	-
	September 17, 2005	Landsat 5 TM

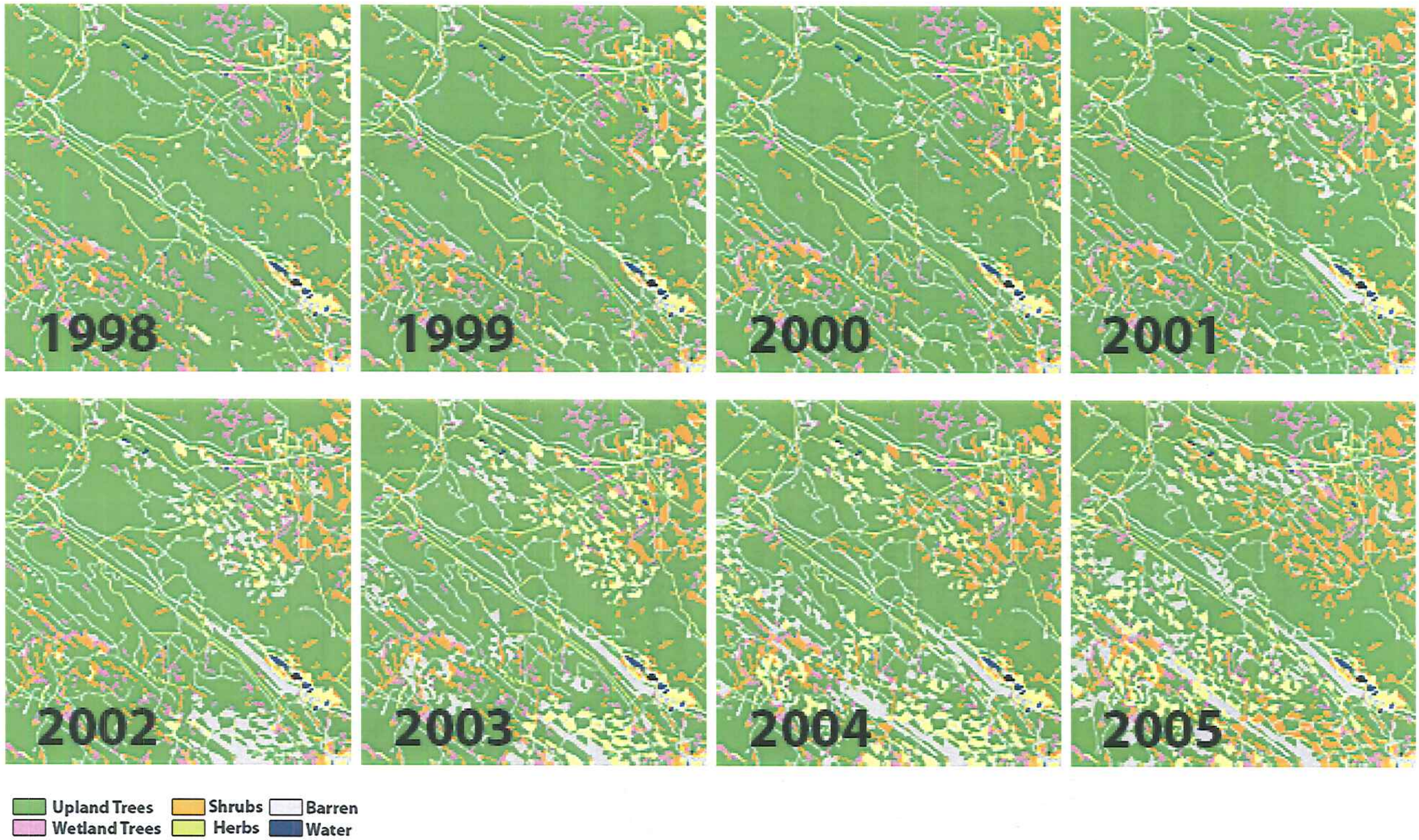


Figure 1: Samples of changing land cover over a small portion of the Health study area, 1998 to 2005.

Human Disturbance Features 1998-2005

A summary of the amounts, densities, and proportions of key human disturbance features across the Health Study Area for the time period 1998 to 2005 can be found in Table 2. These same trends are shown graphically in Figure 2. It is important to note, however, that that the estimates from 1998 to 2001 were derived exclusively from the North Health study area, while those from 2002 to 2005 were derived from the North and South Health study areas combined. The changing base areas over which estimates were summarized reflects the varying spatial extents over which grizzly bear health and stress data were available. Grizzly bear captures in the North Health study area (BMA 3) span the years 1998 to 2005, while those in the South Health study area (BMA 4) range only from 2002 to 2005. This changing base area leads to a number of apparent incongruities when values are summarized across the entire study area. For example, at this scale, pipeline density appears to drop from 0.138 km/km^2 in 2001 to 0.127km/km^2 in 2002. However, the pattern merely reflects the incorporation of new areas in BMA 4 from 2002 onward, where pipeline densities (and other disturbance features) are generally lower. These apparent anomalies only appear in metrics summarized at very broad scales, and do not affect subsequent statistical analyses taking place at the individual home-range scale.

For each year, we observed substantial increases in human disturbance features, clearly reflecting the growing impact of fast-developing resource extraction industries in west-central Alberta grizzly bear habitat. A brief summary of each disturbance element is presented in the following subsections.

Table 2: A summary of road density, cutblock proportion, wellsite density, pipeline density, and mine area across BMAs 3 and 4 from 1998 to 2005. Please note that estimates from 1998 to 2001 were derived from the North Health study area, while those from 2002 to 2005 were derived from the North and South Health study areas combined.

Year	Road Density (km/km^2)	Cutblock Proportion (%)	Wellsite Density (#/km^2)	Pipeline Density (km/km^2)	Mine Area (km^2)
1998	0.35	2.04	0.09	0.126	1.10
1999	0.36	2.33	0.10	0.130	1.10
2000	0.37	2.64	0.11	0.136	3.50
2001	0.39	2.97	0.12	0.138	6.58
2002	0.42	3.03	0.11	0.127	10.64
2003	0.44	3.36	0.12	0.129	12.20
2004	0.44	3.68	0.13	0.131	14.26
2005	0.45	4.04	0.14	0.132	15.73

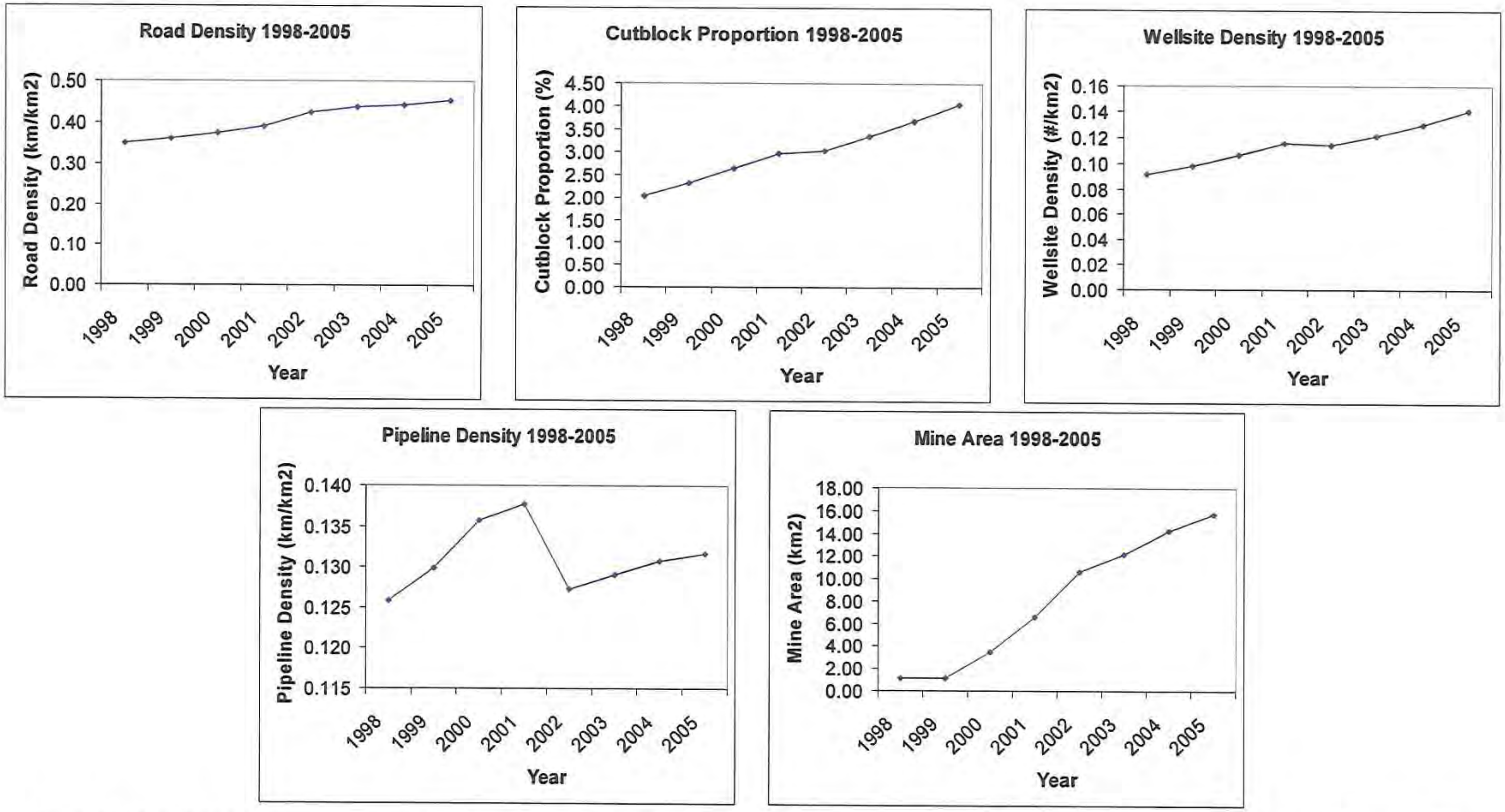


Figure 2: Trends in road density, cutblock proportion, wellsite density, pipeline density, and mine area across BMAs 3 and 4 from 1998 to 2005. Please note that estimates from 1998 to 2001 were derived from the North Health study area, while those from 2002 to 2005 were derived from the North and South Health study areas combined.

Roads and Road Density

Road density changed from 0.35km/km^2 in 1998 to 0.45 km/km^2 in 2005 (Table 3): an increase of more than 28%. We documented an average annual increase of approximately 100m/km^2 over the time period examined. The total length of roads mapped over the Health Study Area (BMAs 3 and 4) was 26,357 km in 2005.

Table 3: Road length, change in road length, road density, and change in road density from 1998 to 2005. Please note that estimates from 1998 to 2001 were derived from the North Health study area, while those from 2002 to 2005 were derived from the North and South Health study areas combined.

Year	Length (km)	Δ Length (km)	Density (km/km^2)	Δ Density (km/km^2)
1998	13377.4	-	0.35	-
1999	13794.1	416.9	0.36	0.01
2000	14351.3	557.2	0.37	0.01
2001	14959.3	608.0	0.39	0.02
2002	24560.6	9601.3	0.42	0.03
2003	25361.9	801.3	0.44	0.01
2004	25640.2	278.3	0.44	0.00
2005	26357.0	716.8	0.45	0.01

Cutblocks and Proportion of Study Area Covered by Cutblocks

The proportion of the study area that is covered by cut blocks changed from 2.04% in 1998 to 4.04% in 2005 (Table 4): an increase of about 98%. The rate of average proportional increase was calculated at 0.29%, with total cut block coverage in the study area exceeding 2300 km^2 in 2005.

Table 4: Cutblock area, change in cutblock area, proportion of study area covered by cutblock, and change in proportion of study area that is cutblock from 1998 to 2005. Please note that estimates from 1998 to 2001 were derived from the North Health study area, while those from 2002 to 2005 were derived from the North and South Health study areas combined.

Year	Area (km^2)	Δ Area (km^2)	Proportion (%)	Δ Proportion (%)
1998	780.9	-	2.04	-
1999	891.5	110.6	2.33	0.29
2000	1012.0	120.5	2.64	0.32
2001	1136.6	124.6	2.97	0.32
2002	1760.4	632.8	3.03	0.06
2003	1951.5	191.1	3.36	0.33
2004	2137.5	186.0	3.68	0.32
2005	2347.0	209.5	4.04	0.36

Wellsites and Wellsite Density

The density of wellsites occurring in the study area changed from 0.09/km^2 in 1998 to 0.14/km^2 in 2005 (Table 5): an increase of about 56%. The rate of average change in wellsite density over the entire study area was calculated at 0.007 wellsites/km^2, with the total number of wellsites estimated at 8,162 in 2005.

Table 5: Number of wellsites, change in number of wellsites, wellsite density, and change in wellsite density from 1998 to 2005. Please note that estimates from 1998 to 2001 were derived from the North Health study area, while those from 2002 to 2005 were derived from the North and South Health study areas combined.

Year	Number	Change	Density (#/km^2)	Δ Density (#/km^2)
1998	3482	-	0.09	-
1999	3749	267	0.10	0.007
2000	4057	308	0.11	0.008
2001	4431	374	0.12	0.010
2002	6612	2181	0.11	-0.002
2003	7038	426	0.12	0.007
2004	7524	486	0.13	0.008
2005	8162	638	0.14	0.011

Pipelines and Pipeline Density

Pipeline density changed from 0.126 km/km^2 in 1998 to 0.132 km/km^2 in 2005 (Table 6): an increase of about 5%. We documented an average annual increase of approximately 10m/km^2 over the time period examined. The total length of pipelines mapped over the Health study area (BMAs 3 and 4) was 7,650 km in 2005.

Table 6: Pipeline length, change in pipeline length, pipeline density, and change in pipeline density from 1998 to 2005. Please note that estimates from 1998 to 2001 were derived from the North Health study area, while those from 2002 to 2005 were derived from the North and South Health study areas combined.

Year	Length (km)	Δ Length (km)	Density (km/km^2)	Δ Density (km/km^2)
1998	4819.7	-	0.126	-
1999	4977.0	157.3	0.130	0.004
2000	5200.4	223.4	0.136	0.006
2001	5278.0	77.6	0.138	0.002
2002	7400.3	2122.3	0.127	-0.010
2003	7501.1	100.8	0.129	0.002
2004	7598.1	97.0	0.131	0.002
2005	7650.5	52.4	0.132	0.001

Mine Area

The total amount of mine area changed from 1.10 km^2 in 1998 to 15.73 km^2 in 2005 (Table 7): a 13-fold increase. We documented an average annual change of approximately 2 km^2 over the time period examined. The total mine area mapped over the Health study area (BMAs 3 and 4) was 15.73 km^2 in 2005.

Table 7: Mine area and change in mine area from 1998 to 2005. Please note that estimates from 1998 to 2001 were derived from the North Health study area, while those from 2002 to 2005 were derived from the North and South Health study areas combined.

Year	Area (km^2)	Δ Area (km^2)
1998	1.10	-
1999	1.10	0.00
2000	3.50	2.40
2001	6.58	3.08
2002	10.64	4.06
2003	12.20	1.56
2004	14.26	2.06
2005	15.73	1.47

Landscape Structure 1998-2005: Regional Scale

A summary of the selected landscape metrics tabulated across the Health Study Area for the time period 1998 to 2005 can be found in Table 8. These same trends are shown graphically in Figure 2. In all cases, the metrics seem to indicate a pattern of increased fragmentation that one would expect from the transition of large natural forest patches to roads, cutblocks, wellsites, and other human disturbance features. Edge density – linear distance of edge per unit area of landscape – changed from 43.7 m/ha in 1998 to 48.5 m/ha: an increase of 11%. Over the same time period, mean patch size changed from 42.0 ha to 37.1 ha: a decrease of 12%. Mean nearest neighbour – a measure of edge-to-edge distance – changed from 271 m in 1998 to 244m in 2005: a decrease of 10%.

Table 8: Edge density, mean patch size, coefficient of variation of mean patch size, mean nearest neighbour, and coefficient of variation of mean nearest neighbour from 1998-2005.

Year	Edge Density (m/ha)	Mean Patch Size (ha)	CV of Mean Patch Size (ha)	Mean Nearest Neighbour (m)	CV of Mean Nearest Neighbour (m)
1998	43.7	42.0	3416	271	233
1999	44.3	41.5	3434	269	234
2000	45.0	40.8	2457	265	235
2001	45.6	40.1	2449	261	237
2002	46.2	29.5	3462	257	238
2003	47.0	38.7	3532	253	239
2004	47.6	38.1	3436	250	241
2005	48.5	37.1	3425	244	242

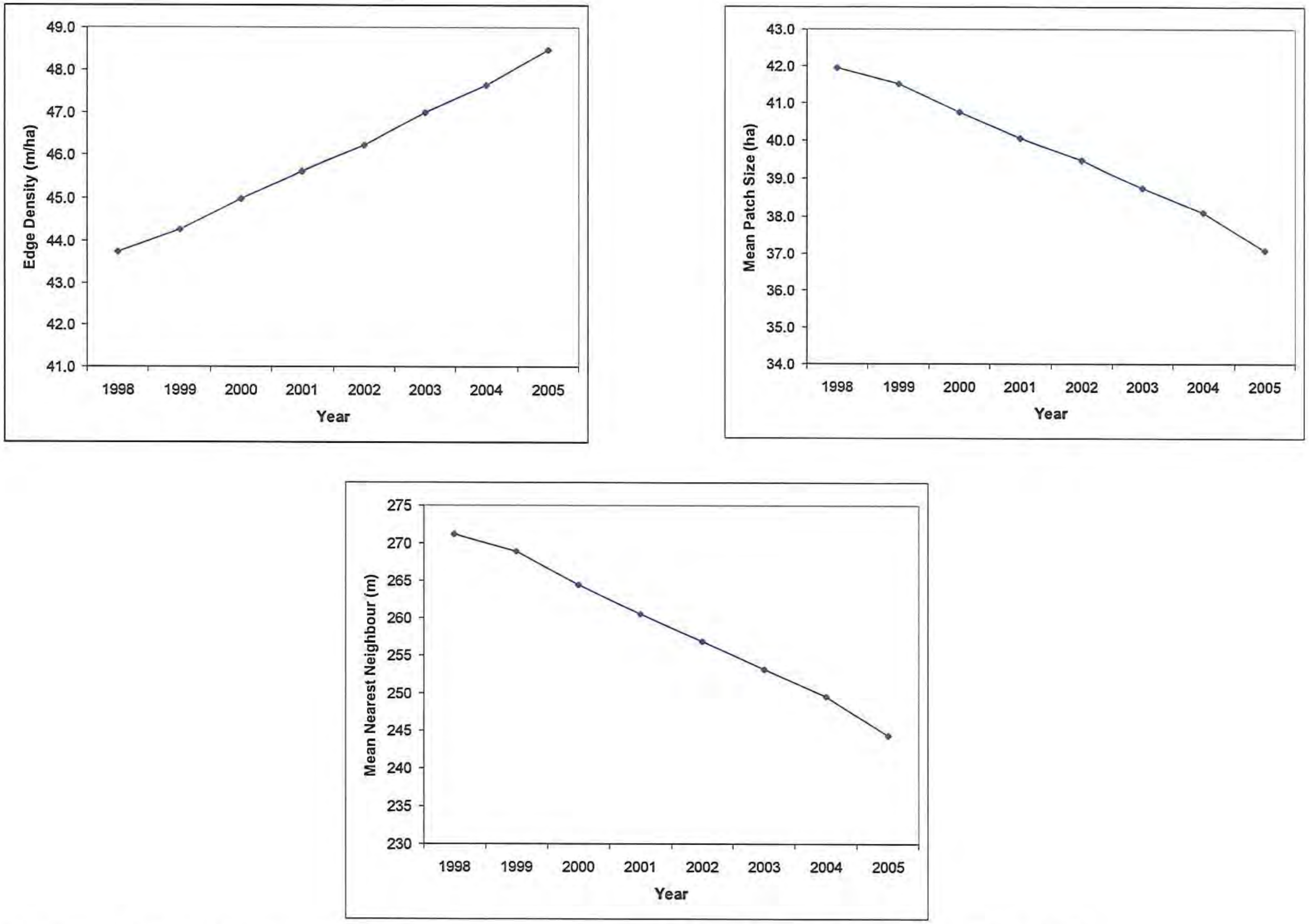


Figure 3: Trends in edge density, mean patch size, and mean nearest neighbour in BMAs 3 and 4 from 1998 to 2005.

Landscape Structure 1998-2005: Local Scale

In order to investigate the range of trajectories in landscape structure observed across time at the local scale, we selected three 13x13 km^2 case study areas from the Health study area selected to represent low (Area 1), moderate (Area 2), and high (Area 3) levels of change (Figure 3).

As expected, landscape structure and conditions displayed significant spatial variability across the study area, both in terms of their mean annual amounts of change (Table 9) and structural trajectories over time (Figure 3). The mean annual area of forest change varied from 38.5 hectares distributed across 3.2 new patches per year in Area 1 to 322.3 hectares distributed across 21.3 new patches per year in area 3. Annual trends over time revealed consistent increases in edge density and decreases in mean patch size (Figure 3). Despite the wide range of cumulative loss of forested areas, the selected landscape metrics appear fully capable of tracking logically-consistent patterns of landscape structure over time, efficiently revealing the changing patterns of land cover associated with increasing human activities.

Table 9: Temporal occurrence and mean annual amounts of forest change patches across the three selected 13 x 13 km case study areas, reflecting low, moderate and high levels of change.

	Occurrence of Annual Forest Change Patches		Annual Amount of Forest Change Patches	
Case Study Area	**Number of Years (n)**	**Time Frame (Years)**	**Mean Annual Area of Change (ha)**	**Mean Number of Change Patches (n)**
1 – Low Change	4	1998-2000; 2001-2003	38.5	3.2
2 – Moderate Change	7	1998-2005	252.5	10.6
3 – High Change	7	1998-2005	322.3	21.3

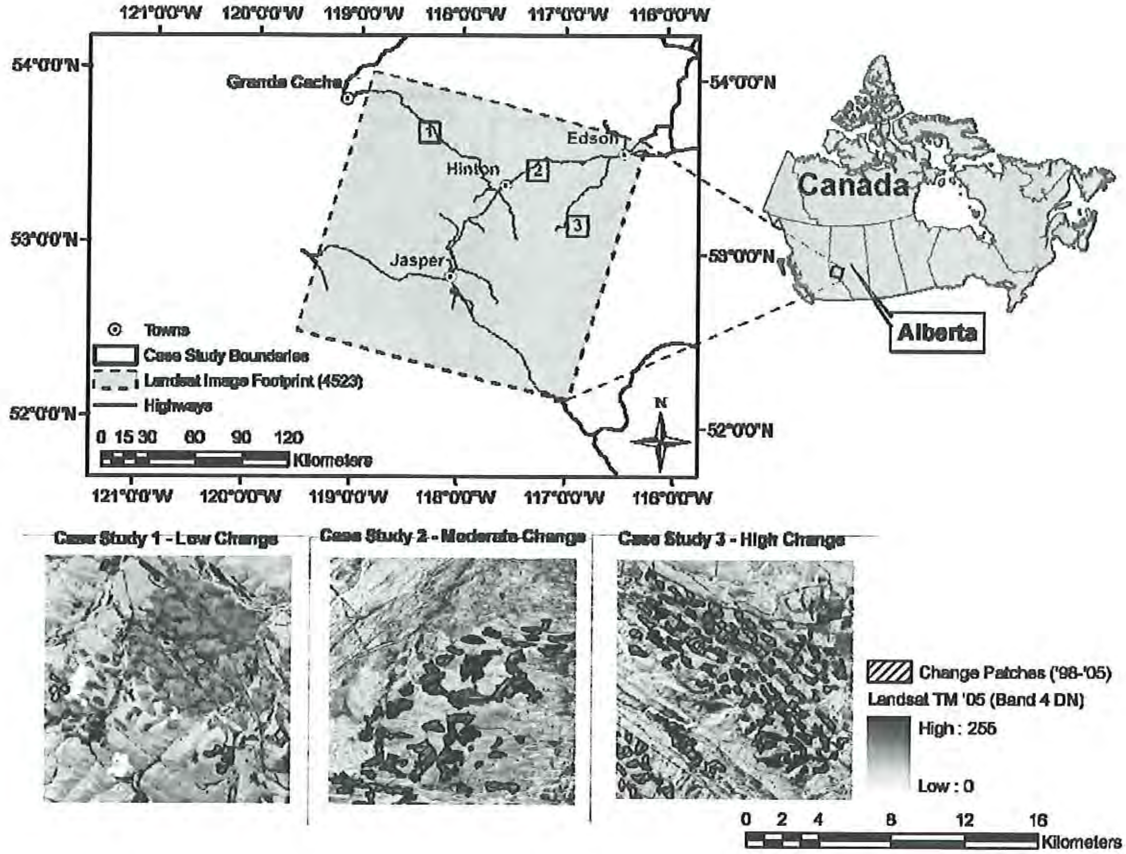


Figure 4: Location of the three 13 x 13 km case study areas in the North Health study area, representing three levels of relative land cover change between 1998 and 2005.

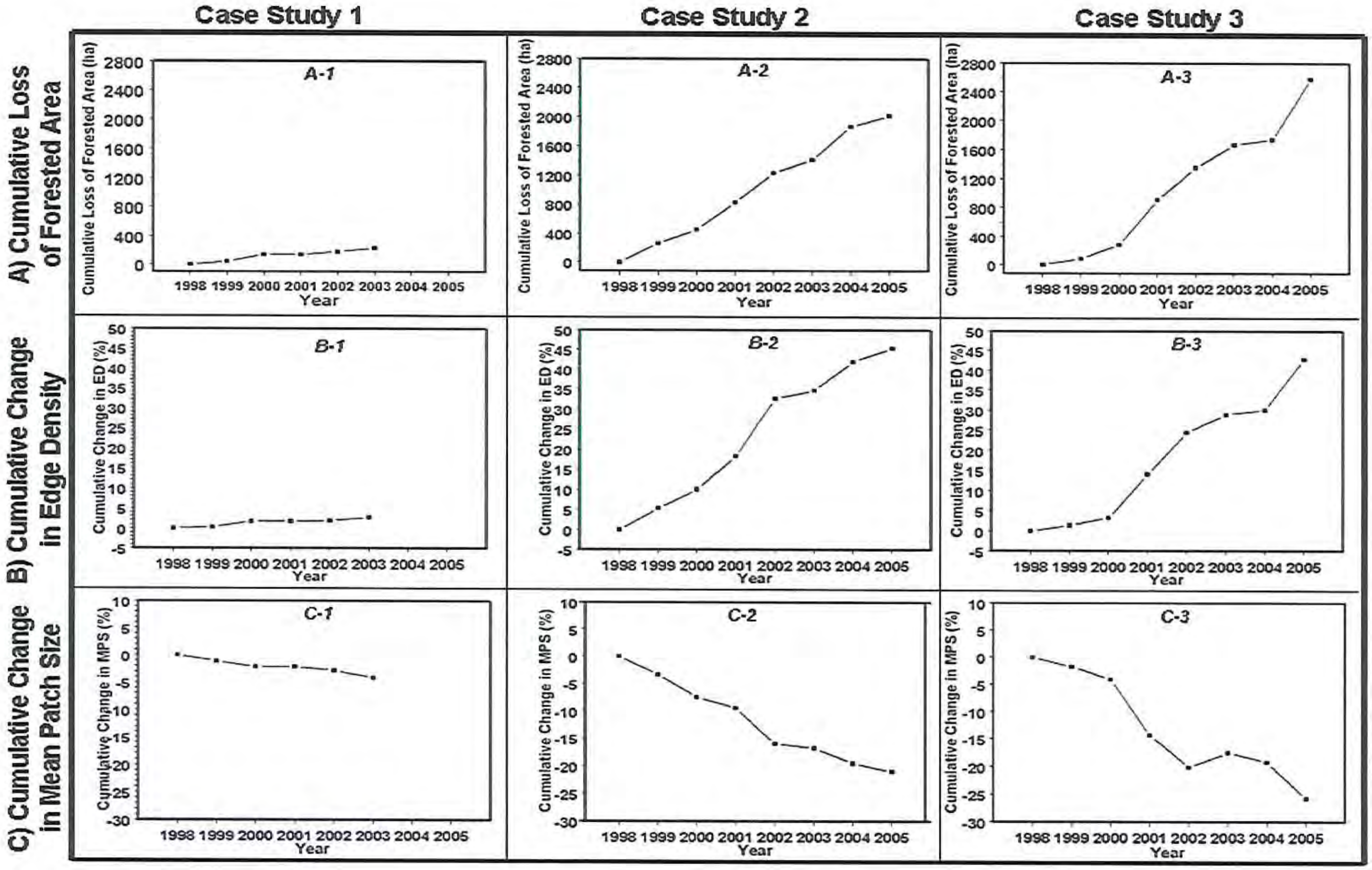


Figure 5: Cumulative change in A) forest area (i.e. forest loss), B) percent edge density, and C) mean patch size, between the years 1998 and 2005 in three case study areas of low (case study 1), moderate (case study 2), and high (case study 3) annual mean forest change.

CHAPTER 4: Geographic Information System (GIS) Progress Report

Jerome Cranston

Introduction

The objective of the GIS component of this study was to summarize the environmental conditions encountered by each grizzly bear prior to its capture, including measures of anthropogenic landscape change.

Understanding the relationships between grizzly bear health and environmental conditions requires not only quantifying landscape attributes over the specific areas experienced by a grizzly bear, but modeling them as they existed at a particular time. Given the rapid changes in grizzly bear habitat caused by industrial activity, and the long period of time over which health data has been collected (1999-2006), it was essential to match environmental conditions to a particular period of interest.

For this analysis we modeled landscape conditions for a 55,000 km^2 portion of grizzly bear range over an eight-year period to correspond to grizzly bear health and activity profiles from radio collared grizzly bears (Fig. 1). We selected two Grizzly Bear Population Units where there is genetic evidence to indicate that these units (BMA's) represent two genetically distinct population units. These BMA's were selected as they represented two populations where we had the most comprehensive and long term data set on health and movement characteristics.

Four sets of environmental condition summaries have been performed.

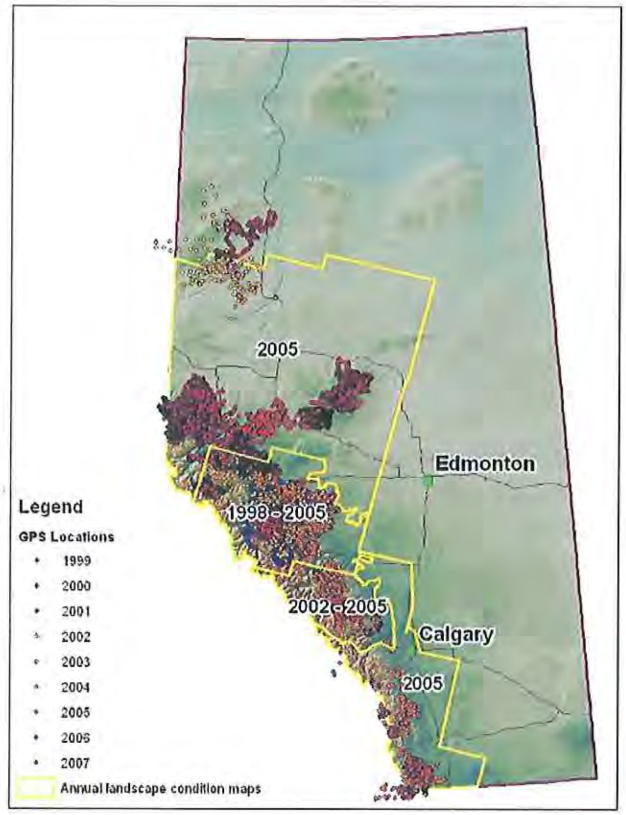


Figure 1. Area and time frame for the annual landscape conditions maps created for the health analysis.

Methods and Results

Analysis 1: BMA 3 and 4

The first summary, in September 2006, focused on 58 bears living in Bear Management Areas (BMAs) 3 and 4, between Highway 1 to the south and Highway 16 to the north (Figure 2), a sample representing over half the total grizzly bear population in this area, as estimated by DNA mark-recapture surveys in 2004 and 2005. These 58 bears had been subject to a total of 155 capture events over 8 years (1999-2006), from which health data had been collected.

The statistical analysis was based on a subset of the available health data. However, the focus was not toward the results *per se*, but instead toward developing the appropriate methodologies to merge and analyze this complex data set. This preliminary exploration allowed us to identify and address potential obstacles (e.g., repeated measures, confounding variables, data redundancy), and to plan an efficient strategy to conduct data mergers and analyze the complete data set.

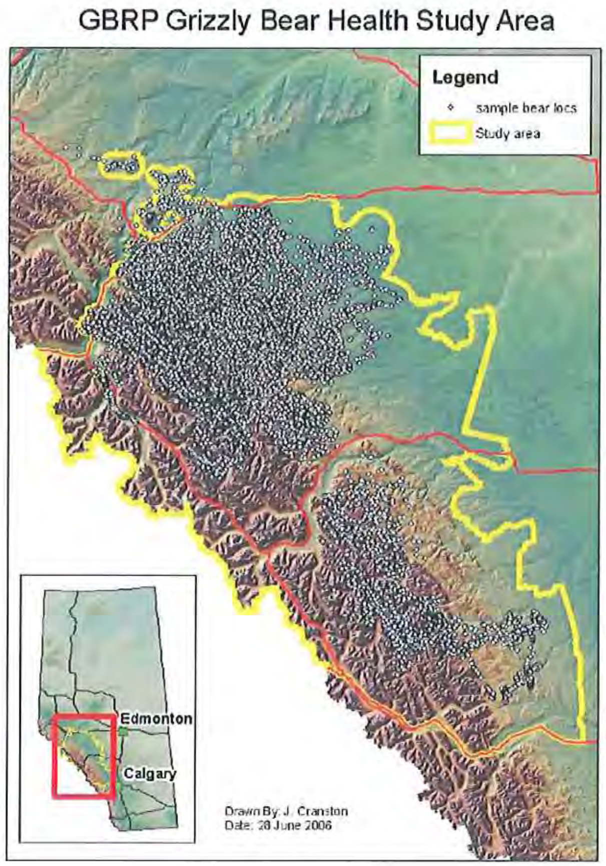


Figure 2. Bear Management Areas (BMA) 3 and 4 and the bear location data available for this area

The health metrics from these samples were matched to environmental conditions experienced by the animal prior to its capture. The portion of the landscape occupied by a bear is called its home range, defined as "...that area traversed by the individual in its normal activities of food gathering, mating, and caring for young." (Burt, 1943). Using ArcView 3.2 Animal Movement extension, we generated 128 annual 95% kernel home ranges from over 55,000 GPS locations collected from these bears. The 95% kernel is a contour on a point density surface within which a point has a 95% probability of occurrence (Fig. 3).

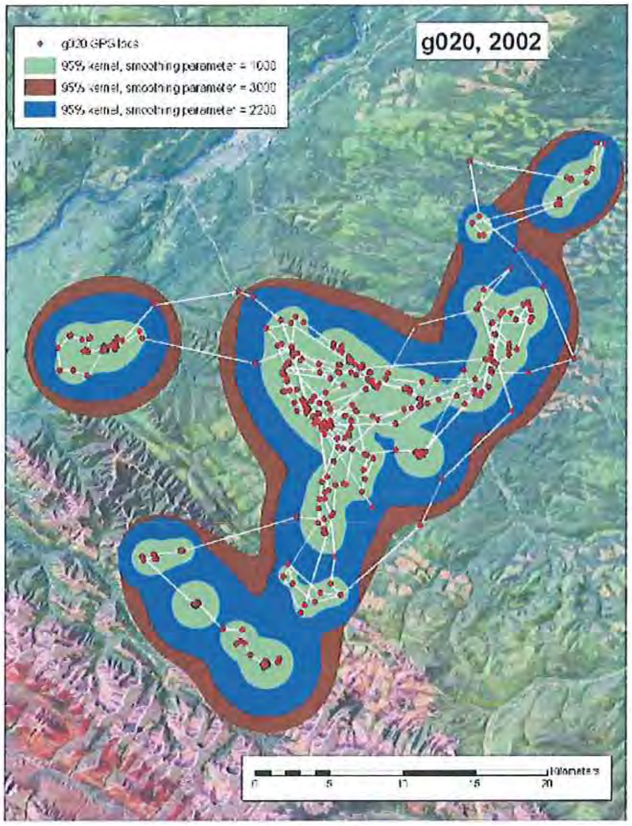


Figure 3. The 95% kernel home range for G020 in 2002 using a single smoothing factor.

Of the 155 captures, over half (81) were the bear's second or subsequent capture and had GPS data preceding the capture event. The home range polygons generated from this data defined the precise portion of the landscape experienced by the bear prior to capture. The balance of captures (74) were initial captures for which the bear did not have GPS data prior to capture, so a home range polygon generated from GPS points collected after the capture was used to represent its approximate home range. Given the high degree of home range fidelity shown by grizzlies from one year to the next, this was considered a valid assumption.

Each capture event was associated with a home range polygon based on GPS data preceding the capture if available, or subsequent to capture if not. Each polygon was then assigned a condition year. ***The condition year is the point in time at which Landsat imagery was acquired and the time in which landscape conditions were considered to have the greatest influence on a bear's health parameters.***

For spring captures, condition year was the year prior to capture; for fall captures (after mid-July), the condition year was the year of capture. For each condition year a GIS layer was created to represent the corresponding configuration of forest and land cover classes, and major anthropogenic features such as roads, well sites, and cut blocks, as it existed at the time. Since Landsat imagery was acquired in late summer or early fall, the landscape conditions would be about six months out of date for spring captures, but most of the change occurring during that time would have occurred during denning season and would have had less influence on the bear's level of stress.

Amount of annual anthropogenic change within a home range was measured between the time of image acquisition in the year prior to capture, to the time of image acquisition in the year during the capture. For spring captures, some of this change may have occurred in the summer months after the capture.

Of the 128 annual kernel home ranges generated for all bears and all years of GPS data, summaries were performed on 89. (Some polygons were used for multiple captures).

For each of the following three sets of environmental variables, summary statistics (mean, range, standard deviation, etc) were calculated for every home range polygon using ArcView 3.2 Zonal Statistics (Spatial Analyst extension).

1) terrain-based or static variables:

(these variables are unchanging and independent of time of capture)

- Elevation: From 25m-resolution Digital Elevation Model (DEM)
- terrain ruggedness: raster surface (30m resolution) derived from DEM
- slope position: raster surface (30m resolution) derived from DEM
- solar radiation: raster surface (30m resolution) derived from DEM
- protected status: the proportion of a bear's home range within a park or protected area.

2) vegetation-based/habitat variables:

- forest age: raster surface (30m resolution), derived from provincial AVI (Alberta Vegetation Inventory) polygons
- crown closure: density of forest canopy; raster surface (30m resolution), a Remote Sensing product developed by the Foothills Facility for Remote Sensing and GIScience.
- Resource selection Function (RSF), an indicator of grizzly bear resource availability: raster surface (30m resolution), derived from Remote Sensing products developed by the Foothills Facility for Remote Sensing and GIScience.
- Mortality Risk, an indicator of grizzly bear habitat security: raster surface (30m resolution), derived from Remote Sensing products developed by the Foothills Facility for Remote Sensing and GIScience.

(Note: these variables were based on 2003 conditions, therefore did not always match the condition year).

3) Anthropogenic features:

- Density and number of roads (line features converted to 30m pixels; total pixel count, and number of pixels per unit area of home range)

- Density and number of well sites (total number, and number per unit area of home range)
- Density and number of cut blocks (total area, and per unit area of home range)
- number and density of roads built in previous year
- number and density of well sites built in previous year
- number and density of cut blocks built in previous year

These anthropogenic features were created for each condition year (1998 – 2005) using attribute data for cut block and well site features. Roads and other linear features were classified using imagery and were assumed to precede the well site or cut block feature to which it led.

Analysis 2: Phase 6 Mapping Extent

In June 2007, a second GIS summary was performed on 95 kernel home ranges that represented the balance of the 184 kernel home ranges that had been generated for every bear and every year since 1999 (Fig.4.). This updated dataset included health data from 2007 captures but GPS home ranges corresponding to these captures was not available as a full season of GPS data had not yet been collected from these bears.

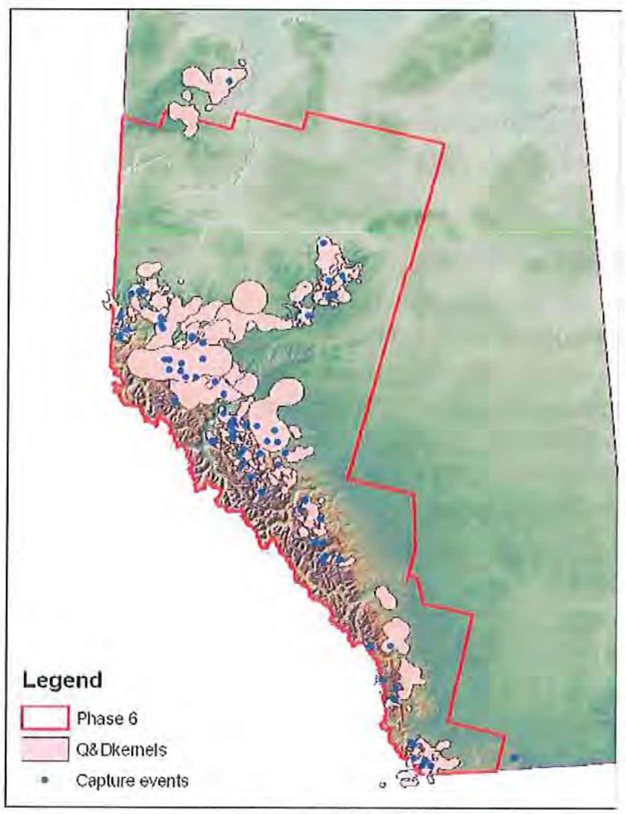


Figure 4. Kernel home ranges created for the second analysis.

Variables:

1) Static variables:
   - Elevation: from 25m-resolution Digital Elevation Model (DEM)
   - Terrain Ruggedness Index: raster surface (30m resolution) derived from DEM
   - Compound Topographic Index: raster surface (30m resolution) derived from DEM ; a measure of soil wetness
   - Solar radiation: raster surface (30m resolution) derived from DEM
   - Percent Protected: the proportion of a bear's home range within a park or protected area.

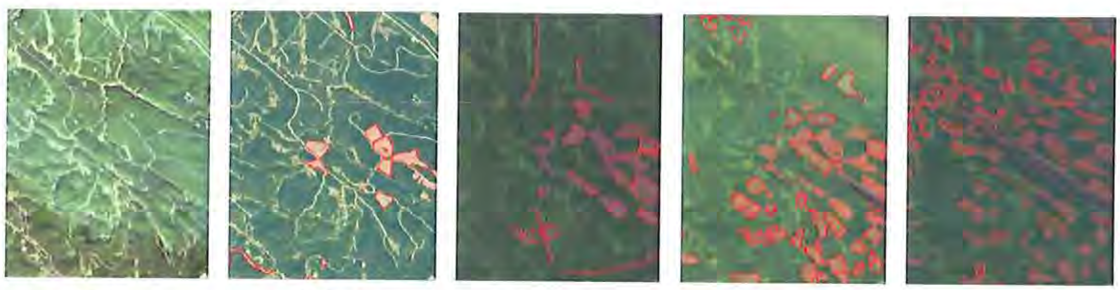
2) Anthropogenic variables:
   - Well site density: raster surface (30m resolution), representing the density of well sites
   - Road density: raster surface (30m resolution), negative exponential decay distance to roads (value = 1 next to road, dropping toward 0 further away).
   - Seismic/trail density raster surface (30m resolution), negative exponential decay distance to trails (value = 1 next to trail, dropping toward 0 further away).

3) Vegetation/habitat variables:
   - Crown closure: density of forest canopy; raster surface (30m resolution), a Remote Sensing product developed by the Foothills Facility for Remote Sensing and GIScience; 2005 conditions.
   - Species composition: (percent conifer in forest stands; raster surface (30m resolution), a Remote Sensing product developed by the Foothills Facility for Remote Sensing and GIScience; 2005 conditions.
   - Forest age: raster surface (30m resolution), derived from provincial AVI (Alberta Vegetation Inventory) polygons; 2005 conditions.
   - Resource selection Function (RSF), an indicator of grizzly bear resource availability: raster surface (30m resolution); average of three seasonal models; derived from Remote Sensing products developed by the Foothills Facility for Remote Sensing and GIScience.(2005 conditions)
   - Mortality Risk, an indicator of grizzly bear habitat security: raster surface (30m resolution), derived from Remote Sensing products developed by the Foothills Facility for Remote Sensing and GIScience. (2005 conditions)
   - Attractive sink: raster surface (30m resolution); combination of RSF surface and mortality risk surface, values proportional to probability of bear occurrence and risk of human-caused mortality; (2005 conditions)
   - Safe harbor: raster surface (30m resolution); inverse of attractive sink surface; combination of RSF surface and mortality risk surface, values proportional to probability of bear occurrence and inversely proportional to risk of human-caused mortality; 2005 conditions.

One challenge encountered in merging this set of GIS summaries with the first was that many of the GIS variables from the first summary did not cover the larger area; and some of the variables for the complete area had not been available at the time of the initial analysis.

Analysis 3: All captures

For the third analysis, in November 2007, a more precise correspondence between condition year and anthropogenic disturbance was required. Using Landsat TM7 imagery acquired in the late summer or early fall of each year, a manual classification of 23,350 cut block polygons, 7615 well sites, and 62,576 linear access features was performed for an area of 38,705 km^2 in BMA 3 (1998-2005) and 17,182 km^2 in BMA 4 (2002-2005). Each point (well site), line (linear access structure, such as road, pipeline, power line, or railway) and polygon (cut block) feature was assigned a year based on the year of imagery in which it first became visible. Figure 5 shows how the anthropogenic features have changed from 2000 to 2004.



2000 2001 2002 2003 2004

Figure 5. An example of the change in anthropogenic features for a small area of BMA 3 from 2000 to 2004.

Of the total of 272 capture events, 225 had associated home ranges and environmental summary statistics. 142 unique home range polygons were used for summaries.

The following variables were summarized:

1) Static variables:
   - Elevation: from 25m-resolution Digital Elevation Model (DEM)
   - Terrain Ruggedness Index: raster surface (30m resolution) derived from DEM
   - Compound Topographic Index: raster surface (30m resolution) derived from DEM ; a measure of soil wetness
   - Percent Protected within 10km: raster surface (30m resolution), proportion of park or protected area within 10km radius kernel.

2) Anthropogenic variables:
   - Well site density: raster surface (30m resolution), kernel density of oil and gas well sites within 10 km radius
   - LAF density: raster surface (30m resolution), kernel density of linear access features within 1 km radius

- MeanRegen: Proportion of home range in regeneration (or agriculture; agriculture only applies to 2005 polygons), calculated using Focal Statistics (Spatial Analyst) and a binary regeneration raster.
- NewFeatures_Mean: Proportion of home range occupied by new cut blocks, roads, and well sites, built between fall of year prior to capture, and fall of capture year.

3) Vegetation/habitat variables:
   - Crown closure: density of forest canopy; raster surface (30m resolution), a Remote Sensing product developed by the Foothills Facility for Remote Sensing and GIScience; 2005 conditions
   - Species composition (percent conifer) : (percent conifer in forest stands; raster surface (30m resolution), a Remote Sensing product developed by the Foothills Facility for Remote Sensing and GIScience; 2005 conditions.
   - Forest age: raster surface (30m resolution), derived from provincial AVI (Alberta Vegetation Inventory) polygons; 2005 conditions.
   - Resource selection Function (RSF), an indicator of grizzly bear resource availability: raster surface (30m resolution); average of three seasonal models; derived from Remote Sensing products developed by the Foothills Facility for Remote Sensing and GIScience.(2005 conditions)
   - Mortality Risk, an indicator of grizzly bear habitat security: raster surface (30m resolution), derived from Remote Sensing products developed by the Foothills Facility for Remote Sensing and GIScience. (2005 conditions)
   - Attractive sink: raster surface (30m resolution); combination of RSF surface and mortality risk surface, values proportional to probability of bear occurrence and risk of human-caused mortality; 2005 conditions
   - Safe harbor: raster surface (30m resolution); inverse of attractive sink surface; combination of RSF surface and mortality risk surface, values proportional to probability of bear occurrence and inversely proportional to risk of human-caused mortality; 2005 conditions.

<u>Analysis 4: All captures, annual habitat conditions</u>
For this extraction, a complete set of land cover, forest canopy, species composition, and grizzly bear habitat models were developed for each condition year (1998-2005) within BMA 3 and 4. For the first time, the condition year for all captures in the dataset could be matched to landscape and habitat conditions for the same year, with the exception of captures from fall 2006 and 2007, which were matched to conditions for 2005. Also, two new environmental variables were summarized: the footprint of anthropogenic change from one condition year to the next, and average movement rates from GPS data.

The remote sensing rasters developed by the Foothills Facility for Remote Sensing and GIScience (land cover type, crown closure, and percent conifer) within BMA 3 and 4 were backcast to conditions for 1998 and later, with vector features for anthropogenic disturbance (roads, well sites, cut blocks, and fires) "burned in" to the land cover to capture features which may have been too small for the Landsat sensor to classify. These layers, along with terrain layers formed the basis of the grizzly bear habitat models describing grizzly bear occurrence (RSF), risk of human-caused mortality (Risk), and a combination of the two (Safe Harbor). Geoprocessing scripts in the Python language were written to derive other predictor variables, such as proximity to edges, from the terrain and remote sensing layers, and to regenerate the Mortality Risk, seasonal RSF, and Safe Harbor models for each year.

The home range kernel type was changed from 95.0% to 99.999% as it was determined that patch-level metric calculations were less sensitive to edge effects with this configuration. There were 228 capture events for which associated home ranges were summarized, using 146 home ranges.

1) Static variables:
   - Elevation: from 25m-resolution Digital Elevation Model (DEM)
   - Terrain Ruggedness Index: raster surface (30m resolution) derived from DEM
   - Compound Topographic Index: raster surface (30m resolution) derived from DEM ; a measure of soil wetness
   - Percent Protected within 10km: raster surface (30m resolution), proportion of park or protected area within 10km radius kernel.

2) Anthropogenic variables:
   - Well site density: raster surface (30m resolution), kernel density of oil and gas well sites within 10 km radius
   - LAF density: raster surface (30m resolution), kernel density of linear access features within 1 km radius
   - MeanRegen: Proportion of home range in regeneration (or agriculture; agriculture only applies to 2005 polygons), calculated using Focal Statistics (Spatial Analyst) and a binary regeneration raster.
   - MeanChange: Proportion of home range within the footprint of anthropogenic disturbance, calculated using Focal Statistics (Spatial Analyst) and a binary annual change raster.

3) Vegetation/habitat variables:
   - Crown closure: density of forest canopy; raster surface (30m resolution), a Remote Sensing product developed by the Foothills Facility for Remote Sensing and GIScience; matched to Condition year.
   - Species composition (percent conifer) : (percent conifer in forest stands; raster surface (30m resolution), a Remote Sensing product developed by the Foothills Facility for Remote Sensing and GIScience; matched to Condition year.
   - Forest age: raster surface (30m resolution), derived from provincial AVI (Alberta Vegetation Inventory) polygons; 2005 conditions.
   - Resource Selection Function (RSF), an indicator of grizzly bear resource availability: raster surface (30m resolution); average of three seasonal models; derived from Remote Sensing products developed by the Foothills Facility for Remote Sensing and GIScience; matched to Condition year.

- Mortality Risk, an indicator of grizzly bear habitat security: raster surface (30m resolution), derived from Remote Sensing products developed by the Foothills Facility for Remote Sensing and GIScience. matched to Condition year
- Safe harbor: raster surface (30m resolution); inverse of attractive sink surface; combination of RSF surface and mortality risk surface, values proportional to probability of bear occurrence and inversely proportional to risk of human-caused mortality; matched to Condition year.

References

Burt, W.H. 1943. Territoriality and home range concepts as applied to mammals. Journal of Mammalogy 24:346-352.

CHAPTER 5: Wildlife Health

Dr.Cattet, Dr.Vijayan, and Dr.Janz

Introduction

Accounts of associations between large-scale, human-caused environmental change and wildlife population declines make newsworthy items, recent examples including reports in the popular press on global warming and polar bear (*Ursus maritimus*) population declines (see www.washingtonpost.com/wp-dyn/content/article/2006 /12/26/ AR2006122601034.html), or descriptions of pollution, habitat loss, and mass localized extinction of amphibian populations (see www.sciencedaily.com/releases/2006/07/ 060707094220.htm). Specific to this study, recognition in Alberta of possible links between habitat change as a result of human land use activities and declining grizzly bear (*U. arctos*) populations is growing (Alberta Grizzly Bear Recovery Team, 2005). A fundamental problem with these and other examples, however, is the knowledge and tools needed to establish causal relationships are often lacking (Fig. 1) (Stevenson et al., 2005). An added impediment is considerable time can lapse between occurrences of environmental change and detection of affected populations (Findlay and Bourdages, 2000). It follows, without understanding causal mechanisms, we cannot predict with accuracy effects of environmental change on wildlife populations before they occur (Wikelski and Cooke, 2006).

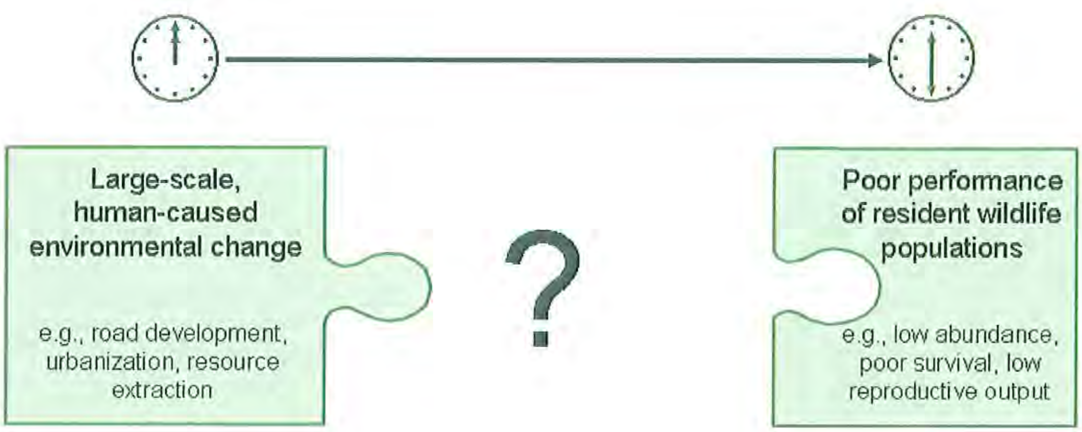


Figure 1. Although associations are sometimes drawn between occurrences of large-scale, human-caused environmental change and poor performance of resident wildlife populations, evidence of cause and effect is usually lacking. An added complication is considerable time may lapse between occurrences of environmental change and detection of poor population performance. The critical issue here is our lack of understanding of causal mechanisms underlying conservation problems, such as population decline, prevents us from predicting with any accuracy the effects of environmental change on population performance before its occurrence.

Although populations are usually a major focus of wildlife monitoring and conservation strategies, the responses of individual animals to human alteration of the environment is what causes or contributes to poor performance of resident wildlife populations (Fig. 2) (Wikelski and Cooke, 2006). Wild animals are exposed to many "stressors" throughout their life, but often cope successfully through a suite of physiological and behavioral mechanisms, collectively known as the "stress response" (Reeder and Kramer, 2005). However, the duration of a stressor is important. Whereas short-term stress (lasting seconds to hours) encountered during the normal activities and experiences of daily life rarely pose a threat to healthy animals, long-term stress (lasting days to months) as can occur with human alteration of the environment, can exceed an animal's ability to cope (Moberg and Mench, 2000). When "stressed" for weeks to months, an animal loses its capacity to sustain normal biological function (i.e., growth, reproduction, immunity, activity) and gradually develops signs of impaired health (termed "distress") including reduced growth, impotency, infection, and sometimes premature death. Whether or not population-level effects occur depends on the proportion of the population that is distressed. If the proportion is small, population performance (i.e., reproductive output, survival rates, abundance) should not change, but if it increases, a reduction in performance is more likely to occur (WWF International Arctic Programme and WWF-DetoX, 2006). Because the time lapse between human alteration of the environment and reduction in wildlife population performance can take many years (Findlay and Bourdages, 2000), broadening the focus of wildlife monitoring and conservation strategies to include assessment of long-term stress and biological function in individual animals provides opportunity to alleviate environmental stressors before population performance is affected. Additionally, this approach can:

- Enable more sensitive evaluation of the efficacy of conservation actions than is provided solely by measuring population-level parameters;
- Provide knowledge that is currently lacking to establish cause and effect between large-scale, human-caused environmental change and wildlife population declines; and
- Provide baseline background data needed to (i) quantify the impact of human land use activities, and to (ii) develop predictive models quantifying the response of wildlife populations in altered environments to understand how future problems can best be avoided.

Figure 2. Tracking long-term stress and understanding wildlife health is crucial to establishing if large-scale, human-caused environmental change is the cause of, or contributes to, poor performance of resident wildlife populations. Where this linkage occurs, the time lag is explained by the fact that long-term physiological stress develops in individual animals in response to environmental stressors. This, in turn, leads to gradual impairment of health in stressed individuals, but only after enough individual animals are affected will evidence of poor population performance become evident. Ability to detect long-term stress, therefore, provides potential to mitigate environmental stressors before population performance is affected, and equally as important to monitor the efficacy of conservation strategies in recovering populations.

<u>Wildlife Health Research Objectives</u>

1. Develop and validate serum-based indicators of long-term stress in grizzly bears.
2. Develop and validate a tissue-based protein array to detect long-term stress in grizzly bears.
3. Develop health profiles for grizzly bears and their populations.
4. Evaluate the relationship between long-term stress and health in grizzly bears.

Progress in Stress Research

Efforts on this front pertain to research objectives 1 and 2.

<u>Development and Validation of Serum-Based Indicators of Long-Term Stress</u>

We evaluated the usefulness of serum cortisol and heat shock proteins (hsp) 60 and 70 as indicators of long-term stress experienced by grizzly bears. This was accomplished by measuring serum concentrations in bears collected over the past 9 years (between spring 1999 and 2007; approximately 140 bears). Serum cortisol levels were elevated by capture stress and, therefore, did not appear to be a good measure of stressors experienced by the animal prior to capture. Serum hsp60 levels did not show any significant differences among biological factors, such as age, sex, and reproductive status, or among regions of grizzly bear distribution in Alberta (see Fig. 5). However, hsp70 levels differed between regional groupings of bears suggesting this measure shows some potential as an indicator of long-term stress. To confirm the usefulness of hsp70, we are continuing to evaluate it in grizzly bears in relation to other health and landscape measures, while also investigating its dynamics in polar bears (in conjunction with the Ontario Ministry of

Natural Resources' Climate Change Program) in relation to seasonal availability of sea-ice in southern Hudson Bay.

In addition to measuring more conventional indicators of stress, we are also currently identifying and developing other serum indicators of stress in grizzly bears. One candidate molecule is the corticosteroid-binding globulin (CBG), a protein carrier to which cortisol is bound in circulation, which is shown to change in response to long-term stress but not to short-term stress in animals. Our preliminary studies attempted to purify this protein from bear serum. While we did purify the protein, the CBG concentration was not sufficient enough to generate antibodies for this protein. We did make polyclonal antibodies by injecting the purified CBG from bear into rabbits. However, the antibody was not specific to CBG, likely due to contamination by other proteins in the purified CBG fraction. We did not have sufficient proteins to repeat the injections. Consequently, we decided to undertake a biotechnology approach to make recombinant bear CBG. Currently, bear CBG mRNA has been partially sequenced using primers designed from dog CBG. When this is complete, the full-length bear CBG cDNA will be cloned into an expression vector for production of protein in recombinant bacteria. Purified recombinant CBG will then be used to produce polyclonal antibodies for developing techniques, including enzyme-linked immunosorbent assay (ELISA) for measuring CBG concentration in bear serum.

As another aspect of our research, we are using proteomic technology to discover novel proteins that may be indicative of the stress state of the animal. For this, we are comparing animals with "low" and "high" stress scores (see Development of Grizzly Bear Health Profiles) to identify differentially expressed proteins in bear serum. We compared four independent groups of animals and we have identified 15 serum proteins that were significantly different in the bears with the high stress scores relative to the low stress scores. These proteins spots have been excised and sent for mass spectrometry at the University of Western Ontario proteomics facility, to identify proteins of interest. We are currently awaiting the results. In the mean time, we are also comparing the impact of repeated sampling on serum protein levels to identify markers of long-term stress. The procedure is exactly the same as mentioned above but the comparison will involve serum of the same bear between first and subsequent captures.

<u>Development and Validation of Tissue-Based Indicators of Long-Term Stress</u>

We have developed an antibody-based protein microarray ("bear stress chip") to simultaneously determine expression of 31 stress-associated proteins in skin and muscle biopsy samples collected from grizzly bears (Table 1). We are currently completing the initial determinations of these stress proteins in 158 grizzly bear skin samples obtained from the Foothills Model Forest Grizzly Bear Research Project (FMFGBRP), and expect to complete this milestone by March 2008. To date we have determined the stress profiles for 30 bears and are conducting a preliminary data analysis to compare stress protein expression patterns (1) among bears of different sex, age class and body condition, (2) with serum stress indicators determined in the laboratory of Dr. Vijayan, and (3) among bears inhabiting different locations.

As described in the previous interim report, our progress in 2007 involved completing the identification of commercially available antibodies for their cross-reactivity with bear stress proteins (i.e., the 31 proteins mentioned above), optimizing the processing of tissue samples, and optimizing the labeling of proteins in samples with fluorescent dyes. Once these milestones were achieved, prototype chips were printed with antibodies for initial validation and optimization experiments (e.g., different antibody dilutions, protein dilutions and blocking/washing procedures). Following this, the final chips were printed with antibodies by an independent company (FirstPhase Technologies, Tempe, AZ).

Table 1. Stress-associated proteins detected by the "bear stress chip", a long-term stress detection tool developed for use in the conservation of grizzly bears. The stress proteins are arranged in general categories associated with their role in the stress response, although it should be noted that there is considerable overlap and integration among these categories.

Category of Stress	Stress Protein
1. Hypothalamic-pituitary-adrenal axis	Adrenocorticotropic hormone (ACTH) Glucocorticoid receptor Corticotropin-releasing factor receptor 1/2 Proopiomelanocortin (POMC) Prolactin Arginine vasopressin receptor V1a
2. Oxidative stress and inflammation	Superoxide dismutase-1 Superoxide dismutase-2 Peroxiredoxin-3 Chemokine receptor-5 Inducible nitric oxide synthase (iNOS) Endothelial nitric oxide synthase (eNOS) Heme oxygenase-2 Cyclooxygenase-2
3. Cellular stress and proteotoxicity	Heat shock protein-27 (HSP27) HSP40 HSP60 HSP70 HSP70 (inducible) HSP90 HSP110 Glucose-regulated protein-78 (GRP78/BIP)
4. Apoptosis and mitosis	Apoptosis-inducing factor (AIF) Annexin II Annexin IV Caspase 1 Caspase 2 Caspase 3 Caspase 6 E-cadherin GAPDH

Progress in Wildlife Health Research

Efforts on this front pertain to research objectives 3 and 4.

Development of Grizzly Bear Health Profiles

With approximately 110 variables relating to grizzly bear health, it is a challenge to summarize the health status of bears without conducting detailed and complex statistical analyses (See Chapter 6). This difficulty is further compounded by observations that:

- The grizzly bear health database contains records from repeated captures of individual bears, i.e., repeated measures effects.
- Some health variables are influenced by method of capture.
- Some health variables are influenced by sex and age of bear.
- Some health variables are influenced by date of capture.
- Not all health records are complete, i.e., missing values.

To overcome these difficulties, we developed a health function score system to enable quick summary of health profiles for individual bears, to identify bears with impaired health, and to explore associations between stress and health and between health and environment at a coarse level. The system is based on five health functions – age, growth, immunity, movement, and stress. We also intended to include reproduction as a function, but lacked sufficient data to calculate a meaningful score for many bears. We calculated scores for four health functions based on raw values for 2-7 constituent variables (Table 2), selected on the basis of biological knowledge and data reduction methods (e.g., principal components analysis), which collectively best represented a specific health function.

We calculated health function scores based on health data collected from 164 grizzly bears during 280 captures occurring throughout grizzly bear range in Alberta from 1999 to 2007. The scores represent averages of percentile values for constituent variables ranging in value between 0.00 and 1.00. Where values for constituent variables differed between sexes and / or between capture methods, percentile values were calculated within categorical classes before averaging. We did not calculate a score for age of bear, but instead used age in years.

Table 2. Constituent variables used to calculate health function scores for grizzly bears captured for the Foothills Model Forest Grizzly Bear Research Project in western Alberta (1999-2007).

Health Function Scores	Constituent Variables
Stress score	Serum concentrations of gamma-glutamyltransferse (GGT), total cortisol, heat-shock proteins 60 & 70, and glucose
Growth score	Body mass, straight-line body length, axillary girth, body condition index (BCI), and serum concentration of alkaline phosphatase
Immunity score	White blood cell count, lymphocyte count, proportion of neutrophils and monocytes, serum concentrations of total protein and globulin, and serum albumin-to-globulin ratio
Movement score	Mean daily movement rate during breeding season (May 16 – July 31) and mean daily movement rate during all other times of year

The transformation of constituent variable values into percentile scores normalized data distributions and resulted in mean scores close to 0.50 (Table 3). Although 95%

confidence intervals were narrow for health function scores, minimum and maximum values were broader (stress score = 0.22-0.76, growth score = 0.13-0.87, immunity score = 0.20-0.71, movement score = 0.04-0.97). Male grizzly bears had higher mean scores than females for growth and immunity, but were similar in other scores as well as age. Although Table 1 represents data collected from individual bears at first capture only, these patterns were also similar when analyzing data collected from all captures.

Table 3. Descriptive statistics[A] for health function scores and ages of grizzly bears[B] captured for the Foothills Model Forest Grizzly Bear Research Project in western Alberta (1999-2007).

Health Functions	Female bears[C]	Male bears[C]	All bears
Stress score	0.47 (0.43-0.50) [55]	0.49 (0.46-0.52) [68]	0.48 (0.46-0.50) [123]
Growth score	0.42** (0.38-0.47) [54]	0.47** (0.42-0.52) [52]	0.45 (0.41-0.48) [106]
Immunity score	0.46* (0.40-0.48) [53]	0.50* (0.48-0.53) [72]	0.48 (0.47-0.50) [125]
Movement score	0.56 (0.46-0.67) [21]	0.48 (0.38-0.59) [19]	0.52 (0.45-0.60) [40]
Age (years)	7.2 (5.8-8.5) [67]	6.2 (5.1-7.2) [80]	6.6 (5.8-7.4) [147]

[A] Presented as mean, 95% confidence interval in round brackets, and sample size in square brackets.
[B] Score and age statistics calculated from data collected at first capture only.
[C] Differences between sexes indicated by '*' for $P \leq 0.05$ and '**' for $P \leq 0.01$.

Individual bears captured multiple times throughout the project duration showed considerable variation in health function scores from one year to the next, but nonetheless displayed changes that paralleled multi-year patterns observed at the population level (Fig. 3). For example, an adult male grizzly bear G017 had higher stress, growth, and immunity scores than most bears captured in the Foothills Model Forest (FMF) core study area (see map on Fig. 5) from 1999 to 2003. However, the direction and magnitude of change in G017's scores from year-to-year were similar to the pattern of population differences between years. This suggests that factors, presumably environmental in nature, influence health at multiple levels (individual and population) simultaneously.

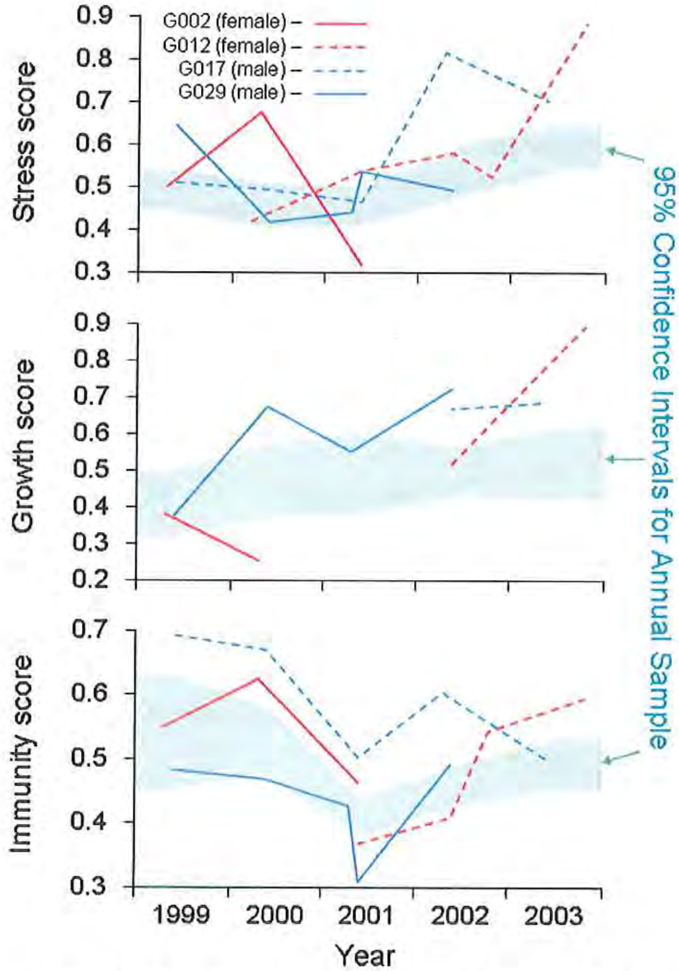


Figure 3. Change in health function scores of four adult grizzly bears captured multiple times in the core study area of the Foothills Model Forest Grizzly Bear Research Project from 1999 to 2003. The green-shaded area represents the 95% confidence interval for the population mean in each year. Movement score values were too few to depict annual changes for individual bears.

Many of the health function scores shown in Fig. 3 are based on data collected during sequential captures of four individual bears with an interval of approximately one year between captures. An exception, however, is the stress and immunity scores for G029 measured over a 2-week interval in 2001. These are noteworthy given the large degree of change – a 10% increase in stress score and a 12% decrease in immunity score – over a short span of time. Although we did not determine specifically the cause of these marked changes, we have identified short- and long-term effects of capture and handling over the course of the FMFGBRP that had not previously been recognized (Cattet et al. 2003, Cattet et al. 2008).

Mean health function scores for the population of bears inhabiting the FMF core study area showed significant variation from year-to-year (Fig. 4). Trends in stress and immunity scores were similar – lowest in 2001 and increasing over the next two years. Although we didn't find statistically significant differences between years in mean growth scores, there was a consistent pattern of increasing mean scores from 1999 to 2003. We have not determined the factors influencing these changes, but this again serves to support our notion that health is dynamic at the population level, as well as the individual level. A next and obvious step in these analyses will be to evaluate associations between annual population mean health scores and annual measures of population performance, i.e., demographic rates.

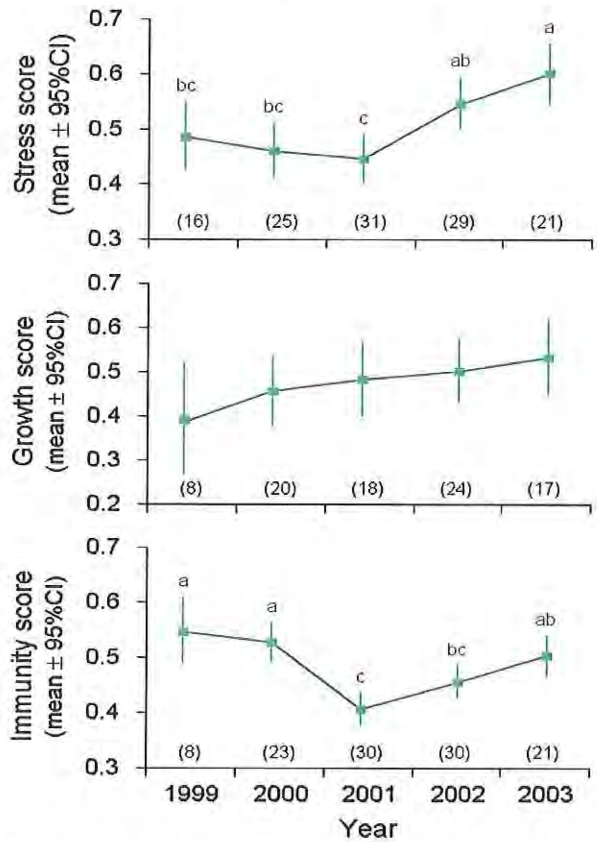


Figure 4. Change in mean population health function scores for grizzly bears captured in the core study area of the Foothills Model Forest Grizzly Bear Research Project from 1999 to 2003. Mean scores and 95% confidence intervals were adjusted for a 7-year old bear and calculated from data collected at first capture only. Statistically significant differences ($P \leq 0.05$) indicated by letters where a > b > c. Error bars with 'ab' or 'bc' above are intermediate in value to, but do not differ significantly from 'a' and 'b', or 'b' and 'c'. Annual sample sizes are provided in round brackets below error bars.

We did not have adequate sample sizes based on data collected at first capture only to compare mean health scores among grizzly bear populations in Alberta. Nevertheless, we did conduct a regional analysis based on 3 regions (Fig. 5) with the following population composition: (i) North of Highway 16 [N16] – populations 5, 9, 11, 12; (ii) FMF core study area [FMF] – population 1; and (iii) South of Highway 11 [S11] – populations 2, 3, and 4. We decided not to include data collected from bears in the Swan Hills area (population 6) because the sample size was too small, and because landscape conditions (natural and human-caused) in this area are distinctly different from other areas included in N16. We found significant differences between regions which imply health of grizzly bears is not uniform across their range in Alberta. Bears inhabiting areas north of Highway 16 (N16) have the highest growth scores, but also have the highest stress and immunity scores in the province. In contrast, bears inhabiting the FMF core study area (FMF) have the lowest growth and immunity scores, and bears inhabiting areas south of Highway 11 (S11) have the lowest stress scores. Our ongoing detailed statistical analyses of grizzly bear health and landscape structure / change data will help to reveal the basis for these differences.

Associations between Age, Stress, and Other Health Function Scores

Stress and growth scores of grizzly bears were directly associated with age tending to be higher in older bears and lower in younger bears (Figs. 6a-b). We also found evidence for these patterns in individual bears captured multiple times suggesting stress scores (Repeated measures ANOVA – $P = 0.031$, $n = 74$) and growth scores ($P = 0.098$, $n = 74$) increased as individuals aged.

Stress scores were significantly associated with all other health function scores (Figs. 6a-d). Our finding of a positive association between stress and growth is counterintuitive as it suggests bears exhibiting the greatest growth were also the most stressed. However, some insight is offered by observations that bears with greatest growth also inhabit areas where road density is greatest whereas bears with lowest growth inhabit areas of higher elevation where human access is less (See Chapter 6). We suggest this pattern may be due to availability of better food resources in disturbed areas (as reflected by road density) where bears are more likely to be stressed by human activities and/or landscape conditions, than in higher elevation areas where human activity is less, but so too is food quality and availability.

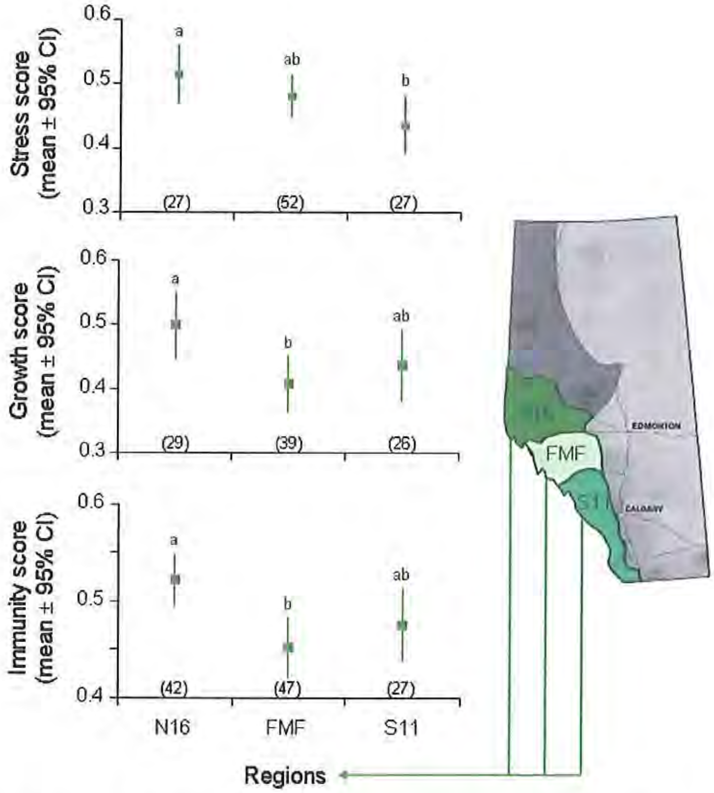


Figure 5. Mean health function scores for grizzly bears that inhabit different regions of Alberta and were captured for the Foothills Model Forest Grizzly Bear Research Project (1999-2007). Regions on a north-south gradient are N16 – between Highways 2 and 16, FMF – core study area between Highways 16 and 11, and S11 – between Highway 11 and Montana border. Mean scores and 95% confidence intervals are adjusted for a 6-year old bear and were calculated from data collected at first capture only. Statistically significant differences (*P* ≤ 0.05) indicated by letters where a > b > c. Error bars with 'ab' above are intermediate in value to, but do not differ significantly from 'a' and 'b'. Sample sizes are provided in round brackets below error bars.

We found a positive association between stress and immunity scores in grizzly bears (Fig. 6c). Long-term stress is believed to compromise immune function in animals (Schwab et al. 2005) which suggests grizzly bears with high stress scores should also have low immunity scores, i.e., an inverse association. However, to date most of the constituent variables used in the grizzly bear stress score reflect short-term (acute) stress instead of long-term (chronic) stress. Dhabhar (2000) found acute stress to enhance immune function in mice while chronic stress had a suppressive effect. This could also explain the pattern observed in grizzly bears. We will continue to investigate the association between stress and immunity scores as we expand our suite of long-term stress biomarkers, e.g., cortisol binding globulin, stress-associated proteins in skin and muscle.

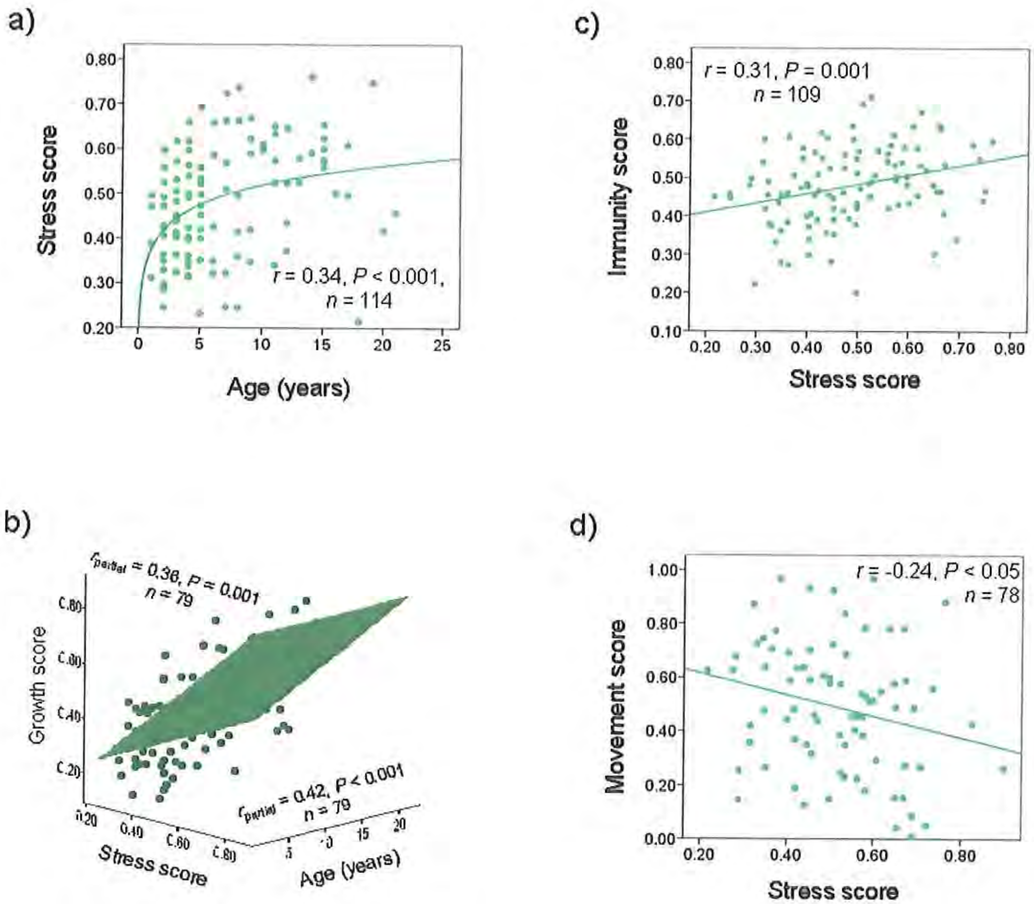


Figure 6. Associations between age, stress score, and other health function scores in grizzly bears captured for the Foothills Model Forest Grizzly Bear Research Project in western Alberta (1999-2007). Scatter-plots represent correlations between a) age and stress score, b) age, growth and stress scores, c) stress and immunity scores, and d) stress and movement scores calculated from data collected at first capture only.

We found a weak inverse correlation between stress and movement scores (Fig. 6d) suggesting bears with higher stress levels moved less. Again, as with the association between stress and growth, this may tie into where "more stressed" vs. "less stressed" bears live and relative differences in habitat characteristics, or more specifically food availability. If "more" stressed bears occupy lower elevation areas with greater food availability, they may move shorter distances and less frequently to find food when compared to "less stressed" bears living at higher elevations (See Chapter 6). At this point, we would not suggest these associations identified between stress and other health functions provide evidence that stress causes alterations in health. Nonetheless, these findings do corroborate results emerging from our more detailed statistical analyses of grizzly bear health and landscape structure / change data.

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CHAPTER 6: Progress report on analysis of GIS, Landscape Metric and Health Variables

John Boulanger

Introduction

The main objective of this section is to provide preliminary finding of some of the current analyses on the relationship between grizzly bear environmental variables and health scores. In this report I use constrained ordination methods, which are robust to many of the issues with health-environmental data, to further explore this data set. This report should be considered in unison with previous analyses (Boulanger 2006) that explored variable inter-relationships, sample size issues, and mixed-model based analysis.

Methods

The analysis of the relationship between landscape and health data is challenging for many reasons. First, the health data is based on repeated live capture of grizzly bears. It is known that live capture affects many of the health variable measurements and therefore the effect of live capture has to be modeled if the health measurement is not robust to capture effects. At the time of the analysis, micro-array, or CBG stress measures that are robust to live capture effects were not available. Second, it is likely that repeated measures of bears are not statistically independent and therefore first captures can only be used for analyses or statistical models robust to repeated measures need to be used. Third, it is likely that many health indicators vary by age and sex of bear. Therefore, the data set contains both categorical (sex, capture type) and continuous data. As a result data may need to be stratified by categorical variables, or statistical methods that allow both categorical and continuous variables need to be used for data analysis. All the above issues are further compounded by small sample sizes which also reflects the population status (N) within the various management units.

<u>Variables</u>

Yearly home ranges were estimated for each of the GPS collared bears using the kernel home range estimator (Worton 1989). GIS and landscape variables were summarized for each home range area. Health records from capture were matched to home range areas as detailed in Chapter 4 above. At the time of report preparation, yearly remote-sensing based GIS maps were not available for all the areas sampled (areas outside BMA's 3 and 4) and therefore in some cases landscape conditions for bears were based upon the 2003 base map. Future analyses (final program report) will utilize the newly completed yearly base maps for all bears in the analysis. As an initial step, all data were assessed in terms of normality and potential outliers were identified. Percentage data was converted into a proportion and then transformed with an arcsine square root transformation to help meet the assumption of normality.

GIS and Landscape variables

Table 1 describes the landscape variables used in the analyses. The majority of variables were based upon a 2003 base map of the study area. Therefore, change in these variables would be due to home range area shifts of bears as opposed to landscape change. Only the main anthropogenic variables (i.e. percent roads) were updated on a yearly basis.

Table 1: Landscape variables considered in analyses. Variables marked with an * were updated for each year so yearly change in these variables reflected both landscape and bear home range shift for a portion of the study area. Other variable values were based upon a 2003 base map. Any yearly change in these variables would be due to home range shift of bears.

GIS	Description
solar_mean	solar radiation
Dem_mean	Mean elevation
topcls_mean	Topographic class
tri_mean	terrain Ruggedness Index
canopy10x_mean	Crown Closure (0-10)
pctcon_mean	Percent conifer (0-1)
age05adj10x	Forest age (10-year increments)
Pct_Protected	Percent home range protected
PctCut*	Percent of each home range that was cut block (new or old).
Numwells*	Number of well sites
PctRds*	Percentage of home range covered in roads
RSF_mean	Mean RSF score
Risk_mean	Risk score for home range

Landscape level metrics were also considered (Table 2). All of these were based upon the 2003 base map and therefore changes in variables were due to changes in bear home range rather than landscape change.

Table 2: Landscape level metrics considered in the analysis

Metric	Full name
L1_Land_AREA_MN	Mean patch size
L2_Land_ECON_MN	Contrast Edge density
L3_Land_SHAPE_MN	Shape index
L4_Land_AREA_CV	Variation in mean patch size
L5_Land_PROX_AM	Area-weighted proximity
L6_Land_ENN_CV	Variation in interpatch distances
L7extra_Land_ENN_MN	Mean interpatch distance

Health variables

Health variables were originally grouped by Marc Cattet and David Janz in terms of their relationship to various health components (Table 3). I further grouped health variables into general components. Variables that did not directly correspond to a health component were not considered in the analysis.

Table 3: Health variables considered in the analysis. Italics variables were suggested after the analysis was conducted and will be considered in future analyses

No	Health component	Variables	Covary with
1	Growth/Condition	BCI	age/sex
		alk_phos_UpL	
		straight-line length	age/sex
2	Reproduction	progesterone_ngml	age/sex
		estrogen_pgml	age/sex
		prolactin_ngml	age/sex
		luteinizing_ngml	age/sex
		testosterone_ngml	age/sex
3	Immunity	wbc_e9pL	
		neu_percent	
		lym_percent	
		lym_neu_ratio	
		mono_percent	capture
		eos_percent	capture
		baso_percent	capture
		total protein	capture
		globulin	capture
		AG_ratio	capture
4	Stress	total_cortisol_UW	capture
		ggt_UpL	capture
		glucose_mmolpL	capture
		hsp_60_uw	hsp are sample size
		hsp_70_uw	limited

Most of the health variables were reduced in sample size when only the first capture of a bear was used for the analysis (Table 4). This was a key limiting factor in analyses given that the overall number of observations used in any type of analysis is based upon the variable with the lowest sample size. Sample sizes were higher when multiple capture events were used.

Analysis strategies

Previous analyses (Boulanger 2006) focused on eliminating redundant variables from each of the respective health and environmental variables using principal component analysis (McGarigal et al. 2000). Mixed models were then used to test for potential relationships between single health variables and suites of environmental variables. For the next phase of this analysis I focused on constrained ordination methods that simultaneously tested the relationship between suites of health variables and environmental variables.

I used program CANOCO for constrained ordination analyses (Jongman et al. 1995, Ter Braak and Smilauer 2002, Leps and Smilauer 2003). In particular, redundancy analysis was used to assess the relationship between suites of health response variables and environmental predictors. The significance of environmental predictors was assessed using Monte Carlo tests for parameter significance (Ter Braak and Smilauer 2002). When applicable, covariates were used to condition out nuisance variables in the analysis such as the differential effect of snare or helidarting on some of the stress variables. Program CANOCO also allowed the modeling of repeated measures of bear captures through the use of randomization tests that were robust to correlations between repeated measures (Ter Braak and Smilauer 2002).

The main analysis strategy can be conceptualized by Figure 1 where each box forms an analysis node with respective indicator variables. Also included are capture effects which is a nuisance variable. I initially focused the analysis on the relationship between bear biology and demography and environmental variables. In particular I was interested if bears were segregated across the landscape as indicated by environmental variables. Using this information I further explored the relationship between bear health, biology/demography and the environment. I focused on the spatial comparison of bears as opposed to temporal change aspects of the data set. The next phase of the analysis will consider temporal change once the landscape and GIS data maps are temporally linked to yearly estimated bear home ranges.

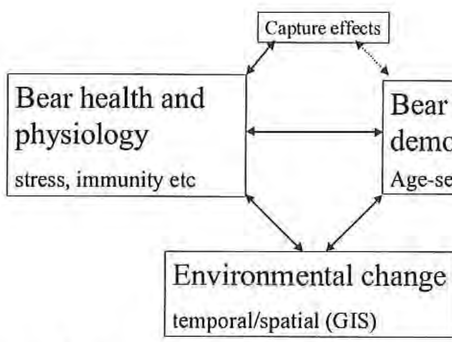

Figure 1: Conceptual diagram of health-environmental analysis.

Results

<u>Sample sizes</u>

Table 4 summarizes sample sizes of captured bears. The actual sample size used for analyses was lower (about 20-30%) due to missing values for some of the health and/or environmental variables.

Table 4: Sample sizes of health variables

Data set	Sexclass	Capture type		
		helidart	snare	Total
Individual	Female	9	43	52
	Female/cubs	9	12	21
	Male	15	68	83
	Total	33	123	156
Repeated	Female	27	51	78
	Female/cubs	24	20	44
	Male	30	78	108
	Total	81	149	230

Exploration of the relationship between bear demography and GIS/Landscape conditions

Constrained ordination (redundancy analysis) was conducted to determine if age and sex class could be predicted by the GIS and landscape conditions in a bear's home range area. The GIS variables (Table 1) were used as predictor variables for this analysis. The amount of total variation in age-sex class explained by the ordination was 11.2% with 78% of the variation explained by the first 2 canonical axes; however, Monte Carlo tests suggested that most of the GIS variables were significant predictors of bear age-sex class (Figure 2).

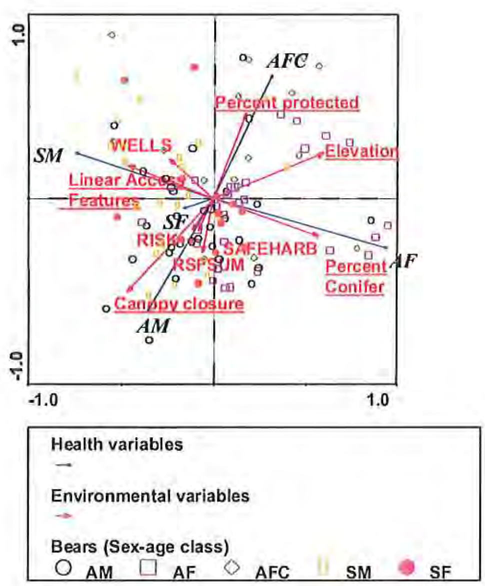

Figure 2: Results of constrained ordination of bear age-sex class with GIS variables as predictor variables. The first 2 canonical axes are shown. All GIS variables that were underlined were significant predictors of bear age-sex class

The ordination diagram reveals potential gradients and relationships in the data set. In review, the constrained ordination creates component axes that maximize the separation between age-sex classes. For each bear a score is produced that is a linear function of the axes. A procedure that is similar to linear regression is then conducted where the score is regressed with each GIS variable as a predictor. The resulting standardized scores from the regression of the GIS variables form the canonical axes that are displayed in Figure 2. The length of arrows for the age-sex and GIS variables is proportional to the strength of the relationship of these variables in the ordination. A value close to the origin implies minimal strength. The angle of arrows within predictor variables, and between predictor GIS variable and age-sex class reveals the correlation of these variables. Variables whose arrows are at a 90 degree angle have no correlation. Variables that are opposed (180 degree separation) have negative correlation and variables that are in the same direction are positively correlated. Finally, predictor variables that are underlined were considered significant predictors (at $\alpha=0.1$).

Using these rules, it is suggested that a gradient of linear access features (roads) and percent conifer is evident in the data set. Subadult males are positively correlated with linear access features (roads) and negatively correlated with percent conifer. Adult females are positively correlated with percent conifer and negatively correlated with linear access features. Another gradient in the data set is canopy closure and percent protected area within a home range. Adult males are positively correlated with canopy closure and negatively correlated with percent protected whereas adult females with cubs (AFC) are positively correlated with percent protected and negatively correlated with canopy closure. Standardized scores for each bear are also shown as subdivided by age-sex class. General clumping of these scores around each of the age-sex arrows can be shown further supporting the general direction of the age-sex arrows in the analysis. To further explore results I plotted the standardized means for each of the age-sex classes as a function of the most significant predictor variables (Figure 3). From this, it can be seen that adult females with cubs have the highest percent of protected area in their home range areas but lowest canopy closure. Subadult males have lowest percent conifer and highest linear access features. Adult males have highest degree of canopy closure. These results suggest that subadult classes are found in more open roaded areas whereas adult classes are found in higher protected areas (females with cubs) or higher percent conifer areas (adult females). Canopy closure is more difficult to interpret since high canopy closure areas are found in both foothills areas as well as mountainous valleys (Figure 4).

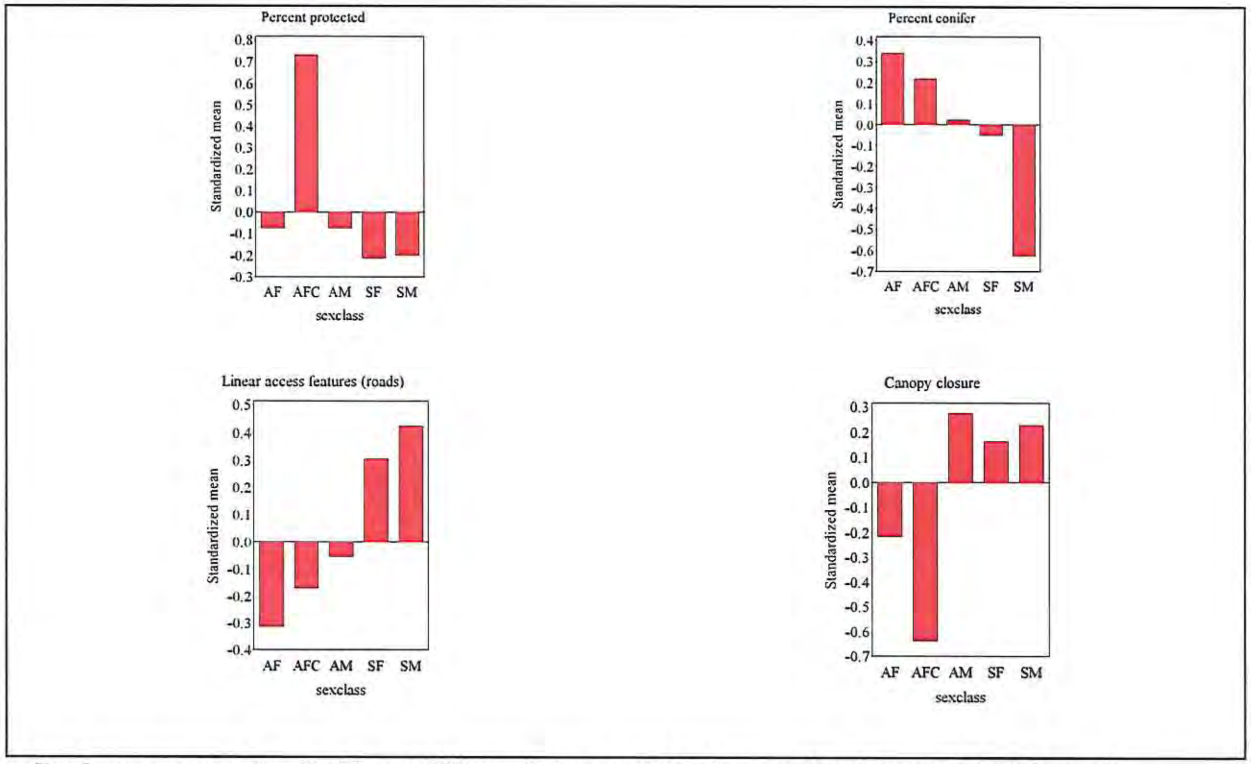

Figure 3: Standardized mean scores for significant GIS predictor variables from ordination analysis (Figure 2)

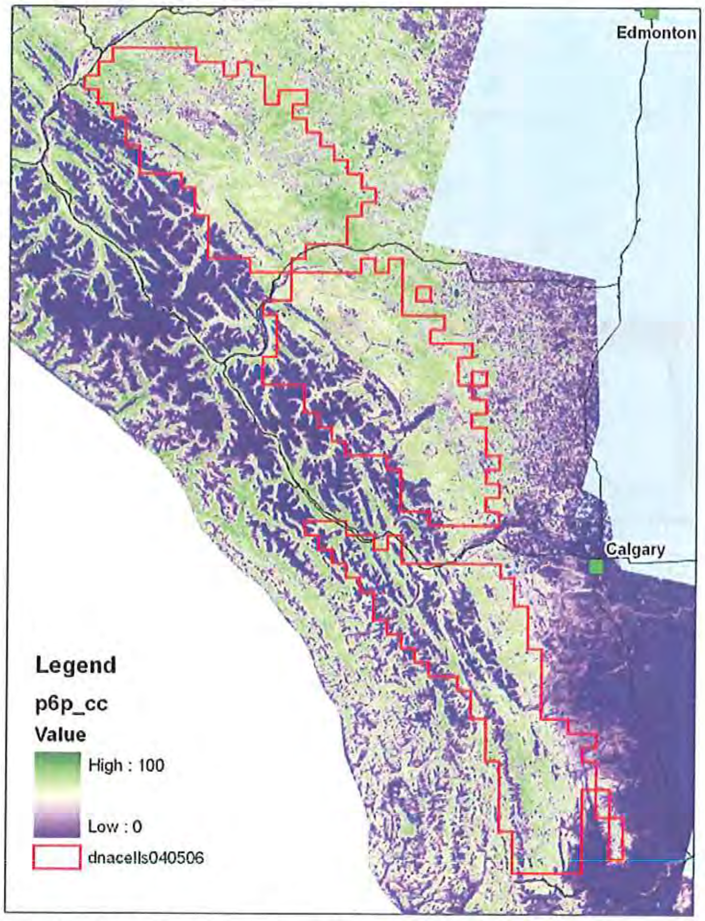

Figure 4: The distribution of canopy closure values across the study area. It can be seen that high canopy closure areas are found both in foothills area and mountain valleys whereas low canopy closure is primarily in alpine areas.

Another ordination analysis was conducted with landscape metric variables and GIS variables as predictors of age and sex class (Figure 5). The ordination diagram from this analysis suggested that all 5 landscape metrics were associated with age-sex classes. It also suggested that some metrics and GIS variables were correlated, such as elevation and mean patch size (L1), percent protected and contrast edge density (L2).

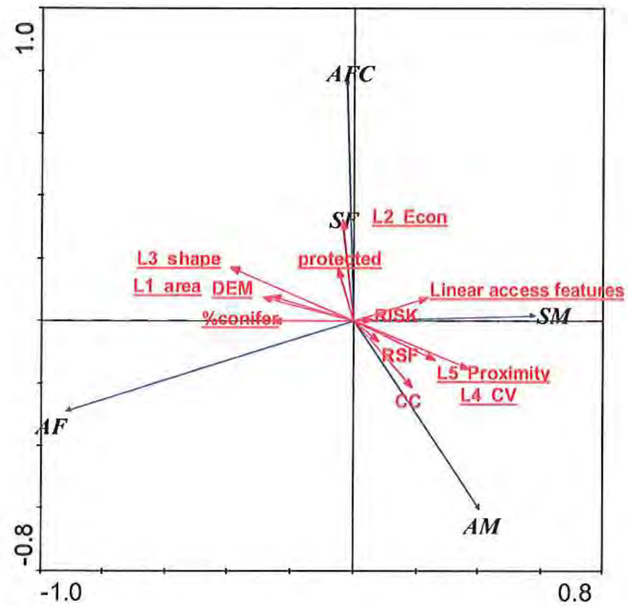

Figure 5: Constrained ordination biplot showing the relationships between age-sex class and predictor GIS and landscape variables. Underlined GIS/Landscape variables were significant predictors of age-sex class

Relationships between GIS and landscape variables were further explored by a constrained ordination to determine if landscape variables can predict GIS variables (Figure 6).

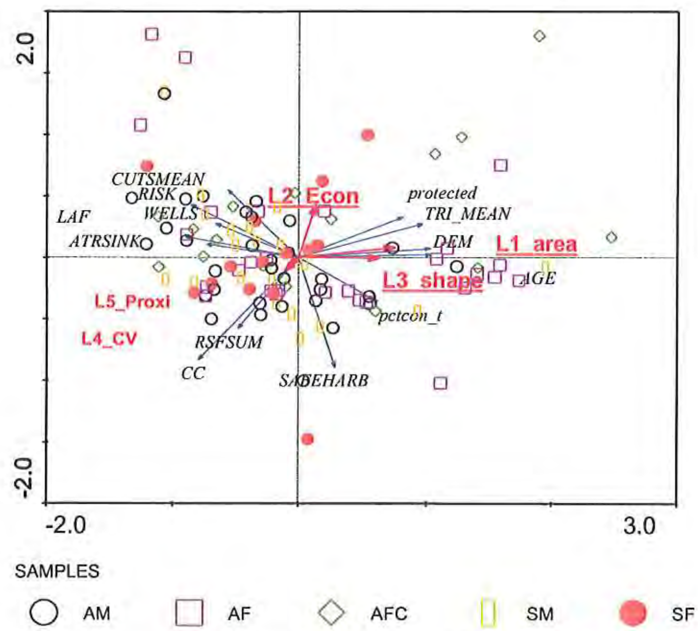

Figure 6. Constrained ordination biplot showing the relationships between landscape and GIS variables. Underlined landscape variables were significant predictors of age-sex class.

Results of this analysis suggest that mean patch size (L1), contrast edge density (L2) and shape index (L3) are most related to various GIS variables. These results suggest that in some cases landscape variables are related to GIS variables. The question then becomes whether bears are responding to changes in landscape structure or GIS based habitat types. This question will be explored further in future analyses that consider temporal change in bear landscape and GIS variables.

Relationship between environmental variables and health scores

Condition scores

Constrained ordination analysis was conducted using the GIS/Landscape variables as predictors of the condition scores. For this analysis, age, sex class, age*sex class and year were used as covariates. In doing this, the principal effects of these variables was conditioned out of the analysis to allow a clearer analysis of the relationship between GIS/Landscape variables and condition indices.

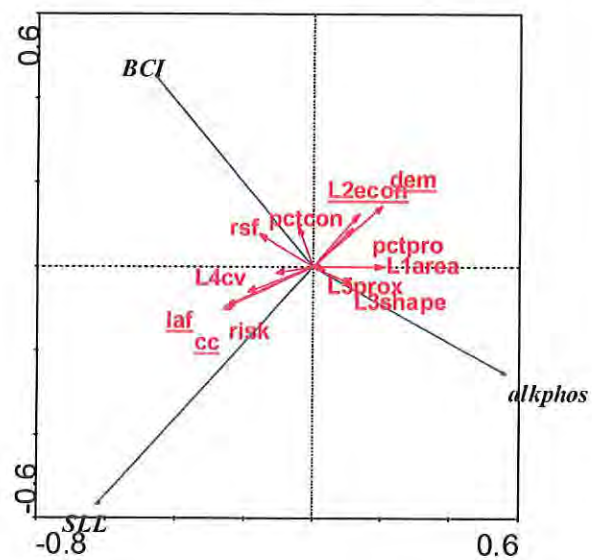

Figure 7. Constrained ordination biplot showing the relationships GIS/landscape variables and condition indices. Underlined GIS/landscape variables were significant predictors of condition indices.

Results revealed that linear access features, canopy closure, edge contrast (L2) and elevation as significant predictors. A gradient composed of canopy closure/linear access features as opposed by edge contrast/elevation was revealed by the biplot (Figure 7). Straight line length was aligned along this gradient. A weaker non-significant gradient of RSF versus area-weighted proximity (L5) and shape index (L3) was also suggested with BCI and alk-phos aligned along this gradient. Plots of the data suggested that straight-line length was influenced by elevation even when age-sex class was accounted for (Figure 8).

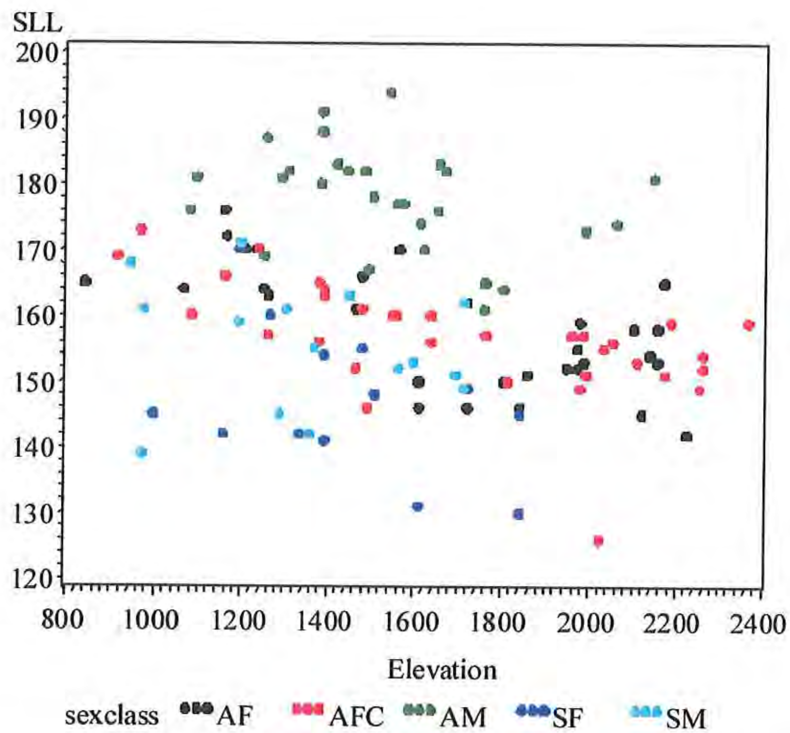

Figure 8: Plot of straight line length (SLL) vs. Elevation as a function of age and sex class. A general decreasing trend in SLL with increasing elevation can be seen for each age-sex class.

A plot of elevation, linear access features and straight line length reveals the relative distribution of these variables that form the predicted SLL gradient (from the ordination analysis) (Figure 9). It can be seen that areas of high road density are in lower elevations and vice versa. Furthermore, a trend for larger SLL bears is suggested with higher road density for males. For females this is also suggested, however, there are some larger adult females clustered in areas of 0 LAF. Further review of the data shows that these are older females. This general relationship could be explained by lower mortality pressure in areas of 0 LAF leading to a larger proportion of older females (with high SLL values).

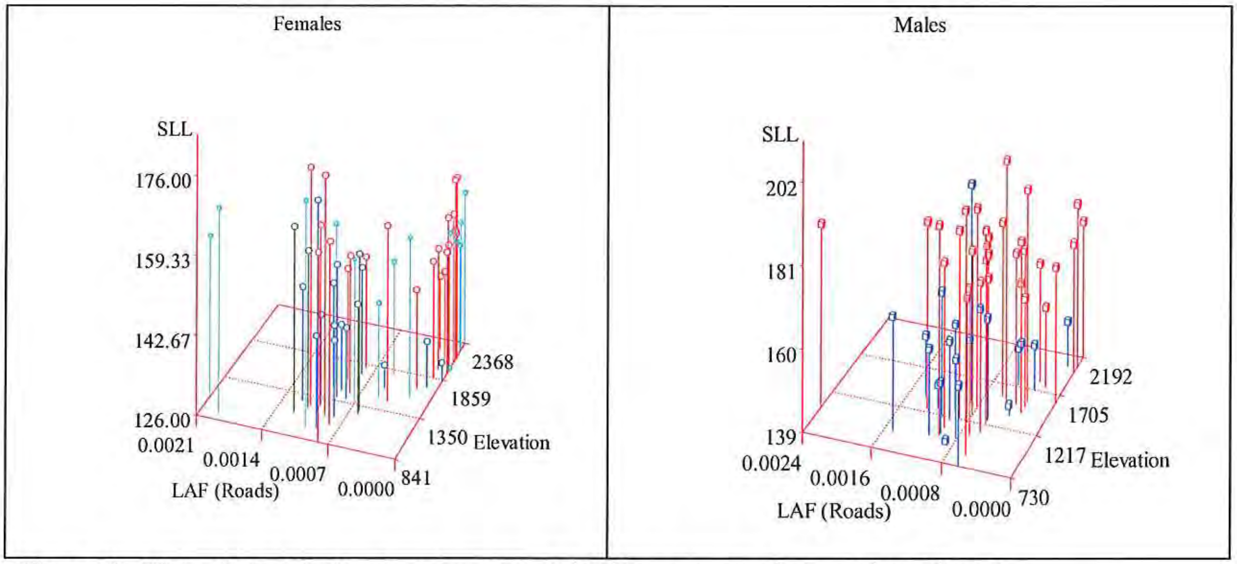

Figure 9: Plots of straight line length versus LAF (linear access features/roads) and elevation as a function of sex. The blue points represent subadult bears and the red points represent adult bears. In addition, adult females with cubs are symbolized by a star point.

Plot of body condition index and RSF score also suggest a weak relationship between these two variables with BCI score increasing with increasing RSF (Figure 10).

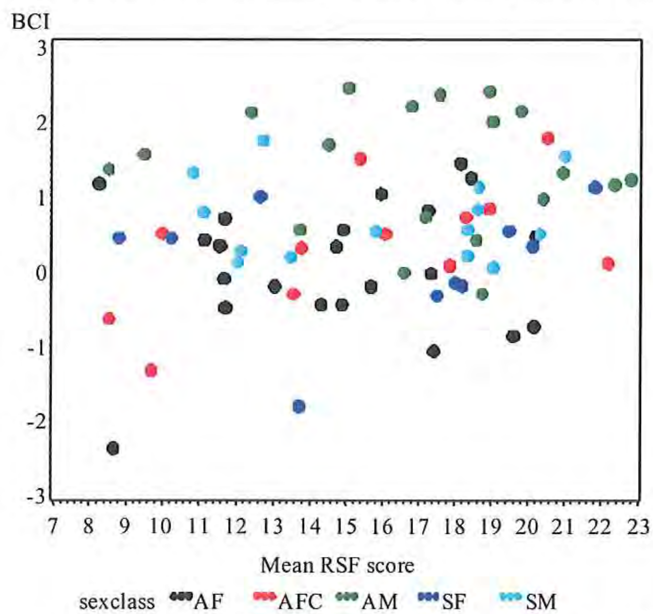

Figure 10: Body condition index versus mean RSF score as a function of age and sex class.

Stress scores (from data sets currently available)

I conducted a constrained ordination to explore the effect of GIS/landscape variables on stress indices. For this analysis, capture type (heli-dart or snare) was used as a covariate to allow bear stress levels to be different dependent on type of capture. I did not include age and sex as covariates but did include them in triplots to see if any clustering of age-sex class around environmental predictors was apparent. Results suggested that canopy closure (cc) and contrast edge density (L2) were significant predictors of stress levels. Examination of triplots suggested a gradient with canopy closure opposing contrast edge density. GGT and hsp60 had the closest orientation to this gradient (Figure 11).

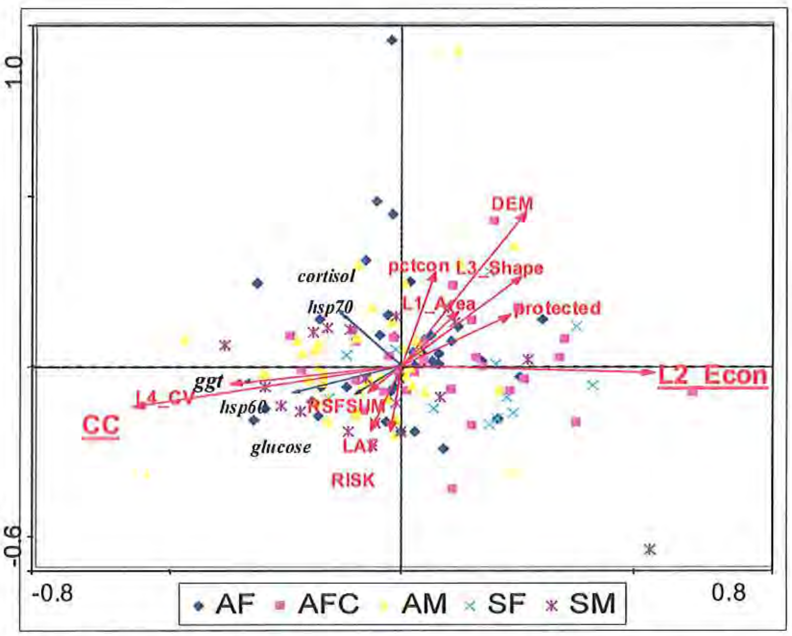

Figure 6: Constrained ordination triplot with canonical scores for bears shown as a function of age and sex class. Significant GIS/landscape variables are underlined.

Plots of the raw data suggest high GGT and high HSP60 scores in areas of highest canopy closure and highest contrast edge density (Figure 12). The trend is most noteworthy for adult and subadult males for canopy closure. For contrast edge density the trend is most apparent for females with cubs as well as subadult males.

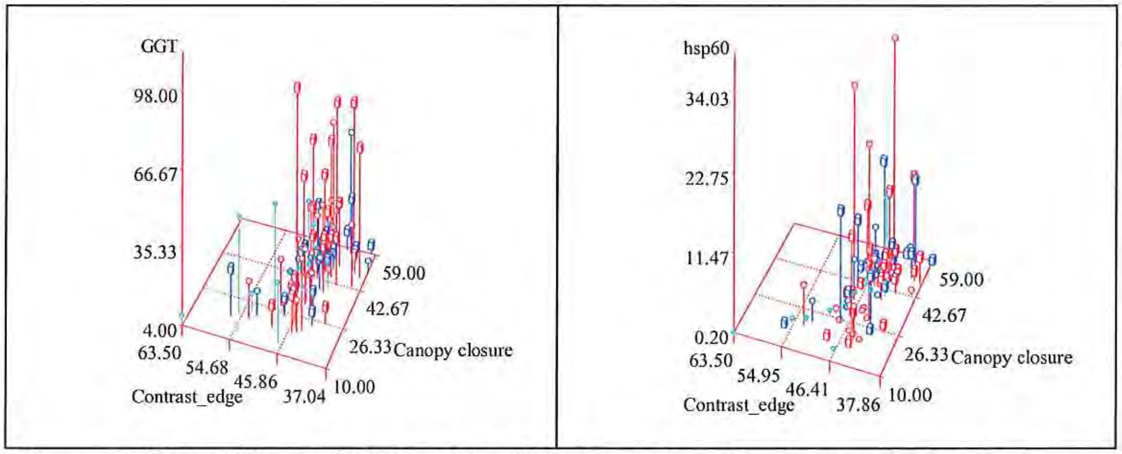

Figure 7: Plots of observed GGT and hsp60 levels as a function of contrast edge density (L2) and canopy closure. Females are depicted by circles and males by squares. Red symbols are adults and blue symbols are subadults. Light blue stars are females with cubs.

Reproduction

Constrained ordination procedures were conducted for the reproduction variables. This analysis was restricted to females captured before July which corresponds in general with the end of the spring breeding time period. Ordination results suggested that variation in mean patch size was significantly related to reproductive variables. Observation of the biplot suggested that variation in mean patch size was most directly related to levels of testosterone (Figure 13). Observation of data plots suggests this relationship is strongest for subadult females and weakest for adult females.

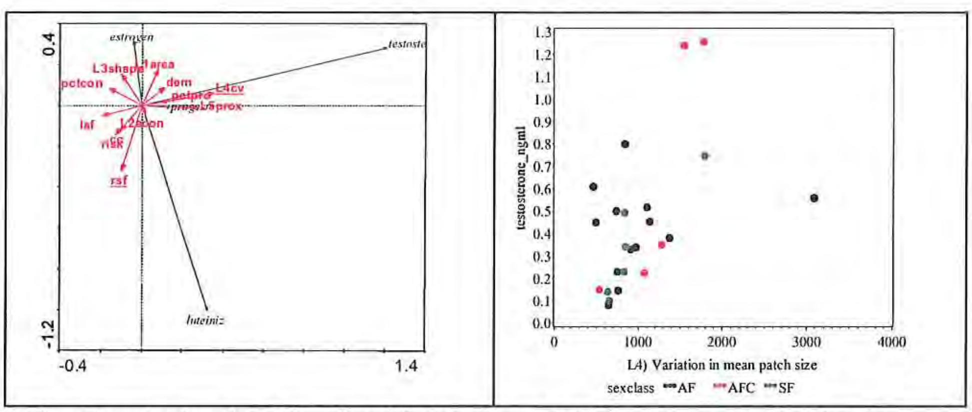

Figure 8: Constrained ordination biplots for adult female reproductive hormone analysis. Significant environmental variables are underline. A plot of observed testosterone versus variation in mean patch size is also shown.

Immunity

Constrained ordination analysis suggested that elevation influenced levels of immunity. However, inspection of biplots did not suggest that elevation was directly related to any of the individual immunity variables (Figure 14). As discussed later, individual biological variation in immunity may limit the ability to detect spatial differences in immunity levels based on environmental variables. Future analysis for the final program report will focus on temporal change in immunity of individual bears.

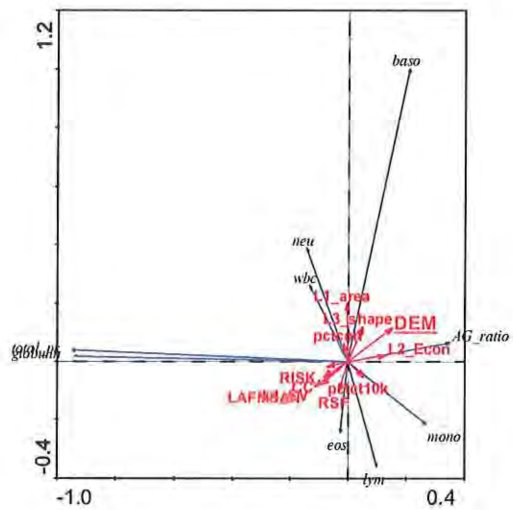

Figure 9: Constrained ordination biplots for immunity analysis. Significant environmental variables are underlined.

Discussion

The results of these analyses demonstrate the utility of constrained ordination methods to explore the relationship between bear demography and health and the environment. There are several advantages to this method. First, it allows the simultaneous evaluation of all the predictor GIS/landscape and demographic/health variables. This approach considers the correlation within GIS/landscape and health variables when evaluating the relationship between these two variables therefore allowing a more thorough investigation of relationships than univariate analyses. By doing this the number of overall statistical tests is reduced therefore reducing type 1 error rates. Program CANOCO adds the use of Monte Carlo significance tests to help interpretation of complex canonical relationships as well as inclusion of repeated measures data. Finally, biplots and triplots condense analysis results into a figure that shows likely gradients as well as statistically strong predictors and response variables.

The main disadvantage of constrained ordination is that the choice of health response variables as well as predictor variables can potentially influence the overall fit of the ordination model to the data. For example, within a data set there may be a few environment-health variables that are strongly related as well as some variables that are completely unrelated. Unlike principal components analysis, the ordination is specifically constrained so that the health variables can only be explained by the predictor variables. This reduces the overall fit of constrained ordination models compared to unconstrained ordination methods.

Some of the most interesting results pertain to potential relationships between bear demography, condition and GIS/environmental variables. The demographic relationship identified environmental gradients in the data set that partially segregated age and sex classes. Some of the gradients could potentially be explained by decreased survival rates in roaded areas shifting the distribution of ages to younger bears. For example, subadult males were more likely to have higher road densities within their home range areas since decreased survival rates in these areas potentially eliminated many of the adult males. However, some of the relationships, such as adult females with cubs displaying home range areas higher amounts of protected status are less easily explained by mortality history. Regardless, this result suggests that different age and sex groups may have different environmental conditions and stressors within their home range areas. The condition analysis suggest that road density and elevation also affect bear size (straight line length). Higher road density is correlated with larger body size which may seem counterintuitive. This is potentially due to better habitat resources such as game and other meat sources whose densities are higher in areas of disturbance and younger forests. In contrast bear body size is lower in higher elevation areas, which is potentially due to lower habitat quality at higher elevations. This general result suggests that while mortality pressure may be higher in anthropogenic areas, the availability of food resources may actually reduce stress of bears living in these areas. Our next planned analysis of temporal trend in individual bears, will include structural equation modeling which will hopefully elucidate further details about this relationship.

Although we are now only working with a portion of the animal stress data our preliminary analyses with available stress variables suggest potential relationships between canopy closure, contrast edge density and GGT levels. GGT is a potential indicator of oxidative stress (Lee et al. 2004). Our finding of higher GGT levels with increasing canopy closure is difficult to explain. Areas of high canopy closure exist in both roaded anthropogenic foothills habitat as well as protected mountainous areas. In general, it is negatively correlated with elevation and terrain ruggedness. However, principal components analysis of GIS variable suggests that it still forms a more unique indicator of the environment (in comparison with other GIS variables). Future analyses will consider this variable in more detail given that it occurs as a significant predictor in many of the health analyses. In addition, future analyses will explore how landscape metrics may influence GGT and other levels.

The results of ordination analyses suggest that landscape metrics are potentially correlated with some of the health indicators. Direct interpretation of metrics is more difficult than GIS variables. Further collaboration with Julia Linke (PhD student – UofC) on interpretation of metrics will help further interpret results. In addition, future analyses will more directly assess the link between energy expenditure and health through the inclusion of movement rates and home range size as predictor variables of health scores. Many of the landscape metrics are descriptors of habitat interspersion. It is possible that bears have to use different strategies, and levels of energy expenditure as anthropogenic change causes changes in landscape metrics and patch interspersion. This will be best examined through the assessment of temporal change in individual bear habitat and health parameters.

These results identify potential linkages between bear demography, health, and the environment. However, the results are statistical correlations, and the next step is to use these results, and the actual biology of bears to derive more ecologically meaningful models. This type of analysis will be conducted using structural equation models (Mitchell 1992, Shipley 1997) in the next phase of the project.

Future analyses for final program report

Future analysis will focus on temporal change in individual bear health and environment now that temporally matched data sets are available. This may potentially have more power than the spatial-only analyses detailed in this report. One interesting approach is the tracking of individual bears ordination scores over time. For example some ordination analyses suggest health and environmental gradients within data sets. The question becomes, if the composition of GIS indicator variables change in a bear home range what is the corresponding change of the bears score relative to health variables? A technique to interpret multivariate time series called principal response curves will be used to explore these type of relationships (Van den Brink and Ter Braak 1999). Further analysis of reproductive rates will be conducted using multi-strata models mark-recapture models. The methods of Schwartz et al (In press) will be used to estimate age of first reproduction and reproductive rate. Both the effect of health (i.e. condition, movement rate) and environment will be explored using covariates. If successful, this analysis will provide a link between environmental/health and population demography (productivity). The results of the ordination and mixed model analyses will influence the choice of covariates for this analysis.

Finally, Structural Equation model analysis (in collaboration with Dr. Tak Fung and Dr. Scott Nielsen) will be used to further explore hypothesized linkages between latent health and environmental variables. This approach provides a useful way to directly test biologically based models of the relationship between health and the environment.

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CHAPTER 7: Delivery of New Products and Development of Training Programs

Gordon Stenhouse

In June 2007 we delivered new program products to all research sponsors. These new products represent the use of landscape and habitat conditions current as of 2005 and the amalgamation of 9 years of intensive data from GPS radio collared grizzly bears. These products include:

- RSF maps for each Bear Management Units (BMU)
- Mortality risk maps for each BMU
- Safe Harbour maps for each BMU
- New Grizzly Bear Movement Corridor Maps for each BMU
- Habitat maps which are comprised of: leading species, crown closure , NDVI
- New GIS applications to allow evaluation of forest management actions within grizzly bear habitat.
- A listing of all research publications from our program (1999-20070

Our research team is now completing teaching materials (chapters) for an integrated training program which will be delivered through the ENFORM training program. We anticipate that all materials from our scientists will be delivered to ENFORM in February 2008 and then we will begin the assembly of training manuals, with a goal of being able to offer the delivery of this course as scheduled in the spring of 2008. An outline of this course is presented in Table 1.

Table 1. Training course outline.

GRIZZLY BEAR HABITAT MANAGEMENT TOOLS: DESIGN DOCUMENT – DRAFT

COURSE OUTCOME: AN UNDERSTANDING OF FMF GRIZZLY BEAR RESEARCH RESULTS AND HOW TO APPLY THESE TO LAND MANAGEMENT DECISIONS.

⇐KNOWLEDGE 1 DAY⇒	**Module 1: What is the data we use?**		
	Outcome:	An understanding on how the key data sets used for product development are gathered. (Strengthens and weaknesses)	
			Includes Subjects/Topics:
	Objectives: (30minutes)	1. Explain how grizzly bear location data is obtained and what this represents. (Gordon Stenhouse)	Capture, collaring, GPS evolution and issues
	(30minutes)	2. Other data and samples collected and what they tell us. (Gordon Stenhouse)	Animal health, vegetation and scats
	(1-1.5 hr)	3. Habitat mapping-evolution and current status. (Dr. Greg McDermid)	RS datasets, GIS layers and Data layers
	Note: These provide the foundation for the development of products		
	Module 2: How are models created to identify grizzly bear habitat and bear movements across the landscape?		
	Outcome:	A basic understanding of the techniques and procedures used to create some of the grizzly bear research products.	
	Objectives:	Dr. Scott Nielsen (1.5 hours) 1. Resource Selection Function Models.	-RSF occurrence -Seasonal use -Mortality risk -Sate harbours -Strengths and limitations
		Barb Schwab (1 hour) 2. Graph Theory Models.	-Methods -Testing -Input layers -Interpreting outputs
⇐APPLI	**Module 3: New Data Sets – Population Inventory and Putting Model Outputs Together**		
	Outcome:	Understanding grizzly bear inventory and key conservation	

		principles	
	Objectives: (30minutes)	1. Review of DNA based grizzly bear population inventory. (Gordon Stenhouse)	-Methods -Population units -Results
	(30minutes)	2. Key concepts for the Conservation of Grizzly Bears in Alberta. (Gordon Stenhouse)	-Use of research products -Human caused mortality -Grizzly bear priority areas -Grizzly bear response to landscape change
⇐APPLICATION⇒	**Module 4: Using Research Products to Support Land Use Planning Decisions**		
	Outcome:	This module will allow participants to understand the steps required in conducting an assessment of 2 land use activities (forestry and oil and gas) using the research program models and tools	
	Objectives: (1.5 hours)	1. Review of GIS applications developed (Jerome Cranston)	-RSF -Risk -Safe harbour
		2. Forestry Analysis Example	-2 pass harvest -Future (10 years) -Mitigation
		3. Oil and Gas Analysis example	-Comparing options
	GROUP DISCUSSION	4. Interpreting Output files	
-End of DAY 1 **-Exam Required**			

DAY 2

This day will be a GIS technical day for those students who will be running script and conducting assessments using the tools and products received from this research program. (prerequisites will be identified for participation). Observers are welcome to attend to gain a further understanding of processes and output files.

We are planning to hold our first training course for program partners with an ENFORM training coordinator and the individual research scientists as the delivery team. As we move forward with additional training courses we may decide to train other course lecturers to deliver this course on our behalf. Regular program updates are expected to occur from the research team as new work is completed.

In addition to the preparation of our training course the program GIS specialist and program leader also delivered a number of group training efforts in Calgary, Hinton and Grande Prairie with a focus on assisting program sponsors in using the research products and GIS applications. These sponsors have provided the industry matching funding within our current Innovation and Science grant. These partner specific training sessions will continue as our larger training program is completed. We also recognize that there will be an ongoing need to assist program partners with the use and application of the products that our research team has provided.

In 2007 we have been working with a group of SRD staff to assist them in using and understanding the new products that we have provided. This work is the next logical step in putting the research results into practice and fulfills the "Service Excellence" goal of our current grant with Alberta Advanced Education and Technology. As part of this ongoing work our team has been working with SRD staff on the development of an instruction or guidance document which the government will provide to industrial planners and developers (forestry/oil&gas sectors). This document will form a crucial link for research results and government policy direction in relation to grizzly bear and landscape management in Alberta. The focus of this document is to explain what is required by an applicant who is planning industrial activities within occupied grizzly bear range in the province. The proposed analysis and applications are deliverables from our research team.

The Draft document is presented below:

Guidelines on Conducting an Analysis of Land Use Activities on Grizzly Bear Habitat in Alberta

February 2008

This document describes how the models and tools developed by the FMF Grizzly Bear Research Program (GBRP) can be used to evaluate proposed developments (roads, pipelines, cut blocks, well sites, etc) in terms of their impact on grizzly bear habitat. This supports the long-term goal of the GBRP, which is:

> **To provide resource managers with the necessary knowledge and planning tools to ensure the long-term conservation of grizzly bears in Alberta.**

Background

All program partners who have contributed to the GBRP during the past 9 years (1999-2007) have received a number of program deliverables from our research team. These deliverables are provided to program partners on a regular basis and are regularly improved as data quality and geographic extent are enhanced with additional work.

We are now able to utilize the program deliverables (maps, models and GIS applications) to conduct assessments of proposed land use activities on grizzly bear habitat. The intent of this document is to provide guidance and direction for those conducting these analyses.

We have provided a step-by-step description of how to conduct these analyses, and recommended specific grizzly bear habitat objectives, as well as listing some possible mitigation options. As more users gain experience with these analyses and application of results we expect that new insights and mitigation techniques will evolve.

The objective of using our models and tools is to assist in managing for landscape conditions necessary for the long-term health and persistence of grizzly bears in the province of Alberta. It is recommended that land-use plans and applications be examined in terms of their current and projected impacts on grizzly bear habitat quality, in order that the effect of planned development/activities, and mitigation efforts, can be quantified.

It is important to keep in mind that the primary objective of these analyses is to ensure the maintenance of adequate grizzly bear habitat to ensure the long-term survival of the species.

Before You Begin

The tools and models that you are using are complex and highly technical. There is no requirement that you have a complete understanding of all aspects of model construction or GIS application development. However there is an expectation that the product user understand the research findings and the key principles of grizzly bear conservation.

To aid with this understanding we have previously provided all program partners with a PowerPoint slide show, which pertains directly to the suggested analysis. (file :GBRP Analysis 2007.ppt)

The GBRP_2006Deliverables_31mar07.ppt PowerPoint is divided into 4 sections. It is recommended that users familiarize themselves with the following slides before performing any analysis:

Slides 1 – 49:

History and objectives of GBRP
Introduction to remote-sensing based habitat mapping
Summary of research results

Slides 50 – 165:

Current program areas:
2.3 Introduction to Graph Theory corridor modeling
2.5 DNA –based population inventory
2.9 GIS applications
2.10 Delineation of habitat zones

Slides 166 – 188:

Description of models and tools

Slides 189 – 249:

How to use the models and tools (sample analysis).

THE PRODUCTS

1. **Remote Sensing -** These datasets are raster-based GIS layers, in ESRI grid format, identifying vegetation and forest structure and are derived from remote sensing imagery (Landsat) at 30m resolution (pixel size). The 10-class landcover, was generated by object-oriented classification of 22 Landsat Thematic Mapper 5 images and topographic derivatives from a digital elevation model, followed by a change-detection update to 2005over the Phase 6 area. Associated datasets include species composition (percent conifer/broadleaf), crown closure, and NDVI (Normalized Difference Vegetation Index), a time-series of 12 biweekly images tracking changes in plant phenology. A 15-class landcover was also created by combining the 10-class landcover with the crown closure and species composition models. Also included is a forest age layer, based on AVI and stand history data.
2. **Resource Selection Function (RSF) -** These are raster-based datasets, at 30m resolution, showing the relative probability of grizzly bear occurrence on the landscape. They are derived from landcover and other GIS layers, and have been

tested and validated with at least 2 years of grizzly bear location data collected by GPS radio collars. Population-level models for each population unit have been developed for three seasons (spring, summer and fall). Grizzly bear occurrence, as represented by the RSF model, is highly correlated with the amount and spatial distribution of grizzly bear habitat resources such as food, water, and thermal cover and thus the RSF model can be used as a surrogate of habitat quality. For more information on the RSF model, please refer to the document ***RSF_faq_v3.doc.***

3. **Mortality Risk** - Using spatial and temporal data on grizzly bear mortalities, we have produced a raster-based grizzly bear mortality risk model, which predicts the probability of human-caused grizzly bear mortality over the landscape. This dataset is based on the most current data for open, motorized linear access structures, including roads and rights-of-way, for the entire Phase 6 area. This model describes habitat security, which is a critical aspect of grizzly bear habitat quality. For more information on the Mortality Risk model, please refer to the document ***risk_faq_v3.pdf***
4. **Grizzly Bear Movement Corridors** - Graph Theory has been applied to the RSF datasets to predict the configuration of grizzly bear travel corridors on the landscape. These datasets also provide a ranking of the relative importance of movement corridors and have been constructed using GPS grizzly bear location data. Only data from the Phase 3 area and Phase 4 areas are currently available (covers the Waterton, Livingstone, Clearwater and FMF Core population units). For more information on the Movement Corridors model, please refer to the document ***GT_faq.doc.***
5. **Watersheds** - Watershed analysis units for the Phase 6 study area were created to provide an appropriate mesoscale landscape unit for generating summary statistics for grizzly bear habitat. Major watersheds were subdivided (generally along heights-of-land, occasionally along watercourses) to approximate the size of an adult female grizzly bear home range (~700 sq km).
6. **Grizzly Bear Population Units** - Alberta Grizzly Bear range has been subdivided into population units based on genetic distinctions within the Alberta grizzly bear population (Fig. 1). The FMF Core population unit, between Highway 16 and Highway 11, corresponds to BMA (Bear Management Area) 3 and was the subject of a DNA-based mark-recapture survey in 2004. Bear density was concentrated in the west half of the study area, and averaged 4.79 bears per 1000 sq km. The Clearwater population unit, between Highway 11 and Highway 1, corresponds to BMA 4 and was DNA-surveyed in 2005. Bear density was concentrated in the west half of the study area, and averaged 5.25 bears per 1000 sq km. The Livingstone population unit, between Highway 1 and Highway 3, corresponds to BMA 5 and was DNA-surveyed in 2006. Bear density was concentrated in the west half of the study area, and averaged 11.77 bears per 1000 sq km. The Waterton population unit, between Highway 3 and the US border, corresponds to BMA 6 and was DNA-surveyed in summer 2007. Results will be released following ministerial review.
7. **Safe Harbours and Attractive Sinks** - From the work of Dr. Scott Nielsen (research team member) comes the concepts of attractive sinks and safe harbours. A safe harbour is an area of good habitat (as indicated by high RSF values) and low risk of

human-caused mortality. An attractive sink, the inverse of a safe harbor, is an area of good habitat, to which bears are attracted by an abundance of resources, but where bears face a high risk of mortality. The safe harbor model combines the two critical aspects of habitat quality – resource availability, and security – into a single model, and has been developed for the entire Phase 6 area.

8. **Habitat States** – This raster-based dataset is categorical classification of the safe harbor model, which identifies primary habitat areas (serving as a population source), and attractive sinks (acting as a population sink).

Class	Description
0	non-critical habitats (very low habitat value to non-habitat)
1	secondary sinks (moderate/secondary habitat value & high mortality risk)
2	primary sink (high/primary habitat value & high mortality risk)
3	secondary habitats (moderate habitat value & low mortality risk)
4	primary habitats (high habitat value & low mortality risk)

9. **Priority Areas and Dispersal Zones** – The Alberta Grizzly Bear Recovery Plan (#15) identifies two important landscape units to aid in recovery efforts in Alberta. The first are Grizzly Bear Priority Areas which contain the highest quality grizzly bear habitat combined with the lowest level of grizzly bear mortality risk. These areas also have road density thresholds of .6km/km2. The second areas have been termed Grizzly Bear Dispersal Zones which are adjacent to the Priority Areas. These Dispersal Zones contain good quality grizzly bear habitat and have a higher level of mortality risk and a road density threshold of 1.2 km/km2. Within Priority Areas, long-term access plans will be required. Draft Priority Areas and Dispersal zones have been submitted to ASRD for review.

OTHER PRODUCT DESCRIPTIONS

10. **GIS applications** - Geoprocessing scripts, written in the Python language, and associated GIS input layers allow the user to regenerate the habitat models with different scenarios and thereby forecast changes to grizzly bear habitat caused by industrial development. Planned features such as roads, trails, cutblocks, wellsites, or pipelines can be incorporated into the model base layers, and the RSF and mortality risk models regenerated. These scripts require ESRI ArcGIS 9x with ArcInfo functionality and Spatial Analyst extension.

11. **Documents:** There are a number of documents included in the deliverables including:
    - 2006 annual report.pdf
    - GBP_Deliverables2_2006_srd.pdf
    - 100k_risk_metadata.txt
    - risk_faq.doc
    - GT_faq.doc
    - RSF_faq_v3.doc
    - Ursus_habitat_modeling.pdf

- Nielsen_RSF_report.pdf
- habitat_states_definitions.pdf
- mortality risk Neilsen et al 2004.pdf
- ReadMe_Risk_p6.pdf

CONDUCTING THE ANALYSIS

The analysis is a 6-step process:

1. Collect datasets from the files provided from the GBRP, and user development plans.
2. Select analysis extent and determine management objectives.
3. Examine current conditions at regional (FMA/FMU) and Grizzly Bear Watershed Units (WU)-levels.
    i. RSF
    ii. Mortality Risk
    iii. Open Route Density
    iv. Safe Harbour Index
4. Incorporate development scenarios into habitat models (using GB GIS tools) and examine future conditions at Grizzly Bear Watershed Units (WU)-level.
    i. RSF
    ii. Mortality Risk
    iii. Open Route Density
    iv. Safe Harbour Index
5. Compare current and future conditions.
6. Investigate and analyze options for mitigation.

This process is explained in more detail below. For a step-by-step description of the analysis process, including a case study analyzing a harvest plan for FMU E8, refer to the Appendix.

1.0 Collect datasets

Using GIS software (ArcMap, ArcView, etc), determine where the planned development lies in relation to the GBRP Phase 6 study area boundary (Fig. 1, outlined in yellow), habitat model extents (blue), and Habitat Zones (brown). This will determine whether analysis is required, and what datasets are available (see list of products above).

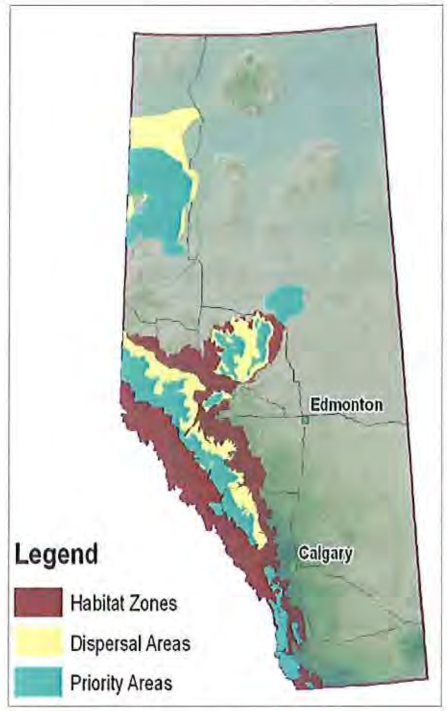

Fig. 1 **Fig. 2**

2.0 Select Analysis extent, determine management objectives

Grizzly Bear watershed units (approx. 700 km2)are provided as an appropriate unit for analysis. Other extents, such as operating compartments or other administrative units of similar scale, may also be suitable. The analysis should be conducted for lands identified as grizzly bear habitat. However the focus should be on projected impacts on Grizzly Bear Priority Areas and Dispersal Zones the management objective for these areas is ***to improve or maintain grizzly bear habitat quality as indicated by an increase in Safe Harbour Index***. The Safe Harbour Index is the mean Safe Harbour pixel value in the analysis unit. If the analysis unit lies within a Priority area or Dispersal area (Fig. 2), an additional management objective is to maintain open route density below 0.6 km/km^2 (Priority areas) or 1.2 km/km^2 (Dispersal zones).

3.0 Examine Current Conditions

Examine the current state of habitat quality in the vicinity of the planned development, at the regional (BMA) and analysis unit levels, using the RSF, Risk, and Graph Theory models.

3.1. RSF*

- Use RSF script to regenerate seasonal maximum RSF model over analysis unit.
- Calculate mean RSF over analysis unit.

3.2. Mortality Risk**

- Use Risk script to regenerate Risk model over analysis unit
- Calculate mean Risk value over analysis unit.

3.3. Open road density (applicable within Priority and Dispersal zones)

- Clip existing open route network by analysis unit
- Sum length of all arcs, divide by area of analysis Unit to calculate open route density

3.4. Safe harbour

- Combine Risk and seasonal maximum RSF to generate Safe Harbour model for analysis unit.
- Calculate Safe Harbour Index (Mean Safe Harbour)

* *note: there are 3 seasonal RSF map layers (spring, summer and fall) along with a mean annual RSF product. The user should select the mean annual RSF for long term activities and a seasonal RSF map for short term activities (i.e. drilling a gas well over a short time frame.*

***note:*

4.0 Generate Future Landscapes

Use the RSF and mortality risk scripts to regenerate the RSF and Risk models with planned roads, trails, and openings (cut blocks, rights-of-way, well sites, etc).

4.1. RSF

- Use RSF script to regenerate seasonal maximum RSF model over analysis unit.
- Add shapefiles or feature classes of planned roads (line) and openings (polygon) in the second and third boxes.
- Calculate mean RSF over analysis unit

4.2. Mortality Risk

- Use Risk script to regenerate Risk model over analysis unit.
- Add shapefiles or feature classes of planned roads (line), trails (line), and openings (polygon) in the second, third, and forth boxes.
- Calculate mean Risk over analysis unit

4.3. Open road density

- Clip future open route network by analysis unit
- Sum length of all arcs, divide by area of analysis Unit to calculate open route density

Mean safe harbour

- Combine Risk and seasonal maximum RSF to generate Safe Harbour model for analysis unit.
- Calculate Safe Harbour Index (Mean Safe Harbour)

5.0 Compare Current and Future Conditions

Compare current and forecast conditions in the table:

Grizzly Bear Habitat Assessment Form

Date of Analysis:					
Analysis performed by:					
1	Watershed Unit #				
2	GB Population Unit				
3	Priority/Dispersal Area:				
Analysis Variables:		**Current**	**Future**	**% Change**	**Increase/Decrease**
	Mean RSF score				
	Mean Mortality Risk				
	Open road density				
	Safe Harbour Index				

Typically, the creation of new openings in forested areas will result in an increase in RSF scores, due to the formation of edges and, in the case of forest harvesting, the replacement of mature or overmature stands with young seral stands. However, the construction of new access features that accompanies such development also leads to an increase in mean mortality risk. The Safe Harbour Index incorporates both these changes into a single value; *if the Safe Harbour Index is forecast to decrease as a result of the planned development, the management objectives have not been achieved and alternative plans or mitigation measures (such as road deactivation) should be provided and an additional analysis conducted.*

6.0 Investigate and Re-Analyze Options for mitigation

The GBRP has provided a several options for mitigating the effect of new developments on GB habitat. Some of these include:

- In the case of forest harvesting – redesign harvest to increase edges (irregular)
- Leave visual buffers around key habitats
- Change timing of operations to seasons of lower occupancy
- Control public access – locked gates, remove access structures.
- Investigate disturbance reclamation possibilities to enhance grizzly bear foods *(note : research currently underway to evaluate well site reclamation at abandoned wellsites.*

Foothills Model Forest
Profit & Loss by Class
December 1, 2005 through February 13, 2008

9:56 AM
02 13 2008
Accrual Basis

	204. 81 & S (Cont)	Total Cont	TOTAL
Income			
Prior Year Balance Forward Cont			
Prior Year Balance Forward Cont - Other	43,890.46	43,890.46	43,890.46
Total Prior Year Balance Forward Cont	43,890.46	43,890.46	43,890.46
6029 · AB SRD other - Gov	400,000.00	400,000.00	400,000.00
6038 · Advanced Ed & Tech (I&S)-Gov	773,000.00	773,000.00	773,000.00
6039 · Ainsworth Lumber - Corp	20,000.00	20,000.00	20,000.00
6059 · Anadarko - Corp	15,000.00	15,000.00	15,000.00
6075 · Blue Ridge Lumber WF- Corp	40,000.00	40,000.00	40,000.00
6082 · BuchananLumber/Tolko OSB - Corp	30,000.00	30,000.00	30,000.00
6137 · Conoco - Corp	20,000.00	20,000.00	20,000.00
6153 · Devon Canada - Corp	30,000.00	30,000.00	30,000.00
6157 · Encana - Corp	30,000.00	30,000.00	30,000.00
6202 · Hinton Wood Prod.WF FRIAA-Corp	38,000.00	38,000.00	38,000.00
6203 · Husky Energy Inc. - Corp	30,000.00	30,000.00	30,000.00
6233 · JNP Core Funding - Gov	100,000.00	100,000.00	100,000.00
6257 · Manning Forestry Research-Contr	60,000.00	60,000.00	60,000.00
6295 · Other Income/Rebates Other	1,936.00	1,936.00	1,936.00
6342 · Reimbursed ExpensesCont	79,244.15	79,244.15	79,244.15
6350 · Slave Lake Pulp WF - Corp	40,000.00	40,000.00	40,000.00
6360 · Spray Lakes Sawmills - Corp	20,000.00	20,000.00	20,000.00
6375 · Sundre Forest Prod WF - Corp	40,000.00	40,000.00	40,000.00
6420 · Weyerhaeuser Canada - Corp	50,000.00	50,000.00	50,000.00
Total Income	1,861,070.61	1,861,070.61	1,861,070.61
Expense			
ADVERTISING			
8002 · General Advertising	396.44	396.44	396.44
Total ADVERTISING	396.44	396.44	396.44
COMPUTER EXPENSE			
8101 · Hardware/Network Maint	148.27	148.27	148.27
8103 · Software Expense	2,964.82	2,964.82	2,964.82
8104 · Supplies & Accessories	844.25	844.25	844.25
Total COMPUTER EXPENSE	3,957.34	3,957.34	3,957.34
CONTRACTS			
8152 · General Contracts	955,526.45	955,526.45	955,526.45
8155 · Letters of Understanding	17,000.00	17,000.00	17,000.00
Total CONTRACTS	972,526.45	972,526.45	972,526.45
EQUIPMENT			
8203 · Field Equipment	35,426.27	35,426.27	35,426.27
8204 · Field Supplies	31,649.92	31,649.92	31,649.92
8206 · Rental	1,335.13	1,335.13	1,335.13
8207 · Repairs/Maintenance	2,779.85	2,779.85	2,779.85
8208 · Telemetry	79,753.12	79,753.12	79,753.12
8209 · Laboratory Costs	11,786.62	11,786.62	11,786.62
Total EQUIPMENT	162,730.91	162,730.91	162,730.91

OFFICE& ADMINISTRATION			
8304 · Freight	5,111.77	5,111.77	5,111.77
8306 · Interest Charges	107.66	107.66	107.66
8310 · Lease/Rent	34,243.00	34,243.00	34,243.00
8314 · Office Equipment	548.59	548.59	548.59
8320 · Photofinishing	317.98	317.98	317.98
8324 · Station. & Off. Supplies	5,592.49	5,592.49	5,592.49
Total OFFICE& ADMINISTRATION	45,921.49	45,921.49	45,921.49
PROFESSIONAL FEES			
8356 · Consulting services	2,100.00	2,100.00	2,100.00
Total PROFESSIONAL FEES	2,100.00	2,100.00	2,100.00
TRAINING			
8381 · General Training	100.00	100.00	100.00
Total TRAINING	100.00	100.00	100.00
TRAVEL			
8401 · Field Camp	11,831.65	11,831.65	11,831.65
8403 · General Travel	41,317.62	41,317.62	41,317.62
8404 · Helicopter			
8404 · Helicopter - Other	305,352.18	305,352.18	305,352.18
Total 8404 · Helicopter	305,352.18	305,352.18	305,352.18
8405 · Fixed Wing	109,098.64	109,098.64	109,098.64
8406 · Jet Fuel	24,603.62	24,603.62	24,603.62
8407 · Meeting Expenses	3,422.93	3,422.93	3,422.93
Total TRAVEL	495,626.64	495,626.64	495,626.64
UTILITIES			
8421 · Gas & Electric	3,068.26	3,068.26	3,068.26
8422 · Telephone & Fax	1,977.20	1,977.20	1,977.20
Total UTILITIES	5,045.46	5,045.46	5,045.46
VEHICLES			
8453 · Gas & Oil	31,006.29	31,006.29	31,006.29
8455 · Insurance	4,599.42	4,599.42	4,599.42
8456 · Lease Costs	42,685.08	42,685.08	42,685.08
8457 · Maintenance	16,093.86	16,093.86	16,093.86
8458 · Radio	903.08	903.08	903.08
Total VEHICLES	95,287.73	95,287.73	95,287.73
WAGES & BENEFITS			
8508 · Full Time Staff	30,000.00	30,000.00	30,000.00
8510 · Part Time Staff	95,419.94	95,419.94	95,419.94
8512 · Payroll Costs	6,171.39	6,171.39	6,171.39
Total WAGES & BENEFITS	131,591.33	131,591.33	131,591.33
Total Expense	1,915,283.79	1,915,283.79	1,915,283.79
Net Income	**(54,213.18)**	**(54,213.18)**	**(54,213.18)**